ST. JOHN'S 2012

GEOSCIENCE AT THE EDGE

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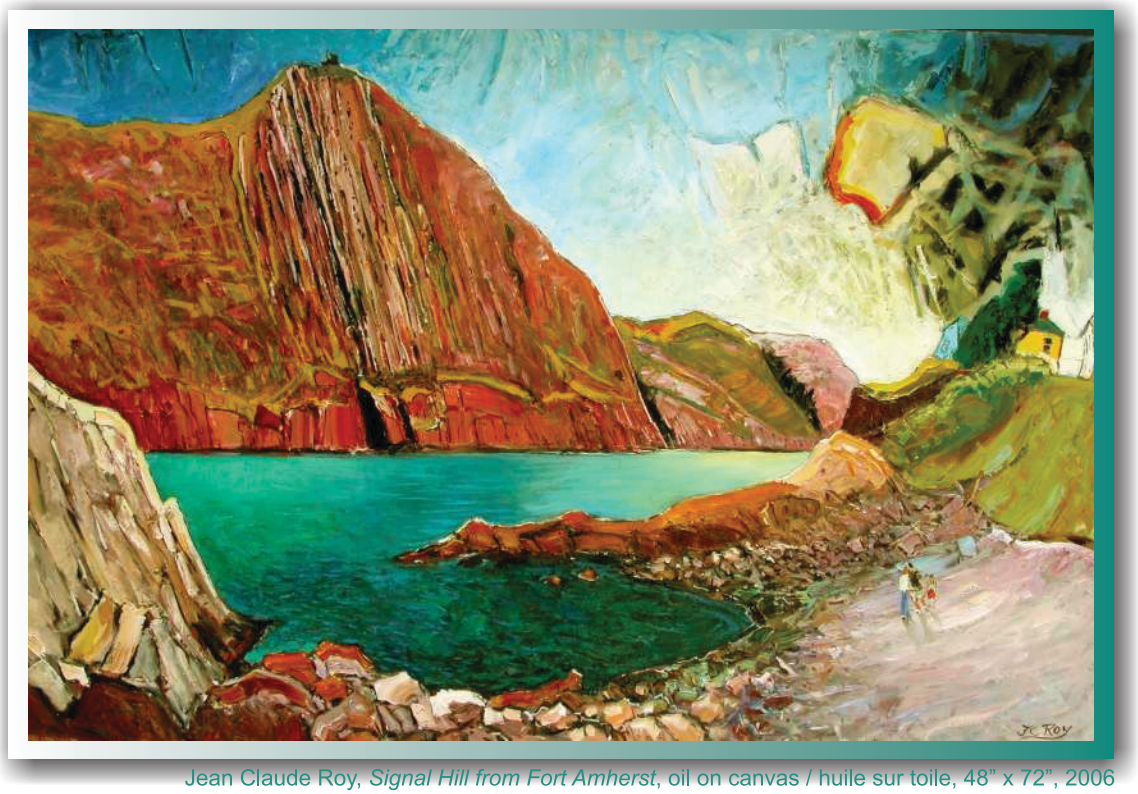

Jean Claude Roy, *Signal Hill from Fort Amherst*, oil on canvas / huile sur toile, 48" x 72", 2006

ABSTRACTS-RÉSUMÉS

Volume 35

GAC®- MAC • AGC®- AMC

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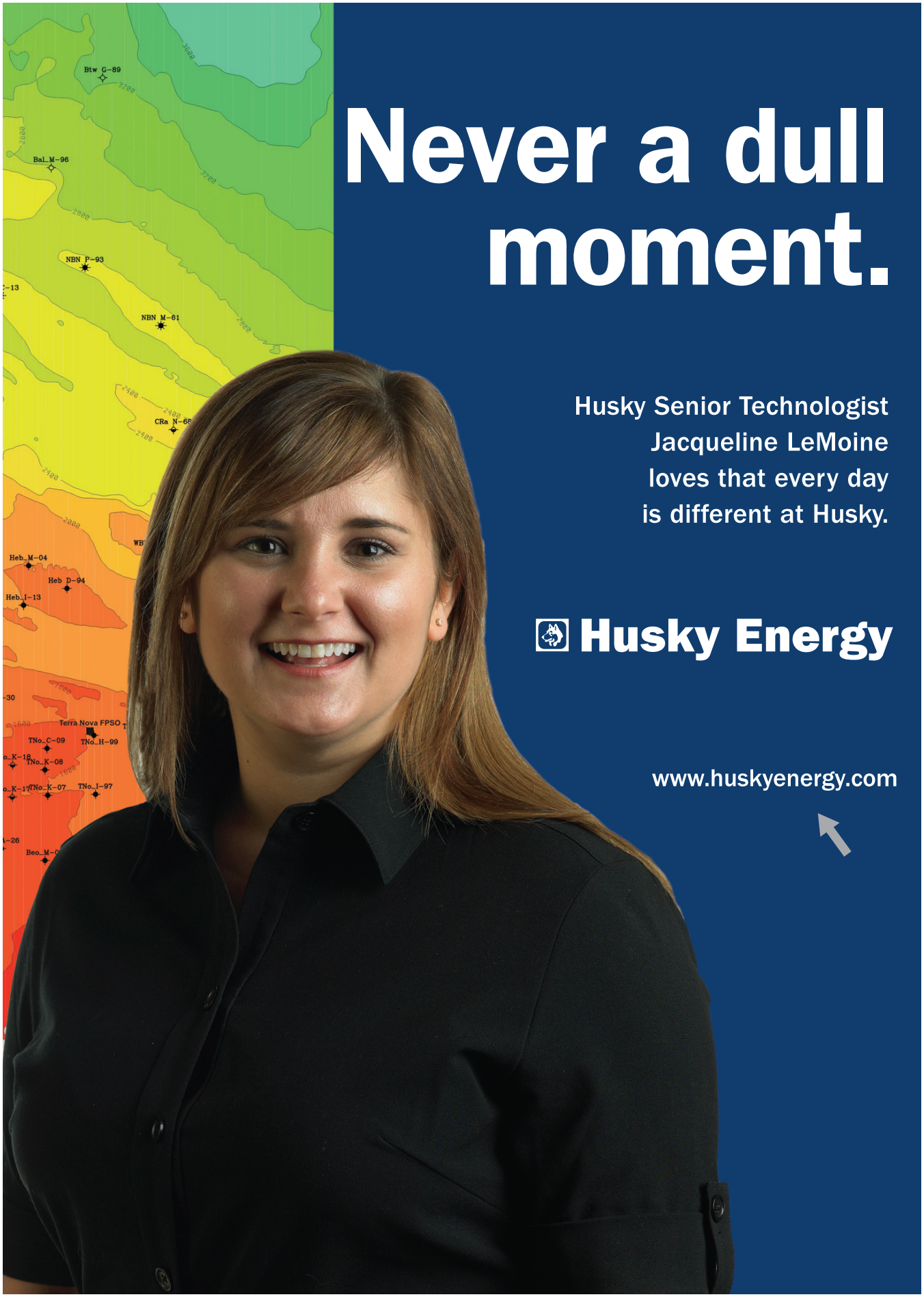
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Welcome to St. John's 2012 / Bienvenue à St. John's 2012

On behalf of the St. John's 2012 local organizing committee, we welcome delegates to North America's oldest city, St. John's, for the joint annual meeting of the Geological Association of Canada (GAC®) and the Mineralogical Association of Canada (MAC). Returning once again to Newfoundland and Labrador, delegates and guests will enjoy not only an exceptional technical program of outstanding geoscience, but also the rich-culture, friendly faces and rugged landscapes that this historic city has to offer.

The meeting is being held at the Delta St. John's Hotel and Conference Centre. The location provides delegates with the convenience of a compact conference venue, located in the heart of downtown and with a spectacular view of the Narrows. We hope you will take the opportunity to explore the history, culture, unique architecture, culinary pleasures and colourful characters that the city has to offer.

The meeting's motto, Geoscience at the Edge, alludes not only to the geographic location of the host city, St. John's, situated at the eastern edge of the North American craton, but also to the leading geoscience research and ideas being presented at the meeting. Whether your focus is on petroleum, base or precious metals, geophysics, bedrock or seafloor mapping, climate change, or geotourism, St. John's 2012 will present the latest research and technical developments in the Earth Sciences. The technical program contains three symposia and twenty one special sessions featuring a cross section of geoscience research from Economic Geology to soft rock sessions including shale gas, facies models, provenance determination, geohazard assessment and oil spill prevention. The program has a short course and a diverse offering of twelve field trips. The meeting contains an expansive outreach program that features events and activities that aim to raise awareness of the Earth Sciences to the general public, as well as to students and teachers.

St. John's 2012 not only has an excellent technical program, but also a diverse special events program. Join us for the Gala Banquet, which features fine dining and memorable Newfoundland entertainment. Other social events include: a lobster dinner, a chance for lobster lovers to enjoy the finest that the North Atlantic has to offer; and a Pub Night, an opportunity to savour local microbrew while enjoying the sights and sounds of historic downtown St. John's.

We hope you enjoy the rich culture and breathtaking beauty that the City of Legends has to offer.

Alana Hinchey, GAC® Chair
Steve Piercey, MAC Co-Chair

Au nom du comité organisateur de St. John's 2012, nous souhaitons aux participants la bienvenue à la plus ancienne ville d'Amérique du Nord, St. John's, à l'occasion de la réunion annuelle conjointe de l'Association géologique du Canada (AGC®) et l'Association minéralogique du Canada (AMC). En revenant une fois de plus à Terre-Neuve-et-Labrador les participants et leurs invités pourront encore profiter non seulement d'un programme d'activités professionnelles géoscientifique exceptionnel, mais aussi de la riche culture, de l'accueil de gens sympathiques et des paysages sauvages particuliers à cette ville historique.

La réunion se tiendra à l'hôtel Delta de St. John's et à son centre de conférence. L'emplacement offre aux délégués l'avantage d'un lieu de conférence compact situé au cœur du centre-ville avec une vue spectaculaire sur le Narrows. Nous espérons que vous profiterez de l'occasion pour vous enquérir de l'histoire, de la culture, de l'architecture unique, et que vous goûterez les plaisirs culinaires uniques et les personnages hauts en couleur de la ville.

Le thème de la réunion, Géosciences de pointe, fait allusion non seulement à l'emplacement géographique de la ville hôte, St. John's, situé à l'extrémité orientale du craton de l'Amérique du Nord, mais également à la recherche géoscientifiques et aux idées de pointe présentées à de la réunion. Que vous vous intéressiez au pétrole, aux métaux de base ou précieux, à la géophysique, à la cartographie des affleurements ou des fonds marins, au changement climatique, ou au géotourisme, St. John's 2012 présentera les dernières recherches et développements techniques en sciences de la Terre. Le programme d'activités professionnelles comprend trois symposiums et vingt-et-une séances spécialisées donneront un aperçu des recherches géoscientifiques en cours, en géologie économique, sur les roches non-consolidées, les gaz de schiste, les modèles de faciès, la détermination des matériaux d'origine, l'évaluation des géorisques et la prévention des déversements de pétrole. Le programme d'activités comprend un cours intensif ainsi qu'une fourchette diversifiée de douze excursions de terrain. La réunion comprend un ambitieux programme de sensibilisation qui propose des événements et des activités qui visent à sensibiliser aux sciences de la Terre le grand public, les étudiants et les enseignants.

St. John's 2012 a non seulement un excellent programme d'activités professionnelles, mais aussi un programme d'événements spéciaux diversifié. Soyez des nôtres à la soirée gala, qui propose un dîner raffiné et un divertissement terre-neuvien mémorable. Les autres activités sociales comprennent entre autre: un dîner de homard, et une soirée au pub.

Nous espérons que vous apprécierez la richesse culturelle et la beauté à couper le souffle de St. John's, cette ville de légendes.

Alana Hinchey, AGC® Président
Steve Piercey, AMC Co-président

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MUN	Memorial University of Newfoundland
MINES	Mines Branch, Newfoundland and Labrador Department of Natural Resources
CNLOBP	Canada-Newfoundland and Labrador Offshore Petroleum Board
ENERGY	Energy Branch, Newfoundland and Labrador Department of Natural Resources
EM	ExxonMobil
SE	Suncor Energy
VALE	VALE

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THERMAL HISTORY OF THE KAPOETA METEORITE: A STUDY OF Fe^{2+}-Mg ORDERING IN ORTHOPYROXENE BY SINGLE-CRYSTAL XRD AND MÖSSBAUER SPECTROSCOPY

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Kapoeta is an achondrite meteorite that belongs to the howardite group. Howardites, eucrites, and diogenites meteorites (HED) are believed to originate from igneous processes on the asteroid 4 Vesta. Kapoeta is characterized as a polymict breccia with a light-dark structure, and the rock consists almost entirely of pyroxene. The study of intracrystalline distribution of Fe^{2+} and Mg between the nonequivalent octahedral sites M1 and M2 in pyroxenes is very useful in tracing the thermal history of a rock. In unshocked and slowly cooled pyroxenes to ~ 500 °C and below, Fe^{2+} orders at the M2 site whereas Mg occurs predominately at the M1 site. In crystals that have been rapidly cooled from high temperatures, a more disordered Fe^{2+}-Mg distribution over the M1 and M2 sites is observed.

Single-crystal X-ray diffraction was used to determine Fe^{2+}-Mg degree of ordering on orthopyroxene crystals from the Kapoeta meteorite, through the intracrystalline distribution parameter, p, defined as: $p = (Fe^{2+}(M1).Mg(M2))/(Fe^{2+}(M2).Mg(M1))$, which is then used to calculate the Fe^{2+}-Mg ordering closure temperature (Tc). The distribution of Fe^{2+} and Mg over the M1 and M2 sites determined by the structure refinement gives Tc values in the range 350-450°C, in agreement with those previously obtained on some orthopyroxene crystals from Kapoeta having similar compositions to our orthopyroxenes (Mg/(Mg+Fe) range: 70-80%), all are within the Tc values reported on orthopyroxenes from diogenites. These closure temperatures indicate a slow cooling rate for these Kapoeta orthopyroxenes, and the similarities of Tc and composition to those of diogenites may suggest a diogenitic origin deep within the parent body of the HED meteorites.

Mössbauer spectra collected on powdered samples from both the light and dark structures of Kapoeta are characteristic of orthopyroxene. The light and dark structures have almost identical Mössbauer spectra. The spectra are fitted with two doublets due to Fe^{2+} at the M1 and M2 sites in orthopyroxene. In contrast to the low Tc values determined by structure refinement, the distribution of Fe^{2+} between the M1 and M2 sites determined by Mössbauer spectroscopy suggests a Tc value of ~ 900 °C, indicating a fast cooling. The results are discussed in relation to the thermal and shock histories of the HED parent body.

ROPER-LIKE MICROFOSSILS FROM THE MESOPROTERO-ZOIC HELENA EMBAYMENT, BELT SUPERGROUP

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Shale samples from the Helena Embayment of the Lower Belt Supergroup (> 1.45 Ga), Montana have yielded well-preserved acritarch assemblages, including a range of taxa characteristic of the broadly contemporaneous Roper Group, northern Australia. Sampled horizons are in the vicinity of White Sulfur Springs, Montana, and include drillcore (Cominco American, #SCC-34) of the Chamberlain Shale and outcrop of the stratigraphically younger Greyson Shale.

The Chamberlain consists of dark siliciclastic/calcareous shales, and has been interpreted as representing a low-oxygen, low-energy shoreward transgressive facies that was eventually replaced by regressive Greyson Shale-like facies. The Greyson Shale appears to represent a shallow water setting, and is gradationally overlain by the conspicuously red and mudcracked Spokane Formation. In addition to simple spheroidal (Leiosphaeridia spp.) and filamentous (Siphonophycus spp., Tortunema sp., Rugosoopsis sp.) microfossils, one drillcore Chamberlain sample yielded four Valeria specimens associated with large, striated tubular sheaths. Each Valeria has been compressed at different relative angles to the poles of their concentric striations, supporting an interpretation that the striations express physical attributes of the vesicle ultrastructure. Greyson samples have yielded an intriguing range of morphologically differentiated acritarch taxa. There are two Tappania specimens, four small Gemmuloides specimens (each with distinct, sub-rounded buds ranging from 9-25% of parent vesicle size) and numerous specimens resembling Caudosphaera, though these specimens possess dark, globose spheroidal vesicles that are not distinguished in Caudosphaera descriptions from Russia.

Spheroids and filaments are found throughout the entire microfossil record, but this assemblage has a typical Mesoproterozoic aspect. Tappania is known from the Mesoproterozoic Roper, Ruyang (China), Vindhyan (India), and Kamo (Russia) Groups, but is conspicuous in the Roper. Roper is also noted for the presence of Satka, which has been previously documented in the Chamberlain, and for fused filaments which may correspond to those recovered in this study. Overall, this preliminary study of Belt Supergroup microfossils reveals an assemblage strikingly similar to that found in the Roper Group and points to an early Mesoproterozoic establishment of a modestly diversified eukaryotic biota, followed by pronounced macroevolutionary stasis with very limited, if any, bioprovinciality. Such patterns have important implications for understanding the macroevolutoionary expression of the Mesoproterozoic biosphere.

FORENSIC PALYNOLOGY: CONSIDERING EVIDENCE FROM FOOTWEAR

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Five forensic samples were collected from five (5) different locations in University of Lagos campus including the Faculty of Science, the Botanical Garden, the faculty of Business Administrations, Distance Learning Institute and University of Lagos Gate. Samples were collected from the pair of shoes of individual students and members of staff who cooperated using brushes in succession (a brush for a pair of shoes) for pollen collection. The dusts were carefully brushed into white envelopes shading them from the direction of the wind. The white envelope were sealed up and labeled. The collected samples were taken into the laboratory and subjected to standard palynological sample preparation to isolate the palynomorphs. The aim of this research was to assess the forensic value of soil samples from footwear in linking suspects to crime scenes. The recovered pollen assemblage were compared with the present vegetation at the vicinity within which the students walked to determine the degree to which pollen assemblages from footwear represent vegetation within the same localized area, and the degree to which the retrieved pollen assemblage differ from distant localized areas. Retrieved palynomorphs assemblage showed a high degree of similarity with vegetation within the sampled locality, the relative abundance of palynomorphs being proportional to vegetation. The recovered palynomorphs also revealed the various locations the people sampled have visited before getting to sampled locations suggesting that forensic palynology should always be incorporated as a vital tool in criminal investigations in countries where this is yet to be accepted. One must however stress the importance of strong background in plant ecology and palynology and necessity of carrying out detailed vegetation surveys of all relevant places, after this can forensic palynology be used to their fullest potentials.

BIOLOGICAL AND ECOLOGICAL FACTORS CONTROLLING CARBONATE BUILD-UPS AND PRODUCING A PRECISION ARCTIC/SUBARCTIC MARINE CLIMATE ARCHIVE: THE CALCIFIED ALGA CLATHROMORPHUM COMPACTUM

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Numerous studies have demonstrated that the coralline alga C. compactum can yield high-resolution precision paleoenvironmental records in regions where other archival records are unavailable. However, at present information on C. compactum biology and ecology is limited. Using an extensive collection of samples from the northwestern Atlantic Coast from northern Labrador to the Gulf of Maine, this study provides an understanding of the complex interaction between reproduction, cellular anatomy and temperature-regulated growth. At mid-photic depths of 10-

25m, C. compactum can cover large areas of rocky bottom, forming clathrostromes (carbonate build-ups). Ultimate crustal thickness is primarily limited by geomorphological stability, very high levels of wave energy and mollusk boring. The thickest specimens found to date (>100mm), in northern Labrador, exhibit more than 800 years of growth. C. compactum reaches maximum coverage and clathrostrome formation in island complexes at moderate wave exposures. In protected bays and fjords, lower salinities, sedimentation and competition by the branching coralline Lithothamnion glaciale prevents significant clathrostrome formation.

Reproductive/anatomical investigation, using mosaic images taken with SEM, have demonstrated how metabolically-emplaced inner wall calcite, integral with growth, is regulated by temperature, while carbonate density is controlled by the addition of secondary inter-filament calcite, deposited primarily in summer, likely by photosynthesis-driven CO_2 removal. Winter crustal accretion (growth), at 10-15 µm/month in Labrador, continues, under sea ice and snow, during short winter days; the available evidence suggests that growth is likely in the high Arctic in complete winter darkness. In Labrador, summer accretion rates are roughly 20-25 µm/month. In the Gulf of Maine, the southern limit of C. compactum, where the species is considerably less abundant than in the Labrador Sea, accretion rates are about 400 µm/year; in northern Labrador, they are about 120 µm/year. C. compactum occurs throughout the Arctic and into the North Pacific, but it is unknown at this time whether or not it is a dominant crust in the Arctic, producing significant carbonate buildups. It is possible that this species can provide a pan-Arctic climate archive of considerable significance.

LATERAL FLUID FLOW UNDERNEATH AND INTO CARLIN-TYPE GOLD DEPOSITS: ISOTOPIC CONSTRAINTS ON THE PATH OF HYDROTHERMAL FLUID FLOW

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In the shallow crust, fluid flow responsible for the formation of many bedrock-hosted hydrothermal ore deposits is commonly conceptualized as occurring in a dominantly vertical direction controlled by high angle fault structures. In this study we use carbon and oxygen stable isotopes in conjunction with a pre-existing trace element database to investigate pathways taken by ore-forming fluids into the Pipeline deposit, a giant Carlin-type sedimentary rock-hosted disseminated gold deposit located in north central Nevada. We sampled deep drill holes within, below and to the side of the main orebodies and this enabled us to assess the extent of lateral verses vertical fluid flow up to 600m below mineralization.

A lack of pervasive $\delta^{18}O$ depletion and low concentrations of trace elements in the rocks beneath the main ore zone at Pipeline demonstrate that mineralization was not the product of any large scale vertical upwelling of ore stage hydrothermal fluid. There is, however, evidence of extensive lateral fluid flow along a major lithological contact between the Roberts Mountains and Weban Formations and along a thrust stack below the regionally extensive Roberts Mountains Thrust. A second thrust, the Abyss Fault, ~100-200m below the Pipeline deposit has minor isotopic depletion but overall no evidence of major fluid rock interaction. Genesis of the Pipeline deposit involved direct lateral flow of hydrothermal fluid on at least a 103m scale and suggests “deeper” might not always be “better” in brownfields exploration for Carlin-type deposits.

TESTING THE OROGENIC COLLAPSE MODEL FOR THE MESOPROTEROZOIC GRENVILLE PROVINCE

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A new tectonic model for the hinterland of the Grenville Province has been proposed that interprets the crustal-scale architecture in terms of pervasive collapse of an orogenic plateau following its construction during the Ottawan orogenic phase. Collapse led to the formation of exhumed mid-crustal core complexes juxtaposed against down-dropped higher crustal levels, including the orogenic upper crust and the cool orogenic lid. This model integrates crustal-scale seismic sections with structural, isotopic/geochronological and petrological data for the Ottawan phase to define the orogenic style, peak P-T conditions, and timing of metamorphism at each crustal level. Specifically, it contrasts the Ottawan tectonic evolution of the three crustal levels: (i) mid-crustal migmatitic gneiss terranes, characterized by sub-horizontal L-S fabrics that formed at peak P-T conditions of 800-1100 MPa and 750-850 °C from 1090-1050 Ma, (ii) upper crustal schist terranes with steep to vertical structures that formed at peak P-T of 300-600 MPa and 600-750 °C from 1050-1020 Ma, and (iii) an orogenic lid that escaped penetrative deformation and in which the peak temperature was < 500 °C. These levels are currently juxtaposed in a crustal-scale horst and graben architecture, the arrangement implying there was an important episode of extension after peak metamorphism in the mid crust. In detail, exhumation of the mid crust was coeval with peak metamorphism in the upper crust, suggesting that heating of upper crust occurred by conduction after it was juxtaposed against the exhumed, hot mid crust.

A test of this tectonic model for the Grenville Province is currently in progress as an MSc project by the first author. The study is based on a transect in the western Grenville Province in Ontario, which incorporates the exhumed mid crust, upper crust and the orogenic lid. At each level of the orogenic crust, representative structures have been recorded and low variance samples collected for the determination of P-T data. *In situ* dating of peak and retrograde metamorphic assemblages will be carried out using monazite chronology where feasible. The aim is to more precisely define the details of the collapse process in adjacent crustal levels, and integrate the results into a more refined tectonic model.

REDUCTANTS INVOLVED IN THE FORMATION OF THE ATHABASCA BASIN UNCONFORMITY-RELATED URANIUM DEPOSITS

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Several possible reductants involved in the formation of unconformity-related U deposits in the Athabasca Basin have been considered from the point of view of their standard reduction potential (E0, V) when reducing U^{6+} to U^{4+} to form uraninite, by far the most abundant U mineral in these deposits. The reductants can be endogenous (e.g., graphite), produced *in-situ* by a pre- or syn-ore alteration (e.g., Fe^{2+}), or exogenous (e.g., CH_4).

The two most commonly suggested reductants are graphite and Fe^{2+}, which are relatively weak ones, with E0 of 0.52 and 0.77V, respectively. Graphite is important for the development of structures with which unconformity-related U deposits are often associated, but is inert and must be converted into a more reactive form (CO: E0 of –0.11V) to be an effective reductant. Methane is a weak reductant as well but its oxidation produces several intermediate products (methanol, formaldehyde, and formic acid), which have increasingly stronger standard reduction potentials, down to –0.11V. Several metals, including iron, are very strong reductants (E0 down to ca. –0.4V), but were not available at the deposition sites in any significant amounts.

Pyrite, FeS_2 (and possibly other sulfides), can also be considered as possible reductant for unconformity-type uranium deposits, as suggested for the Camie River deposit (Otish Basin, Quebec). The break up of pyrite would provide Fe^{2+}, a weak reductant, but most significantly S^{2-}, which is a strong reductant with standard reduction potential of –0.48V. In the acid conditions necessary to break up pyrite, S will be oxidized through a series of compounds from S^{2+} to S^{6+}, some of which are also strong reductants.

An important corollary of these results is that the stronger reductants, such as CO and the oxidation products of methane and S are all highly mobile, meaning that a significant U deposit can be formed away from the source of these reductants, as has been suggested for the Centennial deposit in the south-central portion of the basin. This indicates that unconformity-type uranium deposits can be found off-conductor and possibly explains the formation of “perched” ore-bodies. Finally, an important consideration about the formation of an unconformity-type uranium deposit is not only the relative reduction potential of a particular reductant, but also its abundance, the reduction potential of its oxidation products, and the possible participation of more than one reductant.

MODELING OF THE FLUID FLOW INVOLVED IN THE FORMATION OF THE ATHABASCA BASIN UNCONFORMITY-RELATED URANIUM DEPOSITS

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The fluid flow necessary for the formation of a typical unconformity-related uranium deposit in the Athabasca Basin, Canada, has been modeled using a derivation of Darcy's law. As a simplification, it is considered that the sandstone was the only source of U for these deposits, even though the basement probably contributed a limited amount of U to the system. Of the three possible fluid flow regimes (gravity, convection, overpressure), gravity under pure hydrostatic conditions is most effective considering the vast volumes of fluids needed to form the deposits, even though it is possible that convection may have played a limited role; the role of overpressure has been demonstrated to be limited.

Assuming U concentration of fluid=1 ppm, deposit size=75 million pounds U_3O_8, time to make a deposit=1 My, deposition efficiency=70%, sandstone permeability=10^{-14} m^2, effective length of fluid flow=450 km (size of the basin projected at the time when these deposits formed, at ca. 1.6 Ga), cross section of fluid flow for one deposit=1 by 10 km, and temperature=200°C.

The fluid flow necessary to form a typical Athabasca Basin deposit in 1 My is 1.3×10^{-3} m^3/s. The pressure necessary to mobilize this amount of fluid flow would be 1.46×10^6 Pa, corresponding to a height difference of ca. 150 m over the E-W length of the basin. Such a height difference between distant points could readily occur during a tectonic event affecting the continental crust at the time the deposit formed.

Thus, a typical unconformity-related uranium deposit in the Athabasca Basin can form under pure gravity-driven hydrostatic regime, and only basinal fluids are necessary. The critical fluid circulation factors are be the amount of U in the ore-related fluid, deposition time, and deposition efficiency. Large, world-class deposits can form by increasing all of these parameters and possibly introducing a certain, though limited, proportion of lithostatic regime.

PORPHYRY-STYLE ALTERATION AND MINERALIZATION ASSOCIATED WITH HIGH-LEVEL TONALITE-GRANODIORITE INTRUSIONS AT THE DARALOO AND SARMESHK COPPER DEPOSITS, SOUTH IRAN

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The Daraloo and Sarmeshk copper deposits occur in a NW-SE trending fault zone in the southern section of the Cenozoic Urumieh-Dokhtar Magmatic Belt, Iran. Alteration and mineralization cover a 10 km long, NW-SE trending zone, 500 m wide, with the Daraloo and Sarmeshk deposits located at the NW and SE ends, respectively. Geological mapping and drilling (about 100, 200-500 m deep drill holes) indicate the area is characterized by a series of Miocene (?) age, porphyritic tonalite-granodiorite plutons which intrude Eocene andesitic volcanic and pyroclastic rocks. Alteration assemblages are comparable to those in porphyry Cu±Mo systems and are well developed in both deposits, with phyllic and silicic alteration types dominant. Potassic alteration, identified in the deeper part of the system, occurs as secondary biotite replacing original mafic minerals, and subordinate K-feldspar replacing plagioclases. Chloritic alteration, manifested by a greenish to greenish-gray color, is widespread, particularly to the east of the Sarmeshk deposit. This alteration overprints the earlier biotite alteration, as evidenced by relict hydrothermal biotite and locally abundant biotite in the chlorite alteration. Propylitic alteration, developed mostly in the host volcanic rocks, is distinguished by the presence of epidote, carbonates, and chlorite. A supergene argillic alteration has affected both deposits. Mineralization occurs as quartz-sulfide stockworks and disseminated sulfides in both porphyritic intrusions and adjacent volcanic rocks. This hypogene mineralization is characterized by abundant pyrite and magnetite, minor chalcopyrite, and trace bornite and molybdenite. Magnetite, common in both deposits, occurs both in quartz-sulphide veinlets as well as discrete magnetite veinlets and disseminations. Supergene enrichment is poorly developed at Sarmeshk; however an enriched blanket, 5 to 40 m thick, is developed at Daraloo. This lack of supergene enrichment at Sarmeshk might be attributed to a less efficient leaching, due to the intense silicic alteration, or lower copper assays in the original mineralization. Whole rock chemistry, fluid inclusion studies, and stable and radiogenic isotope analyses are in progress to characterize the source and nature of the magmas and fluids responsible for the alteration and mineralization.

MAPPING OF HYDROTHERMAL ALTERATIONS ASSOCIATED WITH PORPHYRY-STYLE MINERALIZATION IN DARALOO-HANZA AREA, CENTRAL PART OF THE DEHAJ-SARDOEIEH BELT, SOUTH IRAN, USING SPECTRAL ANALYSIS OF ASTER DATA

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The Cenozoic Urumieh-Dokhtar Magmatic Belt (UDMB) of Iran is a major host to porphyry Cu±Mo±Au deposits (PCDs). Most known PCDs in the UDMB occur in the southern section of the belt, also known as the "Dehaj-Sardoeieh belt", or "Kerman Copper belt". The PCDs are commonly associated with well-developed potassic, phyllic, silicic, propylitic, and in some cases, argillic alterations, with phyllic alteration being dominant in most cases. Mineralization occurs as quartz-sulfide stockworks, as well as sulfide disseminations in the parent porphyritic bodies and in the host volcanic-pyroclastic rocks.

To investigate suitable approaches for ASTER data pre-processing and analysis to identify the distribution of the alteration minerals (assemblages) associated with copper mineralization, a case study was carried out on the "Daraloo-Hanza area" in the central part of the KCB. The area is characterized by extensive hydrothermal alteration, covering an area 15 km^2 in extent in NW-SE direction, developed mainly over three porphyry copper systems, known as Daraloo, Sarmeshk, and Bondar-Hanza, lying to the north, center and south of the area, respectively.

The research includes ASTER data pre-processing, processing and field and petrographic studies. Various image processing techniques including different ratio images, relative band depth, minimum noise fraction, pixel purity index, and matched filter processing were used to delineate and generate a hydrothermal alteration map. The analysis of 14-bands ASTER data for mapping hydrothermal alterations was found to provide satisfactory results. VNIR+SWIR relative reflectance spectral analysis was appropriate and helpful for detecting and mapping sericitic, argillic and propylitic alterations. Fe-oxides/hydroxides were successfully mapped by using ASTER VNIR as well as landsat ETM+ data. TIR emissivity analysis proved to be useful for mapping silicified, and quartz-rich rocks. The most promising results were obtained by matched-filter processing that helped revealing extensive phyllic and silicic alterations with Fe-oxides/hydroxides, as well as local areas of kaolinite alteration.

The analysis of ASTER data and follow-up field and petrographic studies suggest that sericitic- silicic alterations and Fe-oxides/hydroxides tend to be associated with copper mineralization at current exposures in the Daraloo-Hanza area. Considering the common association of the PCDs with sericitic and silicic alterations and widespread occurrence of Fe-oxides/hydroxides at surface, the results from this study can be used for exploration for PCDs in other parts of the Kerman Copper belt and likely in other areas.

A FILTERING TECHNIQUE FOR IDENTIFYING LOCAL MAXIMA IN REGIONAL GEOCHEMICAL DATA SETS

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The use of "global" percentiles is effective for identifying very strong, large geochemical anomalies, of which the lake-sediment and water databases from Newfoundland and Labrador contain several. However, such features have the effect of setting the threshold so high that attention is drawn away from potentially significant local maxima in regions where background is lower. An example from Labrador can be seen in the strong, extensive anomalies of fluoride in lake water that characterize the Flowers River Complex, and the dispersion train from the Strange Lake Complex. The influence of these features on the Labrador data set is such that fluoride values from almost all of southern Labrador are classed as

background, despite the presence of several local maxima, one of which is associated with the Popes Hill REE discovery. A similar effect is noted in the case of nickel in Labrador, where strong anomalies in northern Labrador, and over the Labrador Trough in the west, cause a local maximum in the vicinity of the Voisey's Bay deposit to be overlooked.

A filtering method for identifying such local maxima is proposed whereby a percentile value, for a particular element, is assigned to each sample not with respect to the data set as a whole, but with respect to its near neighbours only. The latter are defined by drawing a circle of specified search radius around the sample and identifying all the samples that fall within it. The sample is ranked with respect to this population of neighbours, and its rank converted to a percentile; the procedure is repeated for every sample in the data set. The process is computer-intensive although the algorithm is uncomplicated. Some experimentation is necessary to determine an optimal search radius; this varies from element to element but ranges typically between 40 and 80 km, with the lower radii being more appropriate in the Newfoundland data set where the sampling density is greater.

This approach seems to be most effective in regional data sets that include a few localized features of very strong response, such as fluoride and nickel in Labrador, and bromine in Newfoundland (of which the highest values tend to concentrate in coastal regions). For elements whose values are more evenly-distributed, such as zinc and cobalt, filtering the data provides no significant advantage in anomaly identification.

HISTORY OF REACTIVATED FAULT SYSTEMS IN THE NORTHEAST THELON BASIN REGION: REGIONAL TO LOCAL CONTROLS ON BASIN DEVELOPMENT AND HYDRO-THERMAL FLUID FLOW FOR URANIUM

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Reactivated ENE-WSW-trending dextral fault arrays in the northeast Thelon Basin region have been investigated under the Geomapping for Energy and Minerals Program through detailed outcrop and sample analysis. The sub-vertical fault arrays have dominantly sub-horizontal mineral lineation from strike-slip displacement and steeply raking slickensides from late dip-slip offsets of gently dipping strata against basement. The reactivated, segmented fault zones discordantly transect the main basement foliation, and comprise zones of sub-parallel brittle and ductile fractures. They are ~50 m wide and preferentially localized along the south sides of ~1 km wide deep structures interpreted from broad linear demagnetized zones. Some discontinuities interpreted as related to D_1 thrusting and isoclinal folding also appear to have been reactivated.

We test three fractal methods for synthesizing the fracture, quartz vein and shear zone data: fragment size-frequency distributions, box-counting (geometry, length and spatial distributions), and Cantor-dust analysis (pattern anisotropies and inhomogeneities). Textural data and fractal geometries are consistent with three deformation mechanisms: 1) Brittle dextral shear by attrition, distributed and implosion brecciation, 2) Linkage of pre-existing or precursor structures by oblique structures, as strain was propagated across a laterally expanding fault zone, and 3) Extension resulting in dip-slip movement across metre-wide zones. These observations highlight the importance of the modes and orientations of fracturing, and the orientations of pre-existing fabrics and rock architecture.

Fractal analysis of clast shapes and clast size distributions distinguishes three breccia styles and indicate that fluid pressure fluctuations were important in the brecciation process. Approximate palaeostress orientations during brecciation and their relationship to the deformational history of the terrane have been reconstructed by combining the orientations of microfractures (crack-seal, stylolites, branch cracks) with field data. Results from this study allow brecciation to be placed within a regional framework and constrain relationships with hydrothermal alteration/fluid flow systems, shear zone formation, lithological contrasts within the supracrustal rocks of early –mid Palaeoproterozoic age, and domainal variations in regional deformational phases such as D_2 and D_3.

These methods and findings provide templates for detailed studies of fractures, brecciation and mineralization processes in less well exposed strands of the Thelon, Turqavik and Amer faults, as well as in other terranes where fluid-induced brittle deformation and seismic pumping may have contributed to the generation and localization of uranium deposits. Very late stage fractures and high-dilation breccias are particularly favourable sites for hydrothermal mineral deposition, forming transitory low-pressure channels for repeated rapid passage of hydrothermal fluids.

EFFECTS OF THRUSTING DURING EARLY THIN-SKINNED TECTONICS RECORDED BY INTERCALATED 2.6 Ga FELSIC EXTRUSIVE ROCKS AND EARLY PALEOPROTEROZOIC QUARTZARENITE IN THE NE THELON AREA

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Regional to detailed structural studies under the Geomapping for Energy and Minerals Program have defined four deformation events, with the first (D_1) involving dramatic compressive translation and intercalation of Neoarchean with early Paleoproterozoic strata by multiple thrusts and recumbent isoclinal folds. D_1 significantly changed stratigraphic thicknesses, affecting reconstructions of original units (Ps1, Ps2 and Ps3) within the early Paleoproterozoic Amer and Ketyet River groups. For example the extensive basal quartzarenite (Ps1, hereafter "quartzite"), originally ~100-200 m thick, now ranges from 400 to 1000+ m thick in some places but forms slivers only 10s of metres thick in this study. This study examines the nature of intercalation between the quartzite and a highly foliated 2.58–2.62Ga felsic extrusive unit (hereafter "rhyolite") that directly underlies the quartzite in many places.

In the area of the Kiggavik uranium camp the rhyolite overlies Neoarchean feldspathic metagreywacke (hereafter "wacke") of the Woodburn Lake group. A zone of multiply repeated wacke – rhyolite – quartzite panels forms a key structural complex that lies along the north flank of the uranium camp. Within this complex, the rhyolite and quartzite are thin sheets that record various states of internal plastic deformation along their mutual contact (mylonitic shears, foliation boudinage, imbricated boudins, intrafolial folds, C/S fabric) and multiply refolded foliated gouge materials. Meso- and microstructural observations document alternating brittle and crystal-plastic deformation processes and pervasive dissolution-recrystallization. Even zircon grains are extensively altered and crushed. It is advocated that fluids expelled along multiple thrusts were responsible for hydrofracturing and cataclastic deformation. Periods of brittle fracturing alternated with ductile deformation during the thin-skinned tectonic event. In this interpretation, deformation of the wacke – rhyolite – quartzite assemblage was progressively accommodated by numerous short-lived and strongly localized cataclastic events at the bases of multiple thrusts rather than along a permanently weak décollement unit.

The wacke, rhyolite and quartzite were structurally intercalated during D_1, interpreted as after ~2.15Ga (metagabbro sills tentatively correlated elsewhere with Ps2 basalt) but before 1.9 Ga (detrital zircons in Ps4 that elsewhere unconformably overlies the D1-deformed Ps1-3 assemblage). This took place long before Thelon Basin developed by strike-slip and extensional faulting. However the alternating structural panels of wacke, rhyolite and quartzite may have channeled much later hydrothermal fluid flow that formed basement-hosted uranium deposits during and/or after development of Thelon Basin (1.75 to 1.5Ga). This is one example of applying relevant knowledge from basement deformation history to the uranium metallogeny of Paleoproterozoic basins.

GEOCHEMICAL SIGNATURES OF CARBONATE IMPACT MELTS FROM THE STEINHEIM IMPACT CRATER, GERMANY

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The 3.8 km in diameter Steinheim impact crater counts among the best-preserved complex impact structures with a central uplift on Earth. It lies within a sequence of flat-lying Triassic to Upper Jurassic sediments of the Swabian Alb plateau (SW Germany). Previous studies revealed the existence of silicate and carbonate melt lithologies within rocks of the B-26 core drilled in the western central basin of the Steinheim structure. Here we present a reinvestigation of these results to further evaluate geochemical features and signatures of the carbonate melt.

At a depth of 78-79 m, closely beneath the structural crater floor of the Steinheim Basin, the B-26 drill core consists of Upper Jurassic limestone containing macroscopic fractures that are filled with veins of Ca-Mg-carbonates. These carbonates exhibit an MgO content of up to ~20 wt% and were previously described as "impact-induced dolomitic melt" generated from the Steinheim target rocks and subsequently injected into host limestone fractures. The incorporation of detectable amounts of Si, Al and K into the Ca-Mg-carbonate groundmass is consistent with carbonate melt from other terrestrial impact craters such as Haughton crater, Canada. In general, the major elemental compositions of impact carbonate melts resemble those of carbonatite igneous rocks. The accumulation of Si, Al and Na in carbonatites is assumed to be attributed to chemical exchange with their wall rocks. Geochemical plots of the Steinheim carbonate melt show direct correlations of (Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) and Al^{3+} + (K^{+}, Na^{+}) as well as (Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) and (K^{+}, Na^{+}) + Si^{4+} suggesting a chemical exchange of cations.

So far, the following substitution processes can be determined that might lead to the accumulation of Si, Al and K within the dolomitic melt assemblage:

$$2\ (Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) \leftrightarrow Al^{3+} + (K^{+}, Na^{+})$$
$$(Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) + Al^{3+} \leftrightarrow (K^{+}, Na^{+}) + Si^{4+}$$
$$C^{4+} \leftrightarrow Si^{4+}$$

Further investigation and bulk composition analyses of the dolomite melt assemblage are required to confirm this assumption and to explain the incorporation of Si, Al, and K into the dolomitic melt, their source and possible scenarios of the origin of the Steinheim carbonate melt.

CONTRASTING TECTONOMETAMORPHIC EVOLUTIONS IN THE EASTERN PART OF THE SVECONORWEGIAN OROGEN

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The eastern part of the Sveconorwegian orogen consists of two, crustal-scale orogenic segments: (I) the parautochthonous to allochthonous Eastern Segment, adjoining the pre-Sveconorwegian craton in the east, and (II) the allochthonous Idefjorden terrane overlying the Eastern Segment in the west. The lithotectonic boundary between the Eastern Segment and the Idefjorden terrane is a west-dipping or sub-vertical, major ductile shear belt. These two orogenic segments show fundamentally different igneous, structural and metamorphic evolutions in Sveconorwegian and pre-Sveconorwegian time.

In the Eastern Segment, extensive high-P metamorphism at around 990-980 Ma, in discrete tectonic units reaching the eclogite facies, was followed by penetrative, regional-scale ductile deformation and partial melting under upper amphibolites facies conditions at around 970-960 Ma. Ductile deformation fabrics are cut by c. 960-950 Ma old, undeformed, granite and pegmatite dykes. Records of earlier Sveconorwegian metamorphism are lacking. The high-grade deformation fabrics were folded and stretched along E-W-trending axes and reoriented by regional-scale, open folding along N-S-trending axes. Protoliths to metamorphic rocks in the Eastern Segment are mainly 1.8 Ga and 1.7 Ga old intrusive rocks, equivalent in age and origin to rocks in the foreland east of the orogen. Pre-Sveconorwegian, high-grade metamorphism and deformation is constrained in two discrete intervals at 1.44-1.42 Ga and 1.41-1.38 Ga (Hallandian orogenesis).

In the overlying Idefjorden terrane, high-P metamorphism followed by high-grade ductile deformation and partial melting occurred in the 1040-1020 Ma interval, overlapping in age with cross-cutting, undeformed pegmatite dykes. Records of late-Sveconorwegian metamorphism at 990-960 Ma are only present inside the southern part of the boundary ductile shear belt, close to the contact to the exhumed, high-grade, lower crustal levels of the Eastern Segment. The regional Sveconorwegian structural grain of the Idefjorden terrane is characterised by N-S-trending structures, including ductile deformation fabrics, fold axes of large-scale folds, regional deformation zones, and tectonic contacts between elongated, metamorphic sub-domains. The Idefjorden terrane also hosts tectonic domains that show little or no imprint of Sveconorwegian metamorphism and deformation. The pre-Sveconorwegian evolution of the Idefjorden terrane is dominated by igneous activity, metamorphism and deformation at 1.64-1.52 Ga (Gothian orogenesis). Imprints of 1.4 Ga Hallandian reworking are absent.

The striking differences in age and character of the tectono-metamorphic build up in the eastern part of the Sveconorwegian orogen suggests a polyphase orogenic evolution that possibly included both a significant hiatus and shifts in style and character of plate convergence.

PRECAMBRIAN BASEMENT ROCKS IN THE VICINITY OF THE CHIDLIAK KIMBERLITES: INITIAL MAPPING ON THE HALL PENINSULA, BAFFIN ISLAND

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The Precambrian rocks on the Hall Peninsula, southeastern Baffin Island, are very poorly understood as they have only been mapped at reconnaissance scale. However, unravelling the origin and evolution of these rocks is vital as they should provide important constraints on the assembly of the northeastern margin of the Canadian Shield. At present, it is unclear whether the peninsula is underlain by Archean rocks of the Rae or North Atlantic cratons, or microcontinents, such as Metaincognita, that accreted during Paleoproterozoic collisional events. The western part is intruded by the Paleoproterozoic Cumberland batholith, whereas the north-central part is cut by the Chidliak diamondiferous kimberlites. Regional scale airborne geophysics has emphasized the likely complexity of the geological relationships in the basement rocks to the kimberlites, and so the aim of this project was to determine the field relationships, mineralogical, geochemical and age characteristics of a small 20 km^2 swath of basement rocks in the vicinity of the discovery kimberlites.

All the basement rocks in the area have been metamorphosed to amphibolite grade, and the dominant fabric is a gneissosity that strikes broadly east-west and is parallel to primary compositional variations. Outcrops are scattered and so the character of contacts between units is not known as they are typically not exposed. The most common rock units are garnet-biotite-sillimanite/cordierite faserkiesel-bearing psammitic and pelitic gneisses, the latter containing evidence for melt generation, with rare quartzite layers. The pelitic and psammitic gneisses are sometimes interbedded at the tens of centimetres to metre scale, although there is no convincing evidence for the stratigraphic younging direction. In the north of the study area are amphibolites, up to tens of metres thick, which locally contain stretched centimetre-scale pyroxene phenocrysts. These are interpreted as mafic volcanic flows. The southern end of the mapping area consists of a gneiss dome dominated by and cored by tonalitic gneiss, which is rimmed by less voluminous granodioritic and K-feldspar porphyritic gneisses. These rocks are also intruded by coarse-grained peridotite, which appears to have been boudinaged during the main deformation event. Geochemical and geochronological analysis of these

rocks is ongoing, although it is interpreted, based on extrapolation of regional geological relationships, that the deformation and metamorphism is Paleoproterozoic in age. The presence of diamondiferous kimberlites suggest the presence of Archean crust, although the supracrustal rocks may also be Paleoproterozoic and have been deposited or structurally emplaced on older basement, possibly preserved in the gneiss domes.

FIELD RELATIONS, PETROLOGY, AND TECTONIC SETTING OF THE ORDOVICIAN WEST BARNEYS RIVER PLUTONIC SUITE, SOUTHERN ANTIGONISH HIGHLANDS, NOVA SCOTIA, CANADA

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The West Barneys River plutonic suite consists of gabbro, syenite, quartz syenite, and alkali-feldspar granite outcropping over an area of approximately 100 km^2 in the central part of the southern Antigonish Highlands. Based on mapping and petrological studies, the suite is subdivided into five separate intermediate to felsic plutons (Laggan, Brora Lake, Mount Adam, Leadbetter Road, and Haggarts Lake), two mafic plutons (Garden River and Duck Ponds), and a large, heterogeneous composite pluton (Poor Farm Brook). The Poor Farm Brook pluton is dominantly (65%) gabbroic but also includes syenitic and granitic rocks similar to those in the other plutons. Magma mixing and mingling textures indicate a co-magmatic relationship between the mafic and intermediate-felsic lithologies, although U-Pb (zircon) ages of 484.8 ± 2.5 Ma from a gabbroic sample and 469.4 ± 0.5 Ma from a quartz syenite sample show that emplacement occurred over a significant span of time. Many of the rocks in the suite have high magnetic susceptibilities consistent with abundant modal magnetite, titanomagnetite, and/or ilmenite, and the suite is associated with a large positive magnetic anomaly. Intermediate to felsic rocks are hypersolvus and consist mainly of perthitic K-feldspar and variable amounts of quartz; interstitial granophyre is present in some samples, consistent with shallow emplacement. Mafic phases are Fe-rich amphibole and clinopyroxene, and in some units, fayalite. Gabbroic rocks consist of plagioclase (oligoclase-labradorite) and augite/diopside with less abundant orthopyroxene, olivine, biotite, and ilmenite/magnetite. They are mainly medium-grained and intergranular but locally porphyritic with plagioclase phenocrysts. Their chemical compositions are transitional from tholeiitic to alkalic and characteristic of continental within-plate mafic rocks. Intermediate and felsic samples have chemical characteristics of within-plate A-type granitoid rocks. Epsilon Nd values at 480 Ma are between 0.9 and 4.9 with similar ranges in both mafic and intermediate/felsic samples. These values are typical for rocks derived from Avalonian subcontinental lithospheric mantle and consistent with a co-genetic origin for the mafic and intermediate/felsic components of the suite. Emplacement of the plutonic suite may have been related to long-lived ensialic back-arc extension associated with subduction of Tornquist Sea oceanic lithosphere beneath Avalonia throughout the Ordovician. The West Barneys River plutonic suite represents an important and previously unrecognized magmatic episode during the evolution of Avalonia.

LATE CRETACEOUS MIDDLE FORK CALDERA AND ITS RESURGENT INTRUSION, EAST-CENTRAL ALASKA

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The Middle Fork caldera comprises a 10 × 20 km area of rhyolite welded tuff and granite porphyry ~100 km west of the Yukon border. Intracaldera tuff has quartz and feldspar phenocrysts ≤4 mm, cm-sized fiamme, and a maximum exposed thickness of 850 m. Less densely welded tuff near the caldera margins locally contains 1–2 cm K-feldspar megacrysts and pumice clasts to 6 cm. Zircon from intracaldera tuff yields a SHRIMP-RG U–Pb age of 68.7 ± 1.1 Ma (all ages 95% confidence). Granite porphyry occupies much of an 8 × 12 km area having 650 m of relief within the western part of the caldera fill. Zircon from the porphyry gives a SHRIMP-RG U–Pb age of 68.4 ± 1.0 Ma. These ages agree with a previous $^{40}Ar/^{39}Ar$ biotite age of 69.1 ± 0.5 Ma for proximal outflow tuff. The crystal-rich intracaldera tuff contains embayed quartz, plagioclase>K-feldspar, biotite, and Fe–Ti oxide phenocrysts in a very fine-grained crystalline groundmass. The porphyry carries 40–50% larger phenocrysts of the same phases (K-feldspar to 2 cm, rarely to 4 cm) in a fine-grained groundmass characterized by abundant 50–100 µm quartz. Compositions of 3 tuff and 3 porphyry samples overlap, form a limited differentiation series at 69–72% SiO_2, have arc geochemical signatures, and yield subparallel chondrite-normalized rare earth element patterns with light REE enrichment, concave-upward heavy REE, and small negative Eu anomalies. Although their phenocrysts differ in size and abundance, the similar mineralogy, composition (in spite of crystal concentration in the tuff), and indistinguishable ages of the tuff and porphyry indicate that the magmas were closely related. A rare magmatic enclave (54% SiO_2, arc geochemical signature) in the porphyry may be similar to parental magma and indicates thermal and mafic magma input. The porphyry is interpreted to have been exposed by erosion of thick intracaldera tuff from an asymmetric resurgent dome; proximal outflow tuff, and thus the 69 Ma land surface, remains at the west margin of the caldera structure. The Middle Fork caldera lies within a region of Paleozoic metamorphic rocks and Mesozoic plutons bounded by NE-trending faults. To the NW, Cretaceous plutonic rocks are widely exposed, indicating greater exhumation. The Middle Fork is a relatively well preserved caldera within a broad region of Alaska and adjacent Yukon that contains Late Cretaceous plutons and, in the less deeply exhumed blocks, silicic volcanic rocks.

EXPERIENCING SCIENCE ON THE LAND AT THE TUNDRA SCIENCE CAMP, DARING LAKE, NORTHWEST TERRITORIES

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For ten days each summer, since 1995, the Tundra Ecological Research Station, at Daring Lake, NWT becomes the focus of land-based learning and educational activities for a group of high school students, teachers, researchers, Aboriginal Dene elders and science mentors. The group comes together to learn about plant and animal biology, ecology, geology, archaeology, traditional and cultural knowledge, and climate change studies.

Half-day sessions on each topic begin in a research-tent classroom. Instructors cover basic vocabulary and concepts of each discipline using hands-on props and visual aids. An excursion on the tundra landscape follows every class, to actively engage participants in field work. This is done by observing, recording, collecting information and samples and becoming familiar with instruments and tools used by researchers. Aboriginal elders teach about the land through story-telling and demonstrations. An all-day hike along a sinuous esker provides an opportunity to process the formal learning into a connected synthesis in the overall scope of the landscape. While students are engaged in the multi-disciplinary instruction sessions, they begin a collection of objects which they later research and identify using the resource materials back in camp. A Collections Fair allows each student to display and share their individual collection with their peers.

For the second part of the camp, students choose a discipline and develop a project that interests them, working in small groups or individually, along with a mentor to guide their research. Data collection takes many forms: recording, measuring, mapping, graphing, sketching, counting, interviewing, photo-documenting and describing observations on the land. Projects are presented to peers and mentors through demonstrations, skits, songs and displays, followed by a question period.

Throughout the camp, cultural activities and games play an integral part tying in the human history and a Dene cultural perspective to the present day. Communal chores, as well as free time for journaling and recreation, complete the busy days. This program brings students and educators onto the land to experience a wide variety of science disciplines, traditional knowledge and hands-on learning to help them develop an interest in science-related careers and to integrate information about our past, present and future on the land.

PALEOGEOGRAPHIC CONTROLS ON THE DISTRIBUTION AND CHARACTER OF THE NEOPROTEROZOIC RAPITAN IRON FORMATION, NWT

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The Neoproterozoic Rapitan iron formation is one of the largest undeveloped iron deposits in Canada. Like most other Neoproterozoic iron formations, it is stratigraphically associated with glacioclastic rocks of the Sturtian glaciation, the first of three 'snowball Earth' events. Iron formation is distributed unevenly along the exposure belt: iron formation thickness exceeds 100 m in the Snake River (SR) area, but is less than 20 m in the Mountain-Keele-Redstone River (MKRR) area, and the Rapitan Group is absent between these two areas. Although previous study of the iron formation resulted in several different depositional models, relatively little focus has been placed on explaining its distribution, which is quite distinct from that of older iron formations, in which individual layers can be traced for hundreds of kilometres. Numerous stratigraphic, sedimentological, and geochemical differences in both the Rapitan iron formation and the associated glacioclastic rocks in the two areas containing iron formation indicate that localised sub-basins exerted a strong control on iron formation deposition. This control is expressed as three distinct but related effects: (1) the relative age of each sub-basin; (2) each basin's accommodation space or depth; and (3) the volume of clastic sediment supplied. Iron formation is underlain by rift deposits of the Coates Lake Group and glacioclastic turbidites of the Sayunei Formation in the MKRR area, whereas these units are absent in the SR area; this indicates that the MKRR sub-basin was more evolved. The SR sub-basin had ample accommodation space during iron formation deposition, and the deep basin was isolated from significant clastic input, allowing true iron formation to form. Basin depth influenced the character of the sediments overlying the iron formation: thick iron formation in the deeper parts of the basin is capped by granular iron formation (GIF) and hematitic glacioclastic rocks, whereas thin iron formation in shallower inboard areas is overlain by hematite-poor glacioclastics and no GIF. This distribution of lithofacies indicates that deep areas that were the most favourable for iron formation deposition filled all accommodation space well before the iron supply was exhausted, which resulted in terminal deposition of shallow-water GIF and hematite-rich clastics; whereas areas with thinner iron formation exhausted their iron supply prior to deposition of hematite-poor pebble to boulder diamictites. The assembled evidence indicates that geographic position in the basin and the extent of pre-existing fill were the primary controlling factors in initiation and termination of iron formation deposition.

DEPOSITIONAL AGE OF THE RAPITAN GROUP, NWT AND YT: IMPLICATIONS FOR THE ONSET OF THE STURTIAN GLACIATION

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The timing and causes of the glacial events associated with the 'Snowball Earth' hypothesis remain contentious. The earliest of these events, the Sturtian glaciation, is best typified by the glaciomarine diamictites, turbidites, and iron formation of the Rapitan Group, Canada. Sediments associated with the Sturtian glaciation worldwide have returned U-Pb zircon and Re-Os black shale ages from 740 Ma to as young as 660 Ma, suggesting a either a significant glacial duration, or poor overall age constraints. One of the best publicized mechanisms for the initiation of the Sturtian glaciation is the so-called 'fire and ice' model, in which rapid weathering of a freshly emplaced large igneous province (LIP) would cause sufficient atmospheric CO_2 draw-down to trigger a global glaciation. This model is contingent on the near-simultaneous emplacement of the LIP, its weathering, and glacial onset- all at low latitudes. Consequently, it cannot be tested without age constraints relating Neoproterozoic glacial deposits with known LIPs of sufficient area and volume. Recently, strata correlated with the Rapitan Group have been dated at 716.47±0.24 Ma. This age is within error of that of the Franklin LIP (Canada), and has been touted as evidence that 'fire and ice' involving the Franklin LIP triggered the Sturtian glaciation.

Here we present a new detrital zircon age from the Rapitan Group itself. The sample was extracted from cross-bedded sandstone underlying the Rapitan iron formation by 75 m. A large number of zircon were pilot dated by LA-ICP-MS on double-sided tape and the youngest were then dated by high-precision ID-TIMS. A coherent population of 8 grains defines a concordia age of 711.34±0.25 Ma. This is the new maximum depositional age of the Rapitan Group and for the Sturtian glaciation in the region, and is broadly consistent with both U-Pb zircon dates from ash beds interleaved with Sturtian glacioclastic rocks, and Re-Os dates from shales overlying other Sturtian glacial deposits. Significantly, it is a full 5 million years younger than the Franklin LIP, a span of time that is too long to support the 'fire and ice' model. Furthermore, this suggests that previous correlations between the Rapitan Group and other strata in the region may be erroneous, and that the Sturtian glaciation may have been a diachronous event worldwide.

CONSTRAINING THE AGE OF LOW-TEMPERATURE METASOMATISM OF A CARLIN-TYPE GOLD DEPOSIT, NEVADA

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The Carlin-type gold deposits of NE Nevada have a prolonged history of hydrothermal alteration and gold mineralization, with debate over when the main endowment of gold mineralization occurred. In this study, we use Rb-Sr isotope analysis of variably altered and gold-mineralized lamprophyre dyke from the Banshee deposit, in the northern Carlin Trend to constrain the age of potassic metasomatism. In addition, we use K-Ar dating of illite from altered dykes, and apatite fission track from lamprophyre to reveal a complex history of hydrothermal alteration and metasomatism.

EARLY PALEOZOIC EVENTS AND DEVELOPMENTS DETERMINED FROM CONODONT BIOSTRATIGRAPHIC, PALEOECOLOGIC AND ISOTOPIC STUDIES, CANADIAN NORTH ATLANTIC LAURENTIAN BORDERLAND

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The North Atlantic Laurentian margin in Canada preserves some remarkably complete Lower Paleozoic stratigraphic sequences that have remained relatively unaltered by thermal and tectonic events. This part of Laurentia was positioned about 20° south of the paleoequator through the Ordovician-Silurian and, together with the largely peneplaned Canadian Shield, resulted in extensive epeiric seas that were characterized by carbonate and periodic organic-rich shale deposition. Changes in sea level, epeirogeny and climate are reflected in the stratigraphic, sedimentologic and biotic records of these shallow shelf and deeper offshore basin and slope facies. Five decades of intense, systematic collecting in selected key areas has yielded several hundred thousand conodont microfossils from their origin in the Late Cambrian through the Early Silurian. These areas include: western Newfoundland (Port au Port, Cow Head and Great

Northern peninsulas; Late Cambrian through Early Ordovician); Anticosti Island and the St Lawrence Lowlands of Quebec (mid Ordovician through Early Silurian); eastern and southern Ontario (mid-Late Ordovician); some Precambrian Shield outliers; and the Hudson Bay region (outcrop and offshore wells; Late Ordovician through Early Silurian). Following painstaking taxonomic studies, faunal identifications, some cladistics work, and elucidation of evolutionary lineages, the detailed conodont biostratigraphy has been established for these areas. The extensive regional sampling coverage has allowed determination of paleobiogeographic patterns such as the interplay of provincial faunas, while the intensive stratigraphic studies and sampling with subsequent statistical analyses of the faunas have established the nature and evolution of conodont communities though time. Recent isotopic studies (Sr, Nd, O) on conodonts with other colleagues have provided valuable additional data to help interpret paleoceanographic and paleoclimatic events and trends. Integration of most of these data sets from the Canadian North Atlantic borderland of Laurentia has the potential to contribute significantly to resolving some of the most important issues in the Early Paleozoic (mainly Ordovician-Silurian) including for example: the rapid five-fold increase in biodiversity that characterizes the mid-Ordovician; the nature of ocean circulation and stratification during the extreme greenhouse states; the paleoclimatic switch to an icehouse state with the uncertainties of the duration and sequential biotic effects of the terminal Ordovician glaciation; and the effects of eustasy and climate/ocean change on biotas within epeiric seas.

REMOTE PREDICTIVE MAPPING OF SURFICIAL MATERIALS IN THE FAR NORTH OF ONTARIO IN AID OF LAND USE PLANNING

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In 2008, the Ontario government announced plans to permanently protect half of the Far North region of Ontario and launched a planning process to support this goal. During the initial stages of planning the need for primary landscape data became apparent. A project to remotely predict surficial materials was initiated by the Ontario Geological Survey in response to this information need.

SPOT imagery (4 colour bands and the panchromatic band), a digital elevation model and its derivatives and the Ontario Hydro Network vector drainage shape files are the primary data sources for this remote predictive mapping exercise. Multiresolution segmentation algorithm, using different image layer weights, scale parameters and homogeneity criterion, within an object-based image analysis software is used to achieve meaningful objects representing various surficial material types. Objects are then classified based on digital signature, internal variability of signature and proximity to certain vector layers and certain adjacent material types.

Limited helicopter-supported field work combined with the examination of archival information provides the ground control on the classification of objects. In addition, information from other Far North Information Knowledge Management Program projects, such as base data and land cover information has been used in the interpretation and classification of the surficial materials.

MESOPROTEROZOIC-NEOPROTEROZOIC INFRASTRUCTURE OF GANDERIA: DETRITAL ZIRCON AGES FROM THE BROOKVILLE TERRANE, SOUTHERN NEW BRUNSWICK, CANADA

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The Brookville terrane in southern New Brunswick is the oldest known component of the Ganderian microcontinent of the northern Appalachian orogen. Hence, its composition, tectonic evolution, and provenance are keys to understanding the origin and travels of Ganderia. The Brookville terrane includes metasedimentary rocks of the Green Head Group, in mylonitic contact with the Brookville Gneiss, an assemblage of low-pressure/high-temperature paragneiss and tonalitic orthogneiss. The Green Head Group consists of the locally stromatolitic metacarbonate- and quartzite-dominated Ashburn Formation and metasiltstone-dominated Martinon Formation. Based on previously published detrital zircon ages, the maximum age for the Ashburn Formation is ca. 1230 Ma, whereas the Martinon Formation contains detrital zircon as young as ca. 600 Ma. Both the Green Head Group and the Brookville Gneiss are intruded by ca. 555-525 Ma subduction-related Golden Grove Plutonic Suite, providing a minimum age for the host rocks.

Additional detrital zircon studies reported here were aimed at resolving the original stratigraphic relationship between the Ashburn and Martinon formations, as well as their relationship to the Brookville paragneiss. Analysis by ICP-MS of 72 additional grains from the Ashburn Formation quartzite sample analyzed previously by TIMS similarly yielded no grains younger than ca. 1200 Ma, a predominance of Meso- and Paleoproterozoic ages back to ca. 2100 Ma, and a few Neoarchean ages. A sample from the metasiltstone matrix of a carbonate olistostrome in the Martinon Formation contains rounded grains with ages mainly between ca. 1000 Ma - 2200 Ma, indicating provenance similar to that of the Ashburn Formation quartzite. However, the sample also contains euhedral grains with ages clustered around 650 Ma. A calcareous metasiltstone sample from the Brookville paragneiss also yielded detrital zircon grains with mainly ages between 1150 Ma and 2000 Ma, indicating provenance similar to that of the Ashburn and Martinon formations. An orthogneiss sample yielded euhedral (igneous) zircon grains with a concordia age of 616 ± 4 Ma, slightly older than previously reported ages of ca. 605 Ma and indicating an interval of continental margin subduction at least 60 Ma older than that represented by the Golden Grove suite.

Similar detrital zircon age spectra showing a dominance of Proterozoic ages strongly support a link among the Ashburn Formation, Martinon Formation, and Brookville paragneiss in terms of provenance, but do not resolve the question of the original stratigraphic relationship among these units or the age of the passive margin sequence represented by the Green Head Group.

LANTHANUM DISPERSION IN SOIL-PLANT SYSTEM IN A TROPICAL AREA: THE CAMUTANGA Pb-Ba MINERALIZATION, PERNAMBUCO, BRAZIL

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The study area is located in northeastern Brazil in the city of Camutanga about 120 km northwest of Recife where there is a Pb-Ba mineralization explored in the 1930s. Soil and vegetation samples (Musa spp.) were collected at five stations over (E1 and E3) and outside (E2, E4 and E5) of the mineralized body. Were done soil profiles at each station and collected samples from each horizon identified. For the Musa spp. were collected roots, leaves, bark and fruit. The results of the soil analysis (multi-acid digestion and ICP-MS/AES measurement) showed concentrations of La between 10.9 and 56.5 $mg.kg^{-1}$ at stations outside of the mineralized corps and 44.7 and 77.6 $mg.kg^{-1}$ over the mineralization. The evaluation of the vertical distribution of the La soil profile shows an concentration increase with depth, except in E4 where the highest concentration is in the surface horizon. At the samples of Musa spp. concentrations (*aqua regia* digestion and ICP-MS/AES measurement) ranged from 0.03 to 2.54 $mg.kg^{-1}$ and 0.03 to 6.03 $mg.kg^{-1}$, over and outside of the mineralized corps, respectively. The highest concentrations were identified in the roots (2.49 to 6.03 $mg.kg^{-1}$), followed by leaves (0.22 to 0.70 $mg.kg^{-1}$). The fruit and the bark had the lowest concentrations, ranging from 0.03 to 0.07 $mg.kg^{-1}$ and 0.04 to 0.06 $mg.kg^{-1}$, respectively. The transfer factor calculation between the concentrations of soil and vegetation show that about 5 to 17% of La in the soil is absorbed and retained by the plant root, while only about 0.1 to 2% of La in the soil is absorbed by the plant and set in the aerial part (leaf, bark and fruit). The fruit had the lowest transfer rates of the concentrations of soil La (0.1%) and the leaves had a transfer rate from 0.4 to 2%. The results of the La concentrations in the soil when compared

with reference values (50 to 20 $mg.kg^{-1}$) for similar soils, show that the concentrations obtained not represent a significant La anomaly in the study area. Additionally, the analysis plants show that the main La accumulator organ of Musa spp. is the root. In modern physicochemical conditions presents in the studied area, this organ is effective in protecting the retention of the La in the aerial parts, mainly the fruit.

ARCHITECTURE OF A MASS TRANSPORT DEPOSIT AT THE BASE OF TERTIARY IN THE JEANNE D'ARC BASIN, OFFSHORE NEWFOUNDLAND

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Mass transport deposits form a significant component of deep marine sediments. Knowledge of the architecture of such deposits is relevant to assessment of them as potential geohazards for drilling rigs. The architecture of a mass transport deposit at the Base of Tertiary in the Jeanne d'Arc Basin, offshore Newfoundland displays features that indicate direction of flow, and internal structure. The strata patterns and the internal structure of the studied mass transport deposit jointly indicate zones of extension, compression, and lateral transfer. The intricate distribution of the thrust faults, back thrusts, lateral transfers and extensional faults signifies the forces present upon the failure. This distribution can be mapped in the Thorvald Mass Transport Deposit (MTD), offshore Newfoundland. The MTD is defined by conventional seismic mapping and enhanced by seismic attributes within the Flying Foam 3-D dataset from the Jeanne d'Arc Basin.

The Thorvald Mass Transport Deposit, consisting of semi-chaotic and coherent sediments, underwent contractional and extensional faulting and lateral transfers during failure. The downslope transport, initiated by sliding and slumping, created a thick cap of remoulded debris. The architecture of the remoulded debris includes features such as compression ridges, thrust faults, back thrusts, layered coherent strata, and mounds, which were studied using 3D seismic tools.

PROVENANCE DISCRIMINATION IN SURFACE SEDIMENTS AND CORE RECORDS FROM THE AMERASIAN BASIN (ARCTIC OCEAN) CONSTRAINED BY QUANTITATIVE MINERALOGICAL ANALYSES

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This study focuses on the determination of potential source areas for the terrigenous material derived from Eurasia and North America to reconstruct the late Quaternary sedimentary environments in the Amerasian Basin of the Arctic Ocean. When compared to the potential source areas in the Arctic Ocean hinterland, spatial and temporal variations in bulk mineralogy may provide important information on the trajectories of sea-ice drift, iceberg transport and oceanic currents.

Investigations are carried out on surface samples recovered from the Mendeleev Ridge and shelves of the East Siberian and the Chukchi seas. Mineralogical analysis was performed on bulk sediments by the X-ray diffraction (XRD) method. Dry powder samples were mixed together with corundum for further quantification of mineral contents. Raw XRD data were processed using the RockJock and QUAX software to test the consistency of both methods. Additionally, composition of artificial mixtures was determined to test the accuracy of mineral standards.

Obtained results are used to identify mineralogical provinces in the surface sediments of the Amerasian Basin. This geographical distribution is also compared to the previously published studies, including the numerous research activities carried out in the Siberian shelf seas in the middle of the 20th century.

Bulk mineral composition of surface sediments is further used for unmixing of the downcore mineralogical records for sediment cores recovered along two transects across the Mendeleev Ridge during the ARK-XXIII/3 Expedition of RV "Polarstern". Trends in mineralogical composition are also compared to the grain-size distribution in order to attribute the provenance changes to different transportation mechanisms in variable sedimentary environments.

Re-Os ISOCHRON AGE OF CARBONACEOUS SHALES IN THE UPPER MISTASSINI BASIN, QUEBEC, SUPPORTS CORRELATION OF PALEOPROTEROZOIC BASINS AROUND THE MARGINS OF THE SUPERIOR CRATON

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Recent geochronologic data constrain the age of Paleoproterozoic granular iron formations (GIF) in the Animikie basin, located on the southern margin of the Superior craton, and in the Labrador Trough, on the eastern margin of the Superior craton, to ca. 1878 Ma. Between these basins is the Mistassini basin, which contains, in its upper part, the Temiscamie Formation GIF and overlying shales and wackes of the Kallio Formation. The Temiscamie Formation unconformably overlies shallow-marine carbonate rocks of the Albanel Formation, which record the end of the ca. 2.22-2.1 Ga Lomagundi carbon isotope excursion and thereby provide an indirect age constraint for the lower part of the Mistassini basin. In all three basins, shallow-water GIFs are overlain by a transgressive succession of wacke and shale, interpreted to have been deposited in a foreland basin setting. Tuffs in the basal part of this succession in the Animikie basin were dated by U-Pb method at ca. 1832-1827 Ma, indicating a possible hiatus at the base of the shale-wacke succession. Closely-spaced hand specimens of thinly-laminated, carbonaceous shale from the Kallio Formation were collected from a recently exposed roadside outcrop for Re-Os dating to constrain the age for the upper part of the Mistassini basin. The samples yielded 1826 ± 15 Ma isochron (2σ, Model 3, n=7, MSWD=2.3) with the initial Os isotope ratio of 0.15 ± 0.08, which we interpret as the depositional age. The initial Os isotope ratio indicates limited radiogenic Os flux from weathering of continental crust. Our data provide the first age constraint for deposition in the upper part of the Mistassini basin and further support correlation of the Temiscamie GIF with GIFs in the Animikie basin and in the Labrador Trough. It also supports possible correlation with deeper-water carbonaceous shales and wackes from the Sudbury basin, which lies along the southern margin of the Superior craton between the Mistassini and Animikie basins. Ca. 1.88 Ga GIFs were deposited along the southern and eastern margins of the Superior craton and as far onto the craton as the Belchers Islands and Sutton Inlier over a relatively short time span. Furthermore, our data emphasize the regional extent of hiatuses within the transgressive succession deposited in the foreland basin that likely reflects protracted and multi-stage accretion of the Laurentia.

CHARACTERIZATION OF URANIUM MINERALOGY FROM THE LORADO TAILINGS SITE, URANIUM CITY, SASKATCHEWAN, CANADA

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The study of uranium in mine tailings can be used to develop a better understanding of uranium transport in the environment and its affect on the ecosystem. The main objective of this research is to characterize the uranium mineralogy and uranium transport at the Lorado Mill historical tailings site, Uranium City, Saskatchewan. The Lorado mill operated between 1957 and 1960 and treated ore from the Lorado mine and a number of smaller satellite mines. There is an estimated 177,000 m^3 of tailings on land and an additional 50,000 m^3 within the adjacent Nero Lake, resulting in a total of 227,000 m^3 of tailings at the Lorado mill site. These tailings are highly stratified, comprise of up to four meters of silt and sand overlying peat, and provide a unique opportunity to study uranium transport in a stratigraphically heterogeneous environment.

In 2010 and 2011 the Lorado tailings were sampled using PVC pipes to obtain one 1 m and eleven 0.5 m deep cores to characterize the tailings both vertically and laterally. Cores generally consist of an orange sandy

horizon that varies in thickness from <1cm up to 0.5m, which overlies a fine-grained silty horizon with fine layers of grey and red/purple clay located near the water table. Petrography indicates uraninite (<20 ìm) is the dominant uranium mineral and is generally encapsulated within quartz. Salt crusts, not present in 2010, which covered large areas of the tailings in 2011, were sampled. The salt crust was heterogeneous exhibiting various colours including: white, yellow-green, yellow, orange, brown, black and grey. The salts are a mixture of various sulphate minerals including: gypsum ($CaSO_4$•$2H_2O$), hexahydrite ($MgSO_4$•$6H_2O$) and bianchite ($ZnSO_4$•$6H_2O$).

Bulk chemical analyses of core sediment samples by ICP-MS show uranium concentrations range up to 200 ppm. Uranium concentrations vary with depth. The highest uranium concentrations occur at surface, just below the salt crust and in lower grey-purple silt horizon. Bulk ICP-MS analysis of the salt crust indicates they have high uranium concentrations ranging between 74 and 3,230 ppm. The highest uranium concentrations are associated with orange and yellow salts while the lowest concentrations are associated with the brown, black and grey salts. Uranium concentration profiles at the Lorado tailings site suggest that during dry climatic conditions (summer 2011) uranium is drawn upwards and concentrated in the salt crusts, whereas in wet climatic conditions (summer 2010) uranium is mainly concentrated in the clay-rich layers.

X-RAY DIFFRACTION (XRD) AND X-RAY FLUORESCENCE (XRF) ANALYSIS OF CREMATED HUMAN REMAINS

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In early 2002, people across the United States were appalled as the story of the Tri-State Crematory unfold on national television. After a woman walking her dog discovered a skull, responding authorities kept finding more and more bodies. Rather than performing the contracted cremations at Tri-State, the bodies were simply dumped unceremoniously around the property. More than 330 bodies were eventually recovered, setting off a vast exercise in forensic anthropology. More baffling, most bodies received prior to a certain date were actually cremated, and later on, while most of the bodies were dumped on-site, some were sent to other facilities for proper cremation. Hundreds of families were uncertain as to the contents of the urns in their possession and regional crime laboratories were overwhelmed with questioned remains. Many families had received cement dust, wood ash or other materials instead of the cremated remains of their loved ones.

In such investigations powder x-ray diffraction (XRD) can be a powerful forensic tool. XRD is used for identification of crystalline materials, including differentiating components of mixtures. The major mineral component of bone is calcium phosphate, which is similar in structure and composition to inorganic apatite group. XRD analysis allows investigators to quickly distinguish bioapatite from filler materials such as cement dust and wood ash with little to no sample preparation. More complex is distinguishing bioapatite from mineral apatite. Geologically, trace amounts of around half the elements on the periodic table can be incorporated into geoapatite. Substitution into living organisms is much more limited, thus trace element analysis (XRF), can be used to distinguish organic from inorganic apatite. For example, fluoride substitutes so readily into apatite, occurring even at body temperature, that fluorapatite quickly develops in humans that have been using fluoridated water or toothpaste. Conversely, high levels of arsenic, sulfur, vanadium or antimony are indicative of geoapatite.

The elevated temperatures achieved under burning, or cremation, cause recrystallization of bioapatite, actually simplifying its analysis. The resultant material is clearly distinguishable from the materials reportedly used as fill in the urns from Tri-State and can also be differentiated from geologic apatite. In a study of samples of leg bones and dentin that were collected from a human cremated at 1010°C for 2.5 hours, XRD results clearly show distinctive differences between bone apatite, dentin apatite, and geological apatite. Bone apatite shows a significant component of carbonate while dentin appears to be virtually pure apatite.

UNRAVELLING THE TECTONIC EVOLUTION OF HIGH-GRADE GNEISSES OF THE BEAVERLODGE DOMAIN, SOUTHWESTERN RAE PROVINCE, SASKATCHEWAN, USING A MULTIDISCIPLINARY APPROACH

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The Rae Province, a principal building block of the Canadian Shield, has a remarkably protracted tectonic history, extending from the Archean to late Paleoproterozoic. This longevity is nowhere more evident than in the southwestern Rae Province in Saskatchewan, where, aside from Archean tectonism, Precambrian rocks variably record the effects of four major Paleoproterozoic tectonic events – the 2.45-2.3 Ga Arrowsmith, 2.1-1.93 Ga Thelon-Taltson, 1.9 Ga Snowbird and 1.9-1.8 Ga Hudsonian orogenies. In the past decade, a combination of geological mapping, structural analysis and geochronology has been used to decipher the tectonic complexity of the Beaverlodge domain, one of the largest lithotectonic elements in this region. This high-grade terrain is now known to consist of two main structural levels: a lower level comprising mainly high-grade Archean (3.0 and 2.7-2.6 Ga) gneisses and a higher level comprising mainly 2.33 to <2.17 Ga supracrustal rocks of the Murmac Bay Group, at more variable metamorphic grade. Whereas the older/deeper package underwent tectonothermal events in the Archean (~2.57 Ga) and early Paleoproterozoic (~2.34 Ga) rocks at higher structural levels bear no record of these events, recording only younger (1.94-1.90 Ga) metamorphism. In metapelitic gneisses, an older (1940-1930 Ma) generation of monazite is linked to development of the dominant ESE-trending composite ($S_0/S_1/S_2$) transposition foliation, whereas younger monazite (1910-1900 Ma) is ascribed to resetting during refolding of this foliation about NE-trending (F_4) axes. Two principal tectonic stages are inferred. The first stage (1940-1930 Ma), attributed to Taltson orogeny, involved tight to isoclinal folding ($D_{1/2}$) and development of the main ($S_0/S_1/S_2$) foliation, followed by more open folding (D_3). The absence of Taltson-age plutonic rocks, except for low-volume crustal melts, suggests that this stage involved crustal thickening along a clockwise P-T-t path. High strain along the contact between Archean rocks and the Murmac Bay Group indicates some degree of translation of cover rocks over basement. Pelitic rocks at higher structural levels underwent metamorphism to middle amphibolite facies, whereas deeper crustal rocks attained granulite-facies conditions. The second stage, correlated with Snowbird tectonism at 1.91-1.90 Ga, involved refolding of D_1 to D_3 structures about NE-trending axes in a dextral transpressive regime. Upper crustal rocks remained at the same crustal level whereas deeper crustal rocks were uplifted, instigating decompression reactions. Additional post-1.9 Ga (Hudsonian) shortening and exhumation of this terrain was accommodated by subsequent ductile-brittle thrust reactivation of domain-bounding shear zones, with further brittle extensional reactivation approaching the time of Athabasca Basin development.

CHARACTER AND TECTONIC SETTING OF THE MIDDLE PALEOPROTEROZOIC THLUICHO LAKE GROUP, SOUTHERN RAE PROVINCE, CANADIAN SHIELD: ALLUVIAL-FLUVIAL BASIN DEVELOPMENT IN THE HINTERLAND OF THE TALTSON OROGEN

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In addition to Archean orogenesis, the Rae Province of the central Canadian Shield records the effects of multiple, staggered Paleo-proterozoic orogenic events along both its western and eastern margins. In the Athabasca region of Saskatchewan the legacy of this activity is a complex record of deformation, metamorphism, and intervening periods of

uplift and erosion. This record is preserved in the form of four major Proterozoic successions, each bounded by an unconformity and each relatively less deformed than immediately underlying rocks. The second oldest of these successions, the middle Paleoproterozoic Thluicho Lake Group, is a valuable monitor of tectonic activity in this region. This ~1.5 km thick sequence of continental alluvial-fluvial rocks was deposited on an uplifted Archean to early Paleoproterozoic basement complex, and subsequently deformed and metamorphosed to greenschist facies. Detrital zircon geochronology has established a maximum depositional age of 1.92 Ga, consistent with regional geological relationships indicating deposition after high-grade Taltson (ca. 1.93 Ga) metamorphism in the basement complex but before development of 1.91-1.90 Ga northeast-trending structures affiliated with the Snowbird tectonic zone. Isotopic provenance indicates that detritus was derived exclusively from local sources, namely Archean (ca. 2.6 Ga) to early Paleoproterozoic (2.5-2.3 Ga) basement rocks of the underlying Zemlak and adjacent Nolan, Taltson, Ena and Beaverlodge domains. These provenance characteristics, coupled with the close spatial relationship to basement mylonites, suggests that the Thluicho Lake Group was deposited in east-southeast-trending, fault-controlled basins in the hinterland of the Taltson orogen, and paralleling a major ca.1.93 Ga tectonic front. Similarities in lithology, age and provenance suggest that the Thluicho Lake Group correlates with the more extensive Nonacho Group to the north, although there are differences in primary basin orientation that are not well understood. Both groups are proposed to be part of the youngest of four craton-wide early to middle Paleoproterozoic sequence stratigraphic assemblages, the fourth and youngest assemblage being characterized by immature siliciclastic rocks ascribed to intracratonic basin inversion and/or foreland basin development during the early stages (1.92-1.90 Ga) of the amalgamation of Laurentia/Nuna. However, while the Thluicho and Nonacho Groups may represent proximal foreland basin deposits of the Taltson orogen, certain characteristics are more diagnostic of an intermontane and/or strike-slip pull-apart setting. This paper will examine similarities and differences between the two groups, and explore the question of depositional setting in relation to tectonics and the wider sequence stratigraphic framework established for the Rae Province.

A POSSIBLE CORRELATION OF MANGANESE-RICH SEDIMENTARY ROCKS FROM THE HARLECH DOME AND THE MEGUMA TERRAIN

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It has recently been proposed that the Cambrian successions of the Meguma Terrain of Nova Scotia and the Harlech Dome region of North Wales show a much greater similarity to each other than the adjacent successions on Avalonia. They both contain thick successions of turbiditic sandstones of early Cambrian age, succeeded by alternating mudstones and sandstones of early to middle Cambrian age within which are manganese-rich horizons. It is likely that the two terranes were in close proximity in Cambrian times on the margin of Gondwana, and the term 'Megumia' has been adopted for this proposed tectonic entity.

In the Harlech Dome area the ore bed is typically 30-40 cm thick and is laterally extensive across the region, over an area of around 190 km^2. The ore bed is banded on the cm scale and consists of a mixed carbonate and silicate assemblage. Individual bands are variably red, yellow, dark brown and black. Early studies reported the bed to be dominated by rhodochrosite and rhodonite, although subsequently it was suggested that spessartine was the main silicate component, rather than rhodonite. Kutnohorite was also recognised amongst the carbonates present.

A detailed study of a 16 cm thick section of the ore bed at Llyn du bach mine in the Harlech Dome has confirmed the presence of spessartine, rhodochrosite, kutnohorite and quartz, as well as identifying sonolite, tephroite, dolomite and either titanomagnetite or jacobsite. Spessartine is dominant in the red horizons, whilst the carbonates show a predominance of kutnohorite towards the base of the bed and rhodochrosite higher in the bed; dolomite occurs typically as concretions. Other samples show the presence of alleghanyite. The three silicate phases sonolite, tephroite and alleghanyite have been recorded from other manganese deposits world-wide present in low-grade metamorphic sequences. We suggest that these phases are characteristic of such chemical systems in low-grade metamorphic rocks and might prove to be equivalent to the calc-silicate phases present in low-grade metabasites, such as pumpellyite and prehnite.

The current project aims to investigate and compare the mineralogy of the manganese-rich horizons in the two regions, which are now geographically separated, to determine whether the manganese mineralogy can be used to: (i) further support the correlation proposed between the two regions; and (ii) to confirm the validity of the manganese mineral assemblage as a grade indicator in low-grade metamorphic rocks.

GOLD MINERALIZATION IN THE ARCHEAN BEATTIE SYENITE, DUPARQUET, ABITIBI BELT, QUÉBEC, CANADA

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The standard orogenic gold model characterizes the majority of gold deposits within the Abitibi belt. However, several examples of late-Archean gold mineralization are disseminated and associated with alkaline intrusions, thus differing from the standard orogenic gold model. The Beattie Syenite is an Archean porphyry intrusion emplaced along the major Porcupine-Destor Fault Zone in the Abitibi belt. It was mined from 1933 to 1956, with a total production of about 33 tonnes of gold in 9.2 Mt of ore. The syenite is aligned along an east-west axis; it is hosted by mafic and intermediate volcanic rocks of the Kinojevis Group and is penecontemporaneous with the Timiskaming sedimentary rocks deposition.

The structural evolution of the syenite consists of an early ductile-brittle flattening phase followed by two more shallow stress episodes marked by two different regimes, one north-south with conjugated dextral and sinistral faults, and the other east-west shearing. The obliquity of the two stress tensors, the regional distribution of mineralization, and the 3D geological model suggest a regional tilting event.

Gold mineralization appears as disseminated ore, within the intrusion, and controlled in shear zones in its core and along its contact with the volcanic country rocks. Gold is hosted in arsenopyrite and arsenian pyrite. Gold grains are less than micron-sized. The association with arsenian minerals and the very small size suggests that gold was incorporated into the crystalline structure of arsenopyrite and arsenian pyrite in solid solution (Au1+) or as nanoparticles (Au0).

The metallic assemblage in the Beattie syenite is polyphased: (1) a primary phase enriched in iron-titanium appears to have produced martite in a more oxidizing environment; (2) Several subsequent sulfidation phases were marked by the presence of pyrites and arsenopyrites, some rich in gold, suggesting crystallization under more reducing conditions and at lower temperatures. During the sulfidation phases, three generations of pyrite are identified; the first generation is arsenian and gold-bearing, whereas the second and third are arsenic-poor and gold free. (3) A late silica-enriched hydrothermal phase remobilized the gold and is marked by cataclasis. Gold migrated into the fractures developed in the cataclazed pyrite, where it recrystallized with silver in the form of electrum.

Several petrological characteristics in the Beattie gold deposit, including gold appearances, metallic mineralogy, type of alterations, and ore control, suggest a shallow magmatic deposit.

Keynote THE HOT LONG-LIVED SVECONORWEGIAN COLLISIONAL OROGEN: A REVIEW AND NEW CONSTRAINTS FROM SE NORWAY

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Recently published and new structural, petrological and SIMS U-Pb zircon data refine substantially our understanding of the 500 km wide Sveconorwegian orogen as the product of a hot, long-lived, polyphase, bivergent collisional orogeny developed at the margin of Baltica at the end of the Mesoproterozoic. The Sveconorwegian orogeny followed a 1200-

1130 Ma bimodal, within-plate magmatism in Telemark, Kongsberg and Bamble, more extensive than previously assumed. The earliest documented Sveconorwegian ca. 1144 Ma patchy MP granulite-facies metamorphism in Bamble is probably genetically related to this magmatism. So is the classical MP granulite-facies metamorphism around Arendal, redated at ca. 1132 Ma. Evidence for Gothian 1550 Ma protoliths question previous interpretations that the Arendal granulites correspond to the root of a Sveconorwegian volcanic arc tracing an early-Sveconorwegian suture zone. Bamble and Kongsberg were subsequently thrusted westwards on top of Telemark around 1080 Ma marking the onset of collisional tectonics. To the east, in the Idefjorden terrane, an HP, 1.3 GPa, granulite-facies event is locally recorded and was dated at ca 1050 Ma. This was followed by widespread amphibolite-facies partial melting. Seven leucosomes associated with top-to-the-west regional kinematics and resulting from muscovite-, biotite- and amphibole dehydration melting, range in age from ca. 1039 to 997 Ma. This partial melting is coeval with widespread syn-collisional granitic plutonism and LP amphibolite- to granulite-facies metamorphism in the west of the orogen in Rogaland-Vest Agder. The reported long-lived high grade conditions suggest development of a mid-crustal west-directed (?) channel flow with flow after ca. 1030 Ma and a slowly eroding orogenic plateau. In this model, the low-grade Telemark supracrustals may belong to a shallow orogenic lid, characterized by deposition of immature sediments in grabens (Eidsborg Fm, <1118 Ma, Kalhovde Fm <1065 Ma). At ca. 980 Ma, the Sveconorwegian orogeny propagated eastwards in the footwall of the arcuate, southeast-verging, "Mylonite Zone" thrust, leading to eclogite-facies metamorphism in the Eastern Segment. Convergence was followed by gravitational collapse after ca. 970 Ma. High-grade LP conditions were maintained in Rogaland-Vest Agder until ca. 930 Ma and were associated with post-collisional plutonism, including anorthosites. The Putumayo orogen and Oaxaquia Terrane at the margin of Amazonia are characterized by granulite-facies metamorphism at ca. 990 Ma and possibly represent conjugate margins correlatives during continental collision.

MAFIC IGNEOUS EVENTS AS CONSTRAINTS FOR DEVELOPMENT AND URANIUM MINERALIZATION OF THE PALEOPROTEROZOIC ATHABASCA, THELON AND DESSERT LAKE BASINS

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Mafic igneous rocks, either as extrusive horizons or as intrusive sills and dykes, provide critical time markers in studies of sedimentary basins and mineralized systems. In some systems they also provide the heat engine that drives hydrothermal fluid circulation.

Despite their critical importance, the dating of these rocks has long presented a challenge in terms of obtaining precise and accurate isotopic ages. The initial application of K-Ar whole rock and mineral ages, Rb-Sr whole-rock isochrons, and Sm-Nd whole-rock or internal mineral isochrons have had a checkered history, with ages being plagued by either loss of radiogenic daughters or mixing processes.

This situation changed with the realization that mafic rocks in many cases do contain accessory minerals that are amenable to U-Pb dating: zircon, baddeleyite, zirconolite, titanite, rutile and apatite. Without any doubt baddeleyite (ZrO_2) is the star performer in this line-up because it typically has a sufficiently high U content, low common Pb, is relatively robust, and essentially unknown as an inherited phase. Zircon, if present, is equally valuable but may be plagued by more severe Pb loss and inheritance. Chemical abrasion techniques may partly circumvent the Pb loss problem.

Routine crushing and mineral separation of mafic rocks, however, commonly fails to recover baddeleyite (and/or zircon), resulting in the common perception, often incorrect, that the rocks in question do not contain these phases. Several important developments have changed this situation: 1) better mineral separation, tuned to recovery of fine, platy, baddeleyite crystals; 2) modern SEM imaging in electron backscattered mode allowing efficient identification of all Zr-bearing phases in a thin section, or even in just a quickly polished rock slab; and 3) availability of different analytical strategies for dating the identified phases, e.g. *in situ* ionprobe.

Systematic SEM imaging has shown that baddeleyite, zircon, and zirconolite are more common than appreciated. However, even in some medium-grained mafic rocks, baddeleyite may be less than 20 µm in size and below the physical limit of effective mineral separation. *In situ* ionprobe dating provides the solution in such cases. With further incremental advances in mineral separation and microbeam techniques, more and more mafic rocks will finally yield their ages. In nearly all cases, the initial investment of SEM imaging, to define the mineralogy, abundance, and size distribution of accessory phases, is highly worthwhile, forming the basis on which to decide the analytical strategy. Some case studies relevant to this session will be discussed.

THE 2193 Ma DOGRIB GIANT DYKE SWARM OF THE SLAVE CRATON: PRECISE AGE AND SETTING

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Dogrib dykes of the southern Slave craton (McGlynn & Irving, 1975) represent one of the classic, Paleoproterozoic, giant dyke swarms of the Slave crustal fragment. Recognized early as an important target for paleomagnetic investigations (assessing the coherency of the Canadian shield prior to the Hudsonian orogeny), the utility of the paleomagnetic data has long been hindered by absence of precise isotopic ages. Early age dating efforts (K-Ar and Rb-Sr) yielded scattered results from 0.90 Ga to as old 2.69 Ga, compromising any interpretation of APW paths. Recent U-Pb studies by van Breemen *et al.* on several Slave craton dykes also produced the first baddeleyite age for the Dogrib dykes, showing that this swarm is ca. 2190 Ma.

Since then, we have collected more optimum material from 1) the central gabbroic phase of the largest Dogrib dyke (~80 m wide), and 2) late-stage residual melt veins with pegmatoidal textures. Using the technique of Söderlund, we separated larger baddeleyites from both samples, yielding a precise and reliable age of 2193±2 Ma (upper intercept; Mitchell *et al.*, 2012). Carefully comparing separation results from the different samples, the pegmatoidal veins perhaps yielded slightly more and larger baddeleyites, but only one fraction, from the central gabbro, is fully concordant. The new samples also contain zircon and zirconolite, but SEM imaging shows neither phase to be simple. As seems common in mafic rocks, the zircons look more complex, mottled, and altered, generally showing small bright specks of thorianite (ThO_2).

In the broader Yellowknife area, the swarm consists of half a dozen large dykes, trending ENE and defining a swath ~100 km wide. The major dykes show a subtle but distinct fanning, with trends varying from ~075° in the north to ~060° further south, indicating a magmatic centre for the Dogrib swarm along the eastern (burried) margin of the Slave craton, not along its southwestern corner. This is in agreement with the small number of large, linear dykes, which is typical for the intermediate to distal zone of a giant dyke swarm.

Dogrib magmatism was associated either with uplift and rifting along the southeastern craton margin or was a precursor to such events. The coeval "SW Slave Magmatic Province" is therefore best interpreted as an alkaline province along a magmatic rift arm projecting deep into the craton interior, in perfect analogy to how the Lake Nipissing magmatic province and slightly older Grenville dyke swarm relate to the Iapetan rift margin of eastern Laurentia.

DEPOSITIONAL CONTROLS ON HORIZONTAL WELLBORE PLACEMENT IN THE MARCELLUS SHALE, APPALACHIAN BASIN: INSIGHTS FROM CHEMO- AND SEQUENCE STRATIGRAPHY

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Placement of a lateral in the Marcellus shale necessitates consideration of two properties of the reservoir: location of the hydrocarbon within the reservoir and pre- and post-stimulation deliverability of the formation.

Core calibrated petrophysical analysis of Marcellus logs is conducted to determine total organic carbon (TOC) content, gas-filled porosity, clay volume, and both free and adsorbed gas-in-place volumes. The distribution of in-place hydrocarbons is controlled by the sequence stratigraphic framework of the Marcellus, which comprises two third-order transgressive-regressive cycles. Within a particular T-R cycle, the shale becomes progressively more organic and quartz rich through the transgressive systems tract and progressively diluted by clay through the overlying regressive systems tract. Organic richness throughout much of the Marcellus basin appears to have been controlled principally by a combination of bottom water conditions conducive to preservation of organic macerals and dilution by clastic detritus. Indeed, enrichment of authigenic uranium and molybdenum in tandem with observed size distributions of pyrite framboids suggest a depositional environment dominated by a strongly suboxic to intermittently euxinic water column through Union Springs and locally Oatka Creek deposition. Elsewhere, regional covariance trends of authigenic molybdenum and uranium and their respective enrichment factors define a uniform (Mo/U)auth ratio of ± 2 — 3 times the Mo/U molar ratio of seawater. Mo is enriched relative to U by a factor of 5:1 to 10:1 suggesting accelerated transport of Mo to the seafloor by a particulate (Mn) transport mechanism that would have required frequent fluctuations between suboxic and moderately sulfidic water column conditions. Deposits of the Union Springs Member illustrate the best reservoir development. The importance of TOC to Marcellus gas production goes beyond its ability to adsorb gas; it also appears to host porosity development within the Marcellus shale. Given that the Marcellus accumulated rapidly (~1.5my), condensed intervals are dominated by TOC that is largely unoxidized. Inferred condensed intervals are defined by minimal clay and especially abundant quartz, principally diagenetic. The siliceous horizons serve as higher modulus, brittle intervals necessary for the initiation of hydraulic fracture stimulation. Further, minimal clay within the condensed intervals may be expected to diminish the degree of proppant embedment.

BIOGEOCHEMICAL SIGNATURES AND RELATIONSHIPS TO RARE EARTH ELEMENT AND ZIRCONIUM MINERALIZATION AT THE NORRA KÄRR DEPOSIT, SOUTHERN SWEDEN

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The Norra Kärr rare metal deposit is located in southern Sweden, approximately 300km southwest of Stockholm. It is a peralkaline nepheline syenite complex, enriched in heavy rare earth elements (HREEs). The deposit ranges from 200m to 400m in width, is approximately 1300m long, and has been well defined by ongoing diamond drilling. The HREE mineralization is dominantly found in the pegmatitic "grennaite" unit, a eudialyte-catapleiite-aegerine nepheline syenite.

Biogeochemical exploration can be more useful than traditional soil surveys, particularly at the grassroots scale, because tree and plant root systems interact with large volumes of soil over an extensive region and therefore provide a broader, more composite signal than a single soil sample collected at one site from one specific horizon. Sampling trees and shrubs provides an integrated signal from a much wider area; more ground can be covered with a single biogeochemical sample than with other grassroots exploration methods.

In June 2011 a total of 181 vegetation samples and 14 soil samples were collected from 88 sites along 4 east-west transects located above the deposit and continuing well into the unmineralized granitic country rock. All samples were first completely dried, then digested in a modified Aqua Regia solution, and then analysed by ICP-MS at Acme Analytical Laboratories in Vancouver. The soils sieved to –80 mesh, and analysed by a similar method.

The dominant sample media were Norway spruce, three types of common fern, and Ah and B horizon podzols where available. Earlier work suggests that Zr, as well as REEs, accumulate in higher concentrations in ferns than other organic material.

The results of the analytical work from two particular fern species, *Dryopteris filix-mas* and *Athyrium filix-femina*, clearly show a strong signal to background ratio (in the case of ytterbium up to 20× higher) over the deposit compared to the surrounding barren granitic country rock. The findings from this study confirm the efficacy of ferns as a suitable sampling tool for peralkaline nepheline syenite Rare Earth Element exploration.

POSSIBLE OCCURRENCE OF THE SHURAM-WONOKA NEGATIVE C-ISOTOPE EXCURSION IN THE CLOUDINA-BEARING CORUMBÁ GROUP (EDIACARAN, BRAZIL)

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The genesis of one the largest negative C-isotope excursion - the Ediacaran Shuram-Wonoka – is still the subject of debate. It occurs just below of the appearance skeletal fossils and it could be a primary marine signal or diagenetic. At the base of the Tamengo Formation (Corumbá Group) there are negative C-isotope values, and the correlation of this anomaly with the Shuram-Wonoka excursion is the subject of this study. The Corumbá Group crop out in the southern Paraguay Belt and as cratonic cover comprising a typical Neoproterozoic succession characterized by diamictite, thick banded iron formation, cap carbonate, stromatolitic dolomite, phosphorite and black limestone with carbon isotope data showing negative and positive excursions ($\delta^{13}C_{PDB}$ from – 3 to + 5 ‰) related with the first occurrence of Cloudina and Corumbella (Tamengo Formation). Five sections of Tamengo Formation were studied, the only one showing the entire unit being the Laginha Quarry Section. There, a negative C-isotope excursion occurs at the base, with a nadir value of – 3.6 ‰ with subsequent values around – 1 ‰, by 20 m, with drastically shift to + 5 ‰, associated with the first Cloudina. A plateau around + 3 ‰ follows, which is a characteristical of the upper Tamengo Formation. In the Laginha Quarry section, the negative excursion is recorded in a black limestone overlying the carbonatic polymitic breccia, that mark the base of the Tamengo Formation. This breccia is interpreted as result of an eustatic sea-level fall followed by renewed transgression characterized by organic limestones and rithmites (black shales alternating with black mudstone). The negative excursion is probably related to the beginning of the transgression and its aftermath maximum flooding is related to the highest C-isotope value (+ 5 ‰). Despite the fact that geochemical proxies suggest a primary isotopic signal, we cannot rule out completely a secondary origin for the negative C-isotope excursion at the base of Tamengo Formation, mainly because was not possibly to identify it in different sections. Furthermore it is not so large (only – 3 ‰ and around – 1 ‰ over 20 m) as reported from Oman and the Death Valley (USA). This highlights the need for continued research, may be in other sections showing the same interval, since the Corumbá Group has been showed as an Ediacaran unit of interest for the study of the Shuram Excursion which, if it is primary, has a profound bearing on the cause of early animal evolution.

THE WOLLASTON SUPERGROUP IN MANITOBA: TECTONO-STRATIGRAPHY AND URANIUM-RARE METAL MINERALIZATION

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The Wollaston Supergroup, a Paleoproterozoic rift, passive margin and foreland sequence that overlies and is infolded with Archean basement rocks of the southeastern Hearne craton, extends over hundreds of kilometers from northeastern Saskatchewan through northern Manitoba into Nunavut. The Wollaston metasedimentary sequence consists of psammitic, semi-pelitic, pelitic, and lesser amounts of calcsilicate and marble, all of which are variably injected by leucogranite and were strongly tectonized and metamorphosed to granulite grade during the Trans-Hudsonian orogeny. Regionally, the Wollaston Supergroup rocks

are flanked by largely plutonic Archean basement rocks of the Hearne craton. In northwestern Manitoba, exposures of the Wollaston Supergroup appear to be most similar to the early foreland-basin sequence of the Daly Lake Group in Saskatchewan.

U-Pb zircon results from seven Wollaston domain metasedimentary rocks in northwest Manitoba, ranging from quartzite, to psammite to calc-silicate paragneiss, record up to five geologically distinct detrital sources : 1) >2.5 Ga (mostly ~2.58 and 2.70 Ga), representing detritus eroded from Archean basement rocks of the Hearne craton; 2) rare ~2.4-2.2 Ga, thought to correspond to cryptic cratonic fragments exotic to the Hearne craton; 3) minor 2.1 Ga, interpreted to be derived from reworking of a locally underlying syn-rift succession equivalent to the lowermost Wollaston Supergroup in Saskatchewan; 4) ~2.0-1.90 Ga, interpreted as detritus shed from the advancing volcanic terranes related to either the opening of the Manikewan ocean (Southern Indian and Rottenstone domains) or a Rae-Hearne internal zone; and 5) variable ~1.86-1.85 Ga, inferred as injected melt, contemporaneous and possibly related to the continental-arc Chipewyan (Wathaman) batholith, which intrudes Wollaston Supergroup rocks.

Formation of the Wollaston Supergroup was influenced by the ~2.2 Ga global onset of oxygenation of atmosphere and oceans, which likely led to intense erosion of the exposed Hearne craton, solution of uranium in seawater and precipitation/accumulation in reducing siliciclastic and calcareous sediments. Subsequent high-grade metamorphism led to partial assimilation of the thick sedimentary sequence and in-situ generation of S-type granitic melts, with late-stage enrichment of uranium, thorium and/or rare metals in zones of pervasive metasomatism, alteration and fracture-veining, particularly in the calcsilicate gneiss and marble horizons. Consequently, this presents a different mineralization environment and process compared to the main, unconformity-type uranium deposits in the Athabasca Basin, to which Wollaston Supergroup rocks form part of its basement.

RECORD OF EARLY METABOLISMS AND BIOLOGICAL EVOLUTION IN ARCHEAN STROMATOLITES

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Stromatolites, laminated and lithified sedimentary structures, record microbial interactions with the flowing water and carbonate sediments throughout recorded Earth history and have the potential to illuminate long term trends in biological and environmental evolution. In particular, the stromatolite record older than ~2.5 billion years may contain morphological evidence of the earliest microbial interactions with sediments, early photosynthetic communities, and early oxygenic photosynthesis.

Because fabrics of many Archean stromatolites are obscured by extensive diagenesis, interpretations of Archean stromatolites require quantitative models that consider realistic morphogenetic processes and are able to explain stromatolite scales, macroscopic organization and macroscopic shapes. On the other hand, the reconstruction of microbial metabolisms from Archean stromatolite textures requires a better understanding of fabrics and the preservation potential of anoxygenic microbial communities under chemical conditions relevant for the Archean carbonate depositing environments. Conical, pinnacled and tufted structures are thought to offer some of the most unambiguous evidence for biological processes in the Archean stromatolite record. A recent model attributes the shape of conical stromatolites to the precipitation of minerals under a diffusive boundary, rather than the presence of light-seeking microbes. However, the stabilization of the conical shape may require strong and currently poorly understood biological mechanisms and warrants further experimental work. Light-driven processes may have directly influenced the organization of fields of some mm- and cm-scale stromatolites, whereas dm- and larger scale columns may arise from scale-dependent interactions between microbial stabilization of sediments, flow and scour. Small conical stromatolites as old as 2.9 billion years may also preserve evidence of photosynthetic communities growing around gas bubbles, suggesting that oxygenic phototrophs contributed to stromatolite growth much before the rise of atmospheric oxygen. Because the stromatolite-building potential of anoxygenic photosynthetic communities under conditions relevant for the Archean is poorly constrained, we established anaerobic enrichment cultures of photosynthetic organisms in the presence of low sulfate. Our preliminary results show that these conditions can support the growth of robust anoxygenic photosynthetic mats that are able to withstand similar shear and scour as some modern cyanobacterial mats and form tufted, draped and filmy structures. These systems can be used to investigate the morphogenesis of Archean stromatolites that currently lack clear modern analogs.

THREE DIMENSIONAL GEOLOGICAL MODELS AS TOOLS TO BETTER UNDERSTAND ORE-SYSTEM PROCESSES RESPONSIBLE FOR SOME OF SASKATCHEWAN'S MINERAL RESOURCES

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Over the past several years the Saskatchewan Geological Survey has developed internal expertise in 3D modelling, with the greatest advances occurring during 2010 and 2011. Part of this expertise was gained through collaboration with, and personnel exchanges between, the Geological Survey of South Australia, which was already advanced in the usage of 3D modelling as a geoscience tool.

Using Paradigm's™ GOCAD® software, four 3D models have been produced including: the uranium-rich Athabasca Basin of northern Saskatchewan; potash-rich southern Saskatchewan; the coal deposits in the Pasquia Hills area of eastern Saskatchewan; and the sub-Phanerozoic base metals district west of the Flin Flon camp. Of these, the Athabasca Basin model is the most advanced and includes a number of integrated data types including lithostratigraphic, Quaternary, geophysical, geochemical, structural and mineralogical. Initial work involved modelling of the geological framework, including the Athabasca Group stratigraphy, the unconformity with underlying basement rocks and various structural features. Subsequently, regional outcrop and downhole geochemical, and clay mineralogy information were added.

The ultimate goal of importing the relevant information into the model is to facilitate our understanding of ore-systems, the underlying theme in all the models, within the Athabasca Basin. Current research indicates that the Athabasca Group/basement unconformity, structural corridors and fluids from both the Athabasca Group and its basement, all play key roles in forming unconformity-related uranium deposits. Using 3D software, we can begin to identify locations at which these important ingredients are spatially coincident, and analyze whether or not they might have been interacting at the time of mineralization. Moreover, prospective regions distal to known uranium occurrences could be identified, thus generating new exploration potential. Additional information such as geochemistry and the location of alteration systems, commonly determined by clay mineralogy, can be added which may help further refine these areas of potential. Statistical analysis of geochemical data can be performed quickly and allows the user to generate subsets of anomalous geochemical data. These data can be compared spatially against, for example, the lithostratigraphy or structural features to identify background signatures and potential controls for regions with anomalous characteristics. The purpose of each Saskatchewan 3D model is to advance our geological knowledge in areas of interest to the mineral exploration industry, with the ultimate goal of helping to simplify resource potential evaluation.

MULTI-SENSOR CORE LOGGING IN THE MATAGAMI VMS DISTRICT, ABITIBI GREENSTONE BELT, QUEBEC: CONTEXT AND METHODOLOGY

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Measurements of physical, geochemical, and mineralogical properties on exploration drill cores can be used for various applications in geosciences, namely in 3D geological modeling, to improve geophysical models, to

characterize hydrothermal alteration, for mineral resource calculations, or chemo-stratigraphy. Traditionally, these measurements were taken one at a time, often using destructive methods. Consequently, few base metal mining camps across Canada have access to extensive public databases of physical properties, and high-resolution geochemical or mineralogical measurements are generally not available.

The mobile laboratory for the physical, mineralogical, and chemical characterization of rocks at INRS makes it possible to measure on drill cores, almost simultaneously and in a non-destructive manner, density based on gamma-ray attenuation, magnetic susceptibility, up to 25 chemical elements by energy-dispersive XRF, as well as infrared/visible light spectrometry for alteration minerals. All the measurements can be done at a spatial resolution down to few centimeters, if needed. The multi-sensor core logger also acquires a continuous image of the drill core, making it possible to compare measurements with the visual appearance of the rock in order to better understand variations in the different parameters, and to build a complete digital archive of the drill hole. The results are submitted to a quality control and corrected, when possible, to more realistic values, based on measurements with conventional methods. Each parameter is valuable on its own, but the entire database can also be used in multivariate statistical analysis.

Initial logging was performed in 2010-2011 in the Matagami mining camp, Abitibi Greenstone Belt, Quebec. This district hosts numerous Archean zinc-rich volcanogenic massive sulphide deposits and shows good potential for new discoveries. Ore deposits are clustered in three areas: the North Flank, the South Flank, and the West Camp. Drill holes characterized by the mobile laboratory are located in the three areas. The project was subsidized by Ministère des Ressources naturelles et de la Faune du Québec (MRNF) and logistical support was offered by Xstrata Zinc Canada. We also acknowledge the collaboration of Breakwater Resources, Donner Metals, and SOQUEM. These measurements will be useful for university research projects currently underway in the Matagami area (volcanology, geochemistry, metallogeny, geophysics), for 2D and 3D geological mapping, and for mineral exploration. Detailed scientific reports and a database are available for downloading (sigeom.mrnf.gouv.qc.ca).

LOW-MAGNETIC PRIMORDIAL CRUST OF MARS

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The absence of a global core field at present indicates that the magnetic anomalies of Mars detected by Mars Global Survey over the heavily cratered southern hemisphere arise from remanant magnetization. There are some vast areas on Mars devoid of appreciable magnetic anomalies: the northern lowland and the Tharsis bulge. The lowland formation process has likely demagnetized the crust, and the Tharsis bulge has mainly formed in the absence of a strong core dynamo in the late Noachian. The heavily cratered primordial crust in the southern hemisphere has likely been created during the differentiation of the magma ocean in the later stages of the planet's accretion. It is expected that the crust has been strongly magnetized in case there was a strong core dynamo. However, Arkani-Hamed and Boutin[1] showed that a large area of the southern hemisphere, south of 30S and extending from west of Hellas basin to east of Argyre basin, is also very low-magnetic, which led the authors to propose that there was no strong core field during the first ~120 Myr of the planet's history, when the newly formed crust was cooling below its magnetic blocking temperatures. Here we re-examine the proposal in detail, by studying the magnetic field detected by MGS over impact-related Quasi-Circular Depressions (QCD), 239 in total, and impact crater, 28 in total, on the entire surface of Mars with diameters greater than 250 km. The impacts that have produced these features are capable of demagnetizing the entire crust and creating a distinct magnetic edge effect at the satellite altitudes in case the surrounding crust is magnetized. Two other areas of the primordial crust is now found nonmagnetic, which supports the proposal. We also examined the magnetic signature of 16 giant basins on Mars and concluded that the core dynamo likely ceased within about 200 Myr at ~4Ga, as previously suggested by Lillis *et al.*[2]. Accordingly, the observed strong magnetic anomalies are likely due to magnetic source bodies in the crust which are formed and have been magnetized within the first ~400 Myr of the planet's history, but ~120 Myr after the accretion.

References:

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MINOR AND TRACE ELEMENT COMPOSITION OF MAGNETITE FROM Ni-Cu DEPOSITS WORLDWIDE AND ITS APPLICATION TO MINERAL EXPLORATION

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Iron oxides are common minerals in different types of ore deposits and geologic environments. There are significant variations in the concentration of trace elements in magnetite and hematite depending on the metallogenic environment at the time of formation of the deposit. This makes iron oxides useful as indicator minerals for mineral exploration. Magnetite is a common accessory mineral in Ni-Cu-PGE deposits and it can be either primary, formed by direct crystallization from the sulfide liquid at ~ 1000ºC, or secondary, e.g., replacement of the sulfides during alteration or metamorphism.

Magnetite in sulfide samples (n = 120), representative of 15 worldwide, major Ni-Cu-PGE deposits with a range of geological environments and ages, were analyzed by electron microprobe analysis (EMPA) and a subset (n = 20) by laser ablation-ICP-MS (LA-ICP-MS). The samples are divided into 6 different types according to the composition of the parental host magma: (1) Komatiite (n = 38), (2) Flood basalt (n = 18), (3) Ferropicrite (n =16), (4) Anorthosite (n = 18), (5) Picrite-Tholeiite (n = 36) and (6) Impact melt (n = 23).

Most of primary magnetite (95%) has high Ni+Cr and plot in the Ni-Cu sulfide deposit field on the Ni+Cr vs. Si+Mg diagram. When classified by magma type, the compositions of all the primary magnetite plot on the same trend which indicates that variation in magma composition between mafic and ultramafic does not exert important control on magnetite composition except for Ga and Ge. Instead, magnetite trace element composition is mainly controlled by sulfide liquid differentiation. The composition of primary magnetite records the evolution of the sulfide liquid from early-forming Fe-rich monosulfide solid solution (MSS) and later-forming magnetite hosted in the Cu-rich intermediate solid solution (ISS).

A petrographic study on sulfide samples from the komatiite-hosted Thompson Ni-deposit (Manitoba, Canada) distinguished two types of secondary magnetites in addition to rare primary magnetite: (1) secondary magnetite formed by replacement of pyrrhotite and (2) secondary magnetite formed during the serpentinization of ultramafic rocks or alteration of chromite. In contrast to primary magnetite, both types of secondary magnetite have low Ni+Cr and plot outside of the Ni-Cu sulfide deposit field. There is a clear compositional difference between primary magnetite formed during sulfide mineralization and later secondary magnetites which are depleted in most trace elements (Ni, Mn, V, Ti, V, Al, Cr), with the exception of Si and Mg which are sometimes enriched.

QUESTING THE EVIDENCE FROM EARTH'S OLDEST 'ANIMALS'

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Rangeomorph fossils are among the most abundant and arguably successful groups of Ediacaran soft-bodied organisms. They thrived in deep to shallow water settings for ~40 million years. Over the last decade,

our group has been undertaking comparative analyses of bedding planes from SE Newfoundland and England (~585Ma – 555Ma) germane to the decoding of rangeomorph architecture, ecology and evolution. This has revealed new and remarkably well-preserved bedding planes with specimens of frondose fossils allied to Charnia, including very large Bradgatia preserved down to submillimetric level, and impressive populations of the iconic Newfoundland fossil Beothukis, named in respectful memory of that extinct aboriginal peoples called the Beothuk. We will here present a coherent and comprehensive scheme for the analysis of rangeomorph morphology, in which Beothukis is central. This scheme provides a robust framework for comparative studies of rangeomorph ontogeny and evolution during this critical time in Earth history.

SULFIDE-SILICATE PARTITIONING OF PGEs (AND Au): IMPLICATIONS FOR NOBLE METAL BEHAVIOUR IN MAGMATIC SYSTEMS

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There is considerable variation in sulfide-silicate melt partition coefficients for the noble metals (PGEs and Au), with most direct measurements (analysed by bulk methods) yielding values of 10^4 or less. More recent estimates, which combine separate metal solubility measurements in sulfide and silicate, have suggested partition coefficients exceeding 10^7. Resolving this discrepancy is essential for developing accurate models of noble metal behaviour during melting, and validating metal concentration mechanisms in magmatic systems. In this study, sulfide and silicate were equilibrated at known f_{O2}-f_{S2} conditions, with run-products analysed by LA-ICPMS to ensure exclusion of sulfide contamination from the silicate melt analysis. Experiments were done at 1200°C and 1 atm with f_{S2} controlled using the Pt-PtS buffer and f_{O2} estimated to be FMQ-1 using the Cr content of run-product silicate melts. Three different synthetic basalts were employed, differing in their FeO content (5-15 wt%), with initial sulfide melt composition having FeS stoichiometry + 1 wt% each of Cu and Ni. Two separate sulfide melt compositions were synthesized, with different suites of metals doped at the 1 wt% level for each. Mixtures of powdered sulfide and silicate glass were contained in crucibles made from natural chromite, then loaded, along with the sulfide buffer, in silica ampoules, which were evacuated, then sealed. Samples were held for 1 to 4 days at temperature, then quenched in cold water. Run-product glasses were free of obvious sulfide contamination, as evidenced by uniform, and low time-resolved signals for the PGE and Au. Concentrations of Ru and Os in run-product glasses were always below detection (approx 20 and 5 ppb, respectively), yielding minimum sulfide/silicate partition coefficients of $>10^5$ (Ru) and $>10^6$ (Os). Measurable, but low, abundances for other PGE and Au were determined, with calculated sulfide/silicate partition coefficients of $>10^5$ (Pd, Rh, Ir, Pt) and 4000-11000 (Au). Partition coefficients for Pd, Rh, Ir and Pt were found to increase with increasing concentrations of these elements in the sulfide melt, with little or no change in the silicate melt concentration. This is interpreted to reflect a low level of sulfide contamination in the silicate melt, and argues for even higher partition coefficients for these elements. Thus, results are more in line with the large partition coefficients estimated from combined sulfide and silicate PGE solubility data. This indicates that the concentration of PGEs into magmatic sulfide is likely to depend only on the sulfide to silicate mass ratio.

THE STRUCTURE AND KINEMATICS OF THE CENTRAL TAIWAN MOUNTAIN BELT DERIVED FROM GEOLOGICAL, GPS, AND SEISMICITY DATA

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The structure of the Taiwan mountain belt is thought to be that of an imbricate thrust and fold belt developed above a shallowly dipping basal detachment. In recent years, however, a growing amount of seismicity data from the internal part of the mountain belt indicates the existence of widespread fault activity in the middle and lower crust, suggesting that deeper levels of the crust must be involved in the deformation than is predicted by the imbricate thrust belt model. To address this issue, we present new geological mapping, long-term GPS, earthquake focal mechanism, and seismic energy release data from the central part of Taiwan. We suggest that the foreland basin part of the Western Foothills comprises an imbricate thrust system that is structurally and kinematically linked to a basal detachment at between 7 and 10 km depth. To the east of the foreland basin, in the Hsuehshan Range, our data show the presence of major faults that are steeply dipping and which penetrate 25 to 30 km depth, or more. This indicates that much deeper levels of the crust are involved in the deformation, and that a structural and kinematic model in which this part of the mountain belt forms a zone of transpression with a structural architecture similar to that of a crustal-scale positive flower structure better fits the available data. Eastward, in the Central Range, deep water sediments appear to form an allochthon that is being overthrust by Mesozoic basement rocks. The involvement of such deep crustal levels and Mesozoic basement in the deformation if suggestive of the reactivation of pre-existing basin-bounding faults that where located on the Eurasian continental margin.

TECTONIC PROCESSES DURING THE BUILDING OF THE URALIDES

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The Uralides, together with the Appalachian-Caledonide-Variscan orogenic system, was one of the main orogens that developed during the building of Pangea. The large scale tectonic processes that formed the Uralides include an arc-continent collision that began in the Middle Devonian and ended in the Early Carboniferous, followed by continent-continent collision that began in the Late Carboniferous and lasted until the Early Triassic. In the Southern Urals of Russia, the Laurussia margin involved in the arc-continent collision consisted of a basement that was composed predominantly of rocks of Archean and Proterozoic age that, by the time of arc-continent collision, was overlain by Cambrian, Ordovician, Silurian, and Devonian sediments interpreted to have been deposited in rift-related grabens on the continental slope and rise, and on the shallow marine platform. The Magnitogorsk Arc consists of Early to Late Devonian island arc volcanic rocks and overlying volcaniclastic sediments. Arc-continent collision led to the development of an accretionary complex that includes shallowly and deeply subducted continental margin rocks, ophiolite fragments, and sediments that were deposited in a foreland-basin setting.

The Late Paleozoic continent-continent collision that took place between Laurussia and Kazakhstania reveal a number of tectothermal processes. Reflection and wide-angle seismic profiles demonstrate that the Uralides has an overall bivergent structural architecture, but with significantly different characteristics from one tectonic zone to another. The integration of other types of data sets with the seismic data allows us to interpret that the changes in the crustal-scale structural architecture indicate that there was significant partitioning of tectonothermal conditions and deformation from zone to zone across major fault systems, and between the lower and upper crust. Also, a number of the structural features revealed in the bivergent architecture of the orogen formed either in the Neoproterozoic or in the Paleozoic, prior to continent-continent collision. From the end of continent-continent collision to the present, low temperature thermochronology suggests that the evolution of the Uralides has been dominated by erosion and slow exhumation. Despite some evidence for more recent topographic uplift, it has so far proven difficult to quantify it.

Keynote COLLISION TECTONICS ACROSS THE PROTEROZOIC –PALEOZOIC TRANSITION: SECULAR CHANGE IN UPPER MANTLE TEMPERATURE AND HOT VS COLD OROGENESIS

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Convergent plate boundaries characterized by one-sided subduction create asymmetry in the thermal structure with lower dT/dP in the subduction

zone and by higher dT/dP in the backarc/orogenic hinterland. During orogenesis these thermal environments are imprinted in the rock record as contrasting types of metamorphism with different apparent thermal gradients: blueschists–low-T eclogites record oceanic subduction; ultrahigh-pressure metamorphism (UHPM) records continental subduction; medium-T eclogite–high-pressure granulite metamorphism (E-HPGM) records terminal collision; and, granulite–ultrahigh temperature metamorphism (G-UHTM) is generated in backarcs/orogenic hinterlands. On a plot of apparent thermal gradient vs age there is a dramatic change in the late Neoproterozoic. During the Proterozoic, the geological record preserves two contrasting types of metamorphism: E-HPGM, with gradients of 350–750°C/GPa, and G-UHTM, with gradients of 750–1500°C/GPa. Blueschists and UHPM, with gradients of 150–350°C/GPa, first appear in the Cryogenian–Ediacaran, whereas G-UHTM virtually disappears from the rock record during the Cambrian. The decrease in upper mantle temperature during the Mesoarchean–Neoarchean allowed one-sided subduction to become established globally by the Proterozoic. The appearance of blueschists and UHPM in the rock record could have been due to continued decrease in upper mantle temperature, which was ~100°C warmer than at present in the Neoproterozoic. This postulate may be tested using a 2-D petrological–thermomechanical numerical model of collision. For present conditions, strong lower crust results in coupled collision forming narrow orogenic belts with UHPM rocks, whereas weak lower crust results in decoupled collision with wide orogenic belts and low-to-medium grade metamorphism. Increasing the upper mantle temperature to >100°C above the present value promotes development of hot and narrow convergence zones bounded by regions of lithospheric extension and decompression melting. Strong lower crust results in formation of magmatic belts above hot continental subduction zones, whereas weak lower crust results in narrow two-sided orogens with a deep hot crustal roots. A comparison between geological observations and model results suggests the transition from a hot to cold collision regime occurred during the Neoproterozoic. Furthermore, at the dawn of the Phanerozoic there was a change in the mechanism of breakup and formation of supercontinents from fragmentation, dispersal and reassembly by elimination of the complementary superocean, with suture zones characterized by E-HPGM and backarcs/orogenic hinterlands by G-UHTM, to one in which internally-generated ocean basins opened and closed by terrane transfer, with suture zones characterized by early blueschists and UHPM followed by E-HPGM during terminal collision, but G-UHTM is rare.

SYNGENETIC PRECIOUS METAL ENRICHMENT IN A DE-FORMED VOLCANOGENIC MASSIVE SULFIDE (VMS) SYSTEM: THE MING MINE, BAIE VERTE PENINSULA, NEWFOUNDLAND APPALACHIANS, CANADA

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The early Ordovician Ming Mine (487 Ma; total resource 12.5 Mt ore @ 1.52 wt% Cu, 1.69 ppm Au, 8.11 ppm Ag, and 0.45 wt% Zn), Baie Verte Peninsula, Newfoundland, represents a type example of a precious metal-enriched VMS deposit within the Appalachian Orogen. Despite past production, and a history of research, the origin of precious metal enrichment remains uncertain. New, high-grade Cu-Au±Ag zones were discovered at the moderately metamorphosed and deformed Ming Mine in the early 2000s and have provided considerable new insight into the cause of precious metal enrichment in the deposit, particularly information from the 1806 and 1807 zones, Ming S up and down plunge, Ming N and an upper and lower footwall zone. Rhyolitic tuffs, flows and breccias host massive to stringer mineralization and are altered to quartz–sericite ± green mica ± chlorite ± biotite. Alteration in the rhyolites changes to a more quartz–chlorite–biotite–magnetite assemblage in the lower footwall zone. The hanging wall consists of mixed mafic-felsic volcaniclastic turbidites. The sulfide mineral assemblage varies in the deposit. The lower footwall zone is dominated by a uniform chalcopyrite–pyrrhotite assemblage. In contrast, metal zoning occurs in the stringer to massive sulfide mineralization and is especially well documented from the 1806 zone. The down plunge of this zone is dominated by a pyrite–chalcopyrite assemblage, whereas the up plunge shows a gradual change from a pyrite–chalcopyrite–sphalerite–metamorphic pyrrhotite assemblage to a pyrite–sphalerite–chalcopyrite–galena assemblage vertically upwards. In addition, various sulfosalts rich in magmatic suite elements (e.g., arsenopyrite, tetrahedrite-tennantite, stannite, boulangerite, loellingite), Te-bearing phases (e.g., BiTe, coloradoite), Ag-phases (e.g., miargyrite, unnamed AgCuFeS phase, argentotetrahedrite, AgHg alloy), and electrum occur throughout the 1806 zone. The abundance of these sulfosalts and precious metal-rich minerals increases slightly from down to up plunge in the 1806 zone. Furthermore, microprobe analysis reveal (1) no invisble gold in recrystallized pyrite, arsenopyrite or any other sulfide phase; (2) high Hg-contents in electrum (12 – 17 wt%); and (3) a varying Fe-content in sphalerite (2 – 9 wt%). The abundance of magmatic suite sulfosalts, Hg-rich electrum, and absence of orogenic-gold deposit features (e.g., quartz-carbonate alteration, simple sulfide mineralogy), are consistent with a syngenetic origin for Au-Ag-(Sb-As-Bi-Sn-Te-Hg)-enrichment via magmatic fluids. Internal remobilization due to later deformation and metamorphism was also important in remobilizing Au–Ag, as evidenced by Au-Ag phases along recrystallized pyrite and arsenopyrite grain boundaries and along cracks in these phases.

RELICT ECOSYSTEMS, MATGROUND RESTRICTION AND THE CHANGING FACE OF THE DEEP

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Trace- and body-fossil evidence indicates that the colonization of the deep sea started in Ediacaran times. In fact, the oldest trace fossils are known from deep-marine deposits rather than shallow-water deposits. Ediacaran deep-marine ichnofaunas are poorly diverse, and consists of very simple trails and burrows, essentially representing two main architectural designs (simple horizontal trails and passively filled horizontal burrows). Both ichnodiversity (global and alpha) and ichnodisparity were extremely low. In particular, nonspecialized grazing trails (e.g. Helminthopsis, Helminthoidichnites) are associated with the exploitation of microbial mats, a strategy that was also dominant in Ediacaran shallow-marine environments. However, while matgrounds underwent environmental restriction in shallow, fully marine settings after the agronomic revolution, exploitation of microbial mats persisted during most if not all the Cambrian in the deep sea. Cambrian deep-marine ichnofaunas are of "Ediacaran aspect" and the deep sea can be regarded as a relict ecosystem. However, the Cambrian radiation is expressed in the deep sea by the addition of a number of architectural designs, such as surface-coverage branching burrows (e.g. Oldhamia), horizontal to oblique branching burrows (e.g. Saerichnites), trackways and scratch marks (e.g. Diplichnites), plug-shaped burrows (e.g. Bergaueria) and smooth bilobate trails and burrows (e.g. Didymaulichnus). As a result, Cambrian deep-marine ichnofaunas display a remarkable increase in ichnodisparity, as well as in global and alpha ichnodiversity. Deep-marine ecosystems undertook significant changes by the end of the Cambrian, reflecting the seaward expansion of the agronomic revolution and the demise of matground-dominated ecosystems. The main architectural designs of deep-marine trace fossils were established in deep-sea environments by the Early Ordovician, recording the first appearance of the Nereites Ichnofacies. Lower to Middle Ordovician deep-marine ichnofaunas seem to be moderately diverse, and fodinichnia commonly dominates rather than graphoglyptids. A significant ichnodiversity and ichnodisparity increase occurred in the Late Ordovician-Early Silurian, with ichnofaunas recording higher proportions of graphoglyptids. In the common absence of body fossils, trace fossils represent an important source of information to address the early evolution of deep-sea ecosystems.

LOCATING MANTLE PLUME CENTRES FOR MAFIC DYKE SWARMS OF LARGE IGNEOUS PROVINCES (LIPs) IN NORTHERN CANADA BASED ON NEW MAPPING

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Based largely on a digital map of the mafic dyke swarms of northern Canada, recently completed as a component of the GEM (Geo-mapping for Energy and Minerals) Tri-Territorial Bedrock Compilation Synthesis, we identify or refine the location of mantle plume centres for a number of swarms thought to belong to Large Igneous Provinces (LIPs). Of particular interest are swarms whose radiating geometry or other characteristics, such as dyke density and geographic relationship to cratonic margins, can be used to locate plume centres. On the Queen Elizabeth Islands, five Phanerozoic dyke swarms are now recognized. Two of these, the well known Cretaceous (0.13-0.08 Ga) Queen Elizabeth Islands swarm (a component of the High Arctic LIP) and a smaller newly identified Paleozoic Henson Bay swarm, radiate from foci close to the northwest coast of Ellesmere Island. Dykes associated with the widespread Neoproterozoic (0.72 Ga) Franklin LIP event are mapped in greater detail then previously, especially on Victoria Island and the adjacent mainland. New mapping provides a more accurate location for the swarm's focus near Banks Island on Laurentia's northern margin. The Neoproterozoic (0.78 Ga) Hottah swarm of the Gunbarrel LIP, previously mapped in the Wopmay Orogen and Mackenzie Mountains, is interpreted to extend in a broad fanning pattern beneath Paleozoic cover rocks west of the Canadian Shield, with a focus off Laurentia's western margin. New mapping of the Paleoproterozoic (ca. 2.11 Ga) Indin swarm of the southwestern Slave craton confirms and augments earlier interpretations of a radiating pattern with a focus off the western margin of the craton, and shows an increase in dyke density towards the focus. The Paleoproterozoic (2.23 Ga) Malley swarm of the southeastern Slave craton has recently been interpreted to extend to northeastern as the poorly dated Britchta swarm, having been offset along the prominent Bathurst fault. The reconstructed and remapped swarm appears to show a slight radiating pattern with the dykes dying out to the southwest in the cratonic interior, suggesting a focus off the eastern margin of the craton. Finally, the unusual high density of dykes in a number of swarms, such as the Mesoproterozoic (1.74 Ga) Cleaver swarm of the Wopmay Orogen, Paleoproterozoic (ca 2.19 Ga) MacQuoid swarm of the Western Churchill Province and Paleoproterozoic (1.88 Ga) Ghost swarm of the Slave craton, likely indicates relatively close proximity to their source region (e.g. mantle plume), although the direction to the source is often unclear.

TRACKING HYDROTHERMAL ALTERATION AND MINERALIZATION IN ROCK-FORMING AND ACCESSORY MINERALS FROM THE LYON MOUNTAIN GRANITE AND RELATED IRON OXIDE APATITE (IOA) ORES FROM THE ADIRONDACK MOUNTAINS, NEW YORK STATE

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The Lyon Mountain granite (LMG) is located in the northeastern Adirondack Mountains in New York State and hosts several economic-grade low-titanium iron oxide apatite (IOA) ore deposits. The ores are hosted by perthite granite which has been extensively altered to albite and microcline granite by Na and K metasomatism. Previously dated host rocks of the magnetite-apatite ores from the Adirondacks have zircon core ages ~1150 Ma and rims of zircon crystals and single age zircon from these same rocks have been dated between 1060-1050 Ma.

This study aims to determine the relative timing of LMG emplacement and subsequent hydrothermal alteration and Fe mineralization. For example, the host rocks yield zircon ages of ~1150 Ma and ~1050 Ma yet it is not clear whether these ages represent hydrothermal alteration or pluton emplacement.

Zircon crystals separated from several of these magnetite-apatite ores reveal at least two periods of mineralization; one event at ~1039 Ma and another between ~1015-1000 Ma documenting protracted events that post-date the 1060-1050 Ma LMG magmatism. To better understand the timing of these post ~1050 Ma events U-Pb isotope dilution thermal ionization mass spectrometry (ID-TIMS) of apatite was done on the ore and host rock samples, yielding ages ranging from 1050 to 850 Ma, with large variations within samples and within grains. Two of the ore-apatite samples have homogenous Sm/Nd and elemental ratios, precluding calculation of Sm-Nd ages. However a third ore sample shows a large spread in Sm/Nd and yields a Sm-Nd isochron age of ~850 Ma, in close agreement of U-Pb ages by ID-TIMS of this ore apatite. Initial Nd isotopic composition of both ore and host rocks are identical and consistent with published Adirondack whole rock data, suggesting a local source for rare earth elements (REE) in these ores.

These younger isochron and ID-TIMS ages may reflect cooling recorded in those minerals, or a younger hydrothermal event. Apatite from the LMG also shows varying degrees of oxidation (recorded in Fe and As), which may indicate pulses of hydrothermal fluids over time. The apatites have unusually high REE and Y concentrations (some total REEs > 20wt. % and up to 8 wt. % Y_2O_3). In contrast, the minor and trace element compositions of the major rock-forming minerals (e.g., plagioclase and microcline feldspar, clinopyroxene, fayalite) and the zircon and fluorite in the LMG have generally average igneous granitic trace and minor element compositions.

USING OLIVINE TRACE ELEMENT DATA TO UNRAVEL THE CONUNDRUMS OF THE VOISEY'S BAY INTRUSION AND RELATED Ni-Cu MINERALIZATION, LABRADOR

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The mafic Voisey's Bay (VB) intrusion transgresses the 1.85 Ga collisional contact between the Archean Nain Province and the Paleoproterozoic Churchill Province in Eastern Labrador. It is part of the Mesoproterozoic Nain Plutonic Suite, an anorogenic igneous suite largely dominated by granitic and anorthositic plutons. The VB intrusion comprises a group of troctolitic to olivine gabbroic bodies (Reid Brook and Eastern Deeps) linked by olivine gabbro dikes, and is associated with a world-class Ni-Cu-Co sulfide deposit. Massive and disseminated zones of mineralization are spatially and genetically related to a breccia sequence (BBS) at the base of the dike and at the entry line of this dike into the larger Eastern Deeps intrusion [1]. Upward from this sulfide-laden, brecciated and country rock-contaminated sequence, the troctolitic rocks progressively decrease in sulfide content, contain fewer gneissic fragments and grade into an effectively barren, homogeneous plagioclase and olivine cumulate, collectively termed normal troctolite (NT) [1]. In an attempt to quantify the ore-forming potential and the episodicity of the varied host gabbroic rocks, we performed trace element analyses of olivine from the BBS and troctolite sequences using Secondary Ion Mass Spectrometry. We observe systematic variations in Cr, Mn, Fe, Co, Ni and Zn contents in olivines for both sulfide-free and sulfide-bearing zones. Olivines from the BBS gradually increase in Mn (up to 11,000 ppm) and Zn (up to 550 ppm) closer to massive sulfide and are in general Cr, Co and Ni depleted compared to those from nominally barren troctolites. Olivine compositions from NT samples, on the other hand, reveal the presence of high Ni (up to 2,500 ppm) olivine "reefs", which are bracketed by horizons with olivine Ni contents of $\leq$ 1,500 ppm. These excursions also show excellent correlation with deflections in whole-rock trace element content. Our data imply that: (1) olivines from the homogenous NT display a "cryptic-layering", indicating crystallization from episodically intruding pulses of fresh mafic magma; (2) the high Mn and Zn concentrations are a result of crystallization from a country rock-contaminated mafic magma, and hence, might act as a geochemical indicator for the assimilation of upper crustal material. These observations can therefore assist in identifying

characteristic trace element signatures of olivines that formed in contaminated (and thus potentially sulfide saturated) magmas.

[1] Lightfoot and Naldrett (1999) GAC Vol. 13, 1-30.

USING SMALL CARBONACEOUS FOSSILS (SCFS) TO RESOLVE THE NEOPROTEROZOIC-PALAEOZOIC TRANSI-TION

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The transition from a pre-Ediacaran 'microbial world' to the profusely macroscopic condition of the Phanerozoic revolutionized the course of planetary history. Unfortunately, the fossil record of the critical interval is biased by 1) the over-representation of biomineralized forms accompanying the Cambrian explosion, 2) secular shifts in taphonomic pathways, including an early Cambrian switch from "Ediacara-type" to "Burgess Shale-type" macrofossil preservation, 3) the "exceptional" nature of non-biomineralizing Cambrian macrofossils and phosphatized microbiotas, and 4) laboratory procedures that overlook or eliminate key data.

Shale-hosted organic-walled microfossils have long been used to recover a record of non-biomineralizing fossil organisms, but standard palynological processing tends to destroy larger and/or more delicate material. In order to recover this key fraction, we advocate the use of a low manipulation HF-dissolution procedure, combined with hand-picking of individual microfossils. Such processing recovers a substantially larger range of carbonaceous fossils, most notably those too small to be easily detected on bedding surfaces, but too large to survive the rigors of boiling acids, vacuum-assisted sieving and/or heavy liquid separation. Significantly, this record of small carbonaceous fossils (SCFs) is proving sufficiently common to illuminate key aspects of the Neoproterozoic-Palaeozoic transition.

Like their shelly (SSF) counterparts, SCFs constitute a polyphyletic assemblage of mostly disarticulated fossil remains that nonetheless provide important stratigraphic, biogeographic, phylogenetic and palaeo-environmental resolution. In addition to documenting global occurrences of a wide range of Cambrian SCFs, we have identified a previously unrecognized radiation of crustaceans limited to shallow-water epicratonic seas (which fail to preserve Burgess Shale-type macroscopic counterparts); a wide range of carbonaceous fossils derived from originally biomineralized sclerites (including conodonts, sponges, palaeoscolecids, hyoliths and chancelloriids); and a record of unambiguously metazoan SCFs extending back to the earliest Cambrian.

Probable metazoan SCFs have also been recovered from terminal Ediacaran deposits, but have yet to be identified in earlier Ediacaran or Cryogenian acritarch biotas. It is also true, however, that the potential for high-quality carbonaceous preservation was relatively limited through most of this interval. On the other hand, older, pre-Cryogenian SCF assemblages exhibit the same degree of exquisite preservation as found in the Cambrian, and the absence of any recognizably metazoan remains in these biotas, despite decades of both conventional and low-manipulation processing, points convincingly to the genuine absence animals at this time. As such, the search for the first metazoans should be centred on the Ediacaran, with possible roots into the preceding Cryogenian.

SHEAR ZONE INFLUENCE ON THE EMPLACEMENT OF A GIANT PEGMATITE: THE WHABOUCHI LITHIUM PEGMA-TITE, QUEBEC, CANADA

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This project addresses the factors responsible for the emplacement of the albite-spodumene type Whabouchi pegmatite, located approximately 250 km north-northwest of Chibougamau and 40 km east of the community of Nemaska within the James Bay region, Quebec. The Whabouchi pegmatite is a 1.4 km by 130 m dyke of over 25 Mt with an average grade of 1.54 %Li_2O. The dyke was emplaced into a metamorphosed volcano-sedimentary belt, which is surrounded by granitoids. Preliminary mapping of the Whabouchi property has revealed several rock types including 4 types of pegmatites differentiated by their mineral components: biotite-garnet, muscovite-biotite-garnet, muscovite-garnet and the Whabouchi albite-spodumene pegmatite. In this respective order, there is a progression from the biotite-garnet type in the north, toward the albite-spodumene pegmatite over a distance of approximately 3 km. This progression is interrupted where pegmatites are in contact with deformed granites, which acted as sources for the biotite occurring within the muscovite-garnet pegmatites. Muscovite-garnet pegmatites occur southwest of the Whabouchi pegmatite and grade into biotite-bearing granites that display well-defined foliations. Other rock types identified on the property are deformed granites, brecciated granites, pegmatitic granites, orthogneisses and metabasites. The Whabouchi pegmatite is within a high-strain zone developed in upper greenschist to amphibolite facies metabasites. The metabasite host rocks in the shear zone are thoroughly transposed and the transposition foliation is ubiquitously developed and dips steeply at an average of 60°. Stretching lineations are also well developed and subvertical inside the shear zone. Small branching pegmatite veins from the main mineralized body are strongly folded with subvertical fold hingelines. Shear-sense indicators in outcrops consistently suggest a dextral sense of shear, indicative of a dextral transpressional shear zone. Cross-cutting relationships between the albite-spodumene pegmatite and transposed metabasites suggest a late syn- to post-kinematic emplacement of the Whabouchi pegmatite. These preliminary observations support either a pre-existing shear influence on the emplacement of the Whabouchi pegmatite or fracture-controlled emplacement affected significantly by pre- and post-ductile deformation.

A GEOHERITAGE STRATEGY FOR NOVA SCOTIA

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Long recognized by some of the world's great scientific minds, including Lyell, Darwin and Dawson, the geological heritage of Nova Scotia has been commemorated by local communities, in provincial and federal parks, by private sponsors, and by the ultimate recognition of UNESCO World Heritage. None of this, however, has been achieved from a systematic vision, and the desire for new commemoration requires a systematic approach, both to take inventory of our geoheritage and to provide a clear vision of sites that should be recognized, and in some cases promoted or protected. Geoheritage is defined most succinctly as geological features that inform humanity of its relationship with the Earth. Like UNESCO World Heritage, geoheritage can be divided into two categories: cultural/social geoheritage, where value is tied to human interaction with the site (comprising spiritual sites, mine sites, stoneworks), and physical geoheritage, where value lies in the aesthetic qualities of landscape, or in informing us of Earth history and Earth processes. Geotourism refers to the marketing of visitation to geoheritage sites and its economic benefits. Although there is great potential in geotourism for community-based economic development, not all geoheritage sites are appropriate candidates, for reasons of integrity, visitor safety, or even scientific obscurity (type sections being one example). The geoscience community will help to establish the geoheritage list using a rubric that considers: i) level of significance; ii) interpretive potential; and iii) appropriateness as a geotourism site. The development of a systematic geoheritage list will assist government agencies in making informed decisions and in fulfilling their mandates with wise allocation of resources. Perhaps most importantly, the formal recognition of geoheritage has potential to bring scientists and communities together at a time when we need more than ever to heed the lessons of Earth history as we face very real challenges to our shared future on this Earth.

INTEGRATED GEODATABASE STUDY OF THE COMPLEXLY-DEFORMED U-HOSTING PALEOPROTEROZOIC AMER GROUP, NUNAVUT

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The uranium-hosting Paleoproterozoic Amer Group, central Nunavut, comprises four dominantly sedimentary sequences (Ps1 through Ps4)

deposited unconformably on Archean basement of the Rae sub-province. Ps1 is characterized by Ayagaq Fm. quartzites formed in a stable cratonic and/or marine setting, with minor conglomerate and/or a distinctive schist at its base. Ps2 is a sharply transgressive sequence of graphitic siltstone (Resort Lake Fm.) shallowing up to dolostone (Aluminium River Fm.) and intercalated to overlying porphyritic basalt (Five Mile Lake Fm.). Ps3 comprises three units recording an overall coarsening- then shallowing-upward sequence involving siltstone to feldspathic arenite (Three Lakes, Oora Lake and Showing Lake formations). Ps3 is the primary host of U-mineralization in this region. Ps4 arkose (Itza Lake Fm) is preserved as isolated occurrences above a profound unconformity. The Amer Group is intensely deformed. D_1 produced multiple transposition (three fold generations) and displacement along discrete detachments resulting in sub-horizontal axial surfaces and tectono-stratigraphy. D_2 generated the regional, generally upright synclinoria, and is separated from D_1 by the Ps3-Ps4 unconformity. Late D_3 folds with sub-horizontal axial surfaces are rare. The region is transected by arrays of ENE- and NW- trending faults.

Elucidation of the structure of Ps3 units is central to determining the distribution of U-mineralization in the Amer Group. The difficulties of dealing with a polydeformed terrane are exacerbated by the absence of exposure in critical areas. This problem has been overcome by integrating detailed outcrop examination with high-resolution aeromagnetic data, and legacy drill hole data. The analysis is dependent on the strong, but distinct magnetic responses of the euhedral disseminated magnetite-bearing fine siliciclastic Three Lakes and Showing Lakes formations that, in preserved stratigraphic sequences are separated by the Oora Lake Fm. The aforesaid approach has enabled identification of a consistent, yet distinctly different geometry for the Amer Group "basins". In contrast to the apparent straightforward structure of the regional D_2 synclinoria, it is demonstrated that the D_1 tectono-stratigraphy forms large, regional recumbent structures masked by the lack of outcrop, but for which evidence occurs at all scales and within separate data sets i.e. field, geophysics, drill hole. The occurrence in some areas of elongate "cigar-shaped" mineralized zones reflects U-concentration within D_1 hinge zones coaxially overprinted by D_2. The success of this study in integrating diverse data bases, especially high-resolution geophysics and detailed outcrop mapping, argues for the future extension of such approaches.

THE ANATOMY OF A SUBMARINE SLIDE COMPLEX IN NORTHEAST FLEMISH PASS

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Flemish Pass is a north-south trending, saddle-shaped, mid-slope basin located between Grand Bank and Flemish Cap on the eastern Canadian continental margin. This basin has trapped thick sequences of Quaternary sediment, consisting of hemipelagic and proglacial muds, mass-transport deposits, and turbidites. A sediment slide complex in northern Flemish Pass near the Mizzen prospect, first identified on multibeam data collected in 2009, was investigated in August 2011 using high resolution seismic reflection systems and shallow piston coring.

This multiple failure complex extends about 80 km along the northwest flank of Flemish Cap and about 20 km downslope with three large arcuate slide scars found at its center. These arcuate failures are up to 10 km wide and 9 km long downslope, with scarps over 120 m high. These failures appear to be among the most recent in the complex. Unfailed sediments in the slide area have continuous coherent internal reflectors on seismic profiles. Failed sediments have run out as far as 20 km onto the floor of the pass, forming a mass transport deposit (MTD) up to 130 meters thick. The MTD appears acoustically transparent and massive on seismic profiles, with a hummocky upper surface in some locations, and an erosional base overlying well stratified sediments. Several cores taken along a series of terraces formed by the multiple failure events provide a composite stratigraphy of the upper 150 m below the seabed. Preliminary geotechnical results from a piston core taken in an area of undisturbed seabed adjacent to the failure complex show under-consolidated sediments exist at depth, and may indicate that the sediments are inherently unstable. An existing chronostratigraphic framework in Flemish Pass suggests that this failure complex developed after deposition of the base of Holocene seismic marker, giving it an age of less than 12 ka. Additional age control from recently acquired cores taken within this slide complex may yield a more precise estimate of the age of these slide events.

GEOPHYSICAL EVIDENCE FOR BOTTOM CURRENT ACTIVITY THROUGHOUT THE CENOZOIC FROM THE CONTINENTAL MARGIN OFF NOVA SCOTIA, CANADA

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The widespread sediment drifts that flank the continental margins of the North Atlantic provide geological evidence for bottom current activity throughout the Cenozoic. Prior to this study, sediment drifts and other features indicative of active bottom currents were thought to be of limited extent along the continental margin off Nova Scotia (the Scotian margin), making the Scotian margin anomalous compared to the adjacent margins to the north and south. In this study, we demonstrate that sediment drifts are a common feature in the Cenozoic succession along the Scotian margin. Analysis of recently acquired 2D and 3D multichannel seismic reflection data combined with published biostratigraphic results suggest that large sediment drifts developed in the Late Miocene to Pliocene, and possibly as early as the Late Eocene. These large drifts represent more than 50% of the preserved Cenozoic succession along parts of the western Scotian margin and exceed 1.4 km in thickness. Small sediment drifts developed locally throughout the late Paleogene and Neogene, either southwest and down current of seafloor obstacles or within channels. Increased bottom current intensity contributed to the formation of regional seismic markers, first along the continental rise in the Early Oligocene, then along the continental slope during the Late Miocene and Pliocene. The timing of bottom current intensification appears to be similar to the record from the U.S. Atlantic margin. 3D seismic data show localized erosion surfaces that preserve along-slope seismic amplitude anomalies, barchan bedforms, and possible evidence of helical scour. 3D seismic data also allow determination of paleo bottom-current direction using multiple criteria. All bottom current evidence suggests a northeast-to-southwest, along-slope flowing Western Boundary Undercurrent (WBUC) during the Cenozoic. There is no preserved evidence of northward encroachment of the Gulf Stream or Gulf Stream Rings. Increased intensity of the WBUC in shallower water depths is interpreted to have occurred during the Miocene to Pliocene and possibly represents increased contribution from Labrador Sea water masses. It is clear that along-slope sedimentary processes were far more important in shaping the Scotian margin than previously understood.

PRELIMINARY RESULTS OF RECENT FIELD INVESTIGATIONS OF THE SURFICIAL GEOLOGY AND SEAFLOOR PROCESSES IN FLEMISH PASS

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Flemish Pass is a perched basin in over 1000 m water depth bound to the west by the Grand Banks and to the east by Flemish Cap. It is an area of active hydrocarbon exploration with the completion of 4 exploration wells since 2003. Quaternary and modern geological processes affect seabed stability and shallow drilling conditions in the area. In an effort to augment the regional understanding of these processes and the surficial geology of Flemish Pass, the Geological Survey of Canada conducted a 3 week marine geological expedition to the area in August 2011. Data were acquired using high resolution seismic reflection systems, a large piston corer, an instrumented seafloor lander, and a towed camera system. Expedition planning was guided by regional multibeam bathymetry and sub-bottom profiler data collected during the Nereida Program*.

In northern Flemish Pass, detailed surveying of a widespread mass transport complex shows that the feature formed through multiple phases of seabed failure. Strategic sampling was undertaken to determine the

timing of failure events and geotechnical properties of the failed and unfailed seabed. Preliminary laboratory data indicate unexpectedly low sediment strength for the undisturbed interval. New seismic reflection data over enigmatic mounds on Sackville Spur do not support an interpretation of failure blocks for these features. Video and core data collected over one mound shows abundant gravel near its top, probably due to winnowing of ice-rafted detritus, and suggest the mounds are relict features of uncertain origin. Data from southern Flemish Pass reveal a previously unrecognized contouritic moat and drift system near Beothuk Knoll. A core from the floor of the moat recovered 3 m of very fine sand indicating that bottom current strengths in the area are sufficient to hinder deposition of finer sediment. A large canyon and sedimentary ridge immediately south of Flemish Pass appears to be partially fed by this contourite system. The results show that the Labrador Current has played, and possibly still plays, a significant role in redistributing sediment along Flemish Pass. Ongoing processing of data and samples from the 2011 expedition will provide important new information about the surficial processes and geotechnical properties of the seabed in Flemish Pass.

* A North Atlantic Fisheries Organization vulnerable marine ecosystems mapping project carried out by Spain, with partners from the Geological Survey of Canada, Fisheries and Oceans Canada, and the Centre for Environment, Fisheries and Aquaculture Studies in the UK.

THE BLACK BIRCH LAKE ASSEMBLAGE: A CONTINENTAL SUPRACRUSTAL SUCCESSION IN THE SOUTHERN HEARNE PROVINCE WITH IMPLICATIONS FOR THE SOUTHERN EXTENT OF THE CENTRAL HEARNE PROVINCE

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The upper amphibolite- to granulite-facies Black Birch Lake Assemblage (BBLA) is a supracrustal succession exposed south of the Athabasca Basin in the southern Hearne Province of Saskatchewan. The BBLA is characterised by quartzite and amphibolite near its base, overlain by psammite, semi-pelite to pelite, silicate-facies iron formation and rare dolomitic marble. Quartzite contains rare trough cross beds and amphibolite rare, relict pillows indicating a volcanic origin for some of the unit with mafic plutons constituting the balance. Mafic rocks with amphibolitic texture but where hornblende has been replaced by biotite are common, as are mafic rocks containing garnet-anthophyllite± cordierite that are indicative of Mg-metasomatism. What is striking about the BBLA is the preservation of metamorphosed saprolitic rocks at its base. In most cases meta-saprolites are characterised by blebby white leucosome, sillimanite along foliation planes, and magnetite. These were interpreted as pelitic units by previous mappers but their stratigraphic position between unaltered orthogneiss and plutonic rocks and quartzite of the BBLA is conspicuous. In addition, a zoned, metamorphosed, saprolite is preserved at Black Birch Lake that includes an upper aluminous zone, underlain by iron-rich and "rotten" and rusty zones before finally grading into granitoid gneisses. The relationships suggest an unconformable relationship between the BBLA and Archean granitoid rocks and derived gneissic equivalents, including ca. 2.6 Ga granites. Therefore, the BBLA is likely a continental supracrustal succession.

Previous workers suggested that the BBLA and equivalents might represent the western extension of the ca. 2.1-1.86 Ga Wollaston Supergroup, whereas others proposed correlation with the ca. 2.71-2.68 Ga Ennadai group in the extreme northeastern part of Saskatchewan. Our field observations, however, indicate that the BBLA is younger than 2.6 Ga and therefore not correlative with the Ennadai group. Equivalence with the ca. 2.1 Ga Courtenay Lake group, the basal strata of the Wollaston Supergroup, remains possible and requires further testing.

In conclusion, the BBLA appears to represent a continental supracrustal succession, contrasting the Rankin-Ennadai greenstone belt, which is oceanic in origin and was composed solely of juvenile material before 2.68 Ga. This implies a break between the southern and central Hearne in the vicinity of the Athabasca Basin. Coincident negative Bouger gravity and aeromagnetic anomalies that terminate just to the northeast of the Athabasca Basin and underlie the Ennadai group in northeastern Saskatchewan may represent an expression of this boundary.

THE VIRTUAL MUSEUM OF CANADA BURGESS SHALE WEBSITE – REACHING OUT TO A GLOBAL AUDIENCE

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The Burgess Shale in Yoho National Park (British Columbia) is famous for its spectacular soft-bodied organisms dating from the Cambrian Period. Designated a UNESCO World Heritage Site in 1980, it is now part of the Canadian Rocky Mountain Parks World Heritage Site. The Burgess Shale is located in a protected area, but Parks Canada allows a limited number of visitors to access this site each summer and only through licensed guided hikes. While hiking to the site offers a unique learning experience for visitors to the Parks, it is not for everyone (the hike is long and strenuous) and the number of participants remains small to minimize environmental disturbance. In order to expand public education and awareness, the Royal Ontario Museum and Parks Canada have launched a new bilingual (English and French) website entirely dedicated to the Burgess Shale (http://burgess-shale.rom.on.ca/). The website was funded by Canadian Heritage through the Virtual Museum of Canada Program. Visitors can access a wealth of information about the fossils, the geology, and the history of discoveries in ways not available before, from anywhere in the world. Presentation of our diverse geological heritage through the development of websites of this kind will facilitate protection of sensitive environmental areas where, for example, visitation is an issue, while at the same time expand opportunities for education.

PIKAIA GRACILENS FROM THE BURGESS SHALE: REVISITING WALCOTT'S MOST FAMOUS WORM

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Pikaia gracilens is one of the most iconic fossils from the 505 million year old Burgess Shale. Originally described in 1911 by Walcott as a possible polychaete worm, Pikaia has also been regarded as a primitive chordate, a possible stem group craniate, and a cephalochordate – but its status has remained controversial. A modern restudy of this animal was long overdue. For the first time, we present a detailed description of all 114 specimens, including 60 newly collected by the Royal Ontario Museum. Specimens range from 1.5 to 6 cm and comprise up to 100 sigmoidal myomeres. A small bilobed head bears a pair of slender, flexible tentacles. There is no evidence of eyes. Below the head are up to nine bilaterally arranged appendages that are potentially connected to pharyngeal pores. Internally, portions of the notochord and nerve chord, a dorsal organ and a vascular system are preserved. Its sigmoidal myomeres and notochord mark Pikaia as a chordate, but it differs from all other primitive chordates known in the Cambrian fossil record. We regard this animal as the most basal stem group chordate, with potential affinities to yunnanozoans.

ANATOMY AND STRUCTURAL EVOLUTION OF THE RETROWEDGE OF THE SOUTHERN CANADIAN CORDILLERA

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In the southern Canadian segment of the Cordillera, a doubly verging, "warm medium-sized" orogen formed in the Cretaceous to Eocene in a plate tectonic setting of oblique convergence. We document the internal geometry and structural evolution of the ~400 km wide, east-verging, retrowedge side of the orogen. The External Rocky Mountains and Foothills comprise three major east-verging, Late Cretaceous to Eocene, thin-skinned, piggyback thrust and fold systems. They root westward into

a basal décollement and accommodated ~180 km of shortening. The Western Internal zone is characterized by tracts of metamorphic rocks and metamorphic core complexes (e.g. Kettle, Okanagan, Priest River and Valhalla), some of which are basement-cored domes (e.g. Frenchman Cap, Thor-Odin, and Spokane). They have a downward-younging progression of Late Cretaceous to Eocene metamorphism and deformation in infrastructural flow zones characterized by transposition foliation, migmatites, flow folds and 1-7 km thick shear zones. Nested between the External and Western Internal zones is a relict ~100-200 km wide Early Cretaceous orogen that predated emplacement of ca. 100 Ma plutons. The geology and architecture of the Western Internal and External zones can be explained by progressive development of major Late Cretaceous to Eocene shear zone systems in the Internal zone that can be directly linked with coeval thrust and fold systems in the External zone. The linkage was via Late Cretaceous activation and Late Cretaceous to Early Eocene reactivation of the 150-200 km-wide central portion of the Rocky Mountain basal décollement that lies beneath and translated the intervening Early Cretaceous orogen. Thickening in the retrowedge insulated the underlying rocks of the incipient Internal zone leading to progressive heating, weakening and localization of the basal shear zone. At the base of the wedge, cooler stiffer rocks lay to the east of the Internal zone, at each stage, acting as an indentor. Thus, the development of a basal shear zone was coupled with flow of the hot mass of the Internal zone up and over an indentor, strain softening of it, and incorporation of it into the wedge in successive stages. During Early Eocene shortening, extensional shear zone systems were localized on the margins of tectonothermal culminations. Motion of deep-seated décollements beneath some of these culminations may have contributed to their doming. Crustal shortening ended at ca. 52 Ma in a transtensional tectonic regime, coinciding with crustal-scale extension in the Western Internal zone.

TESTING JOINT INVERSION CODE WITH GEOLOGICALLY REALISTIC MODELS

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Joint inversion is a type of inversion carried out for two different physical properties simultaneously. When a single Earth model is derived which fits different, complementary survey data that are sensitive to two physical properties it is more likely to be closer to the true subsurface structure than a single property inversion. A number of synthetic Earth models based on the geology of the Eastern Deeps zone of the Voisey's Bay deposit in Labrador have been constructed in order to test recently developed joint inversion modelling code. This code performs a joint inversion of seismic tomography and gravity data. The code uses unstructured triangular and tetrahedral meshes which are more easily comparable to the wireframe meshes commonly used to describe the geometry of ore deposits. Several triangular (2D) and tetrahedral (3D) unstructured mesh test models have been developed. The 2D models were based on conceptualized models of the Eastern Deeps and are varied in complexity. The 3D tetrahedral model was built based on Datamine wireframe models. The Datamine models had to be simplified to remove small scale features, and to improve mesh quality in order to be appropriate for geophysical numerical modelling. A method for creating geophysically suitable meshes was devised, and from this method software was developed to partially automate the creation of meshes. Single property and joint inversions were carried out to evaluate the ability of the inversion code to reproduce the models and to determine which inversion parameters were most crucial in generating the best inversion results. Inversions included a number of different gravity station distributions in order to determine the effect of employing borehole gravity, a relatively new technique. Through these tests it has been shown that the joint inversion code was able to locate a buried high contrast target in 2D tests with a variety of gravity distributions. Adjusting the sensitivity weighting improved the results of inversions where only borehole gravity stations were used. During 3D tests it has been concluded that a balance between the noise levels, maximum cell size of the inversion mesh, number of cells in a mesh, memory usage and CPU time has to be attained in order to apply this joint inversion code in practice.

EASTERN BAIE VERTE PENINSULA REVISITED: FROM EARLY PALEOZOIC SUPRASUBDUCTION ZONE OPHIOLITE, THROUGH SYN-OROGENIC CONTINENTAL VOLCANISM, TO LATER PALEOZOIC EXTENSIONAL COLLAPSE

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Baie Verte Peninsula in the Newfoundland Appalachians records a complex Paleozoic history of plate interaction between Laurentia and outboard terranes. A geological map of the eastern half of the peninsula combines published government, academic and industry data with new bedrock mapping, geophysics, lithogeochemistry and geochronology. In this area, a tectonic window exposes late Precambrian to early Paleozoic continental margin rocks of the Ming's Bight Group. The eastern half of Baie Verte Peninsula is more notable for its well-preserved supracrustal and plutonic rocks of the tectonic upper plate and younger continental cover. During the Taconic Orogeny, the Laurentian margin was overthrust by a 489 Ma suprasubduction ophiolite and 487 Ma juvenile island arc that host VMS copper and late gold mineralization in the Betts Cove and Pacquet complexes. A syn- to post obduction, >470-467 Ma submarine ophiolite cover sequence is represented by the Snooks Arm Group in the Betts Cove and Pacquet complexes. In eastern Baie Verte, this basinal facies, volcano-sedimentary cover disconformably overlies the ophiolite and island arc sequence, and is separated by the Nugget Pond iron formation and host to younger gold mineralization. Emergence of this marine succession in eastern Baie Verte is linked to voluminous, episodic arc- and later granite magmatism represented by 457 Ma felsic dykes and the voluminous 445-433 Ma Burlington Plutonic Complex. Bimodal, post-arc magmatism in the Cape St. John Group (428-426 Ma) and synvolcanic plutons including the 429 Ma Cape Brule porphyry and 427 Ma Dunamagon granite are the vestiges of a large, continental caldera complex and its satellite plutons that are broadly contemporaneous with the Salinic Orogeny. Rocks of the eastern Baie Verte Peninsula have been affected by at least four phases of deformation. An early, NW-directed fault in the Betts Cove ophiolite, is the sole evidence of early D_1 deformation related to Taconic obduction of the Baie Verte oceanic tract. Penetrative D_2 deformation involved S-SE overturned folds, and later, SSE-directed ductile to brittle-ductile shear zones that affect both Ordovician and Silurian units. Open, upright F_3 cross folds are interpreted as penecontemporaneous with D_2 and resulting from an overall Salinic transpressional regime. In the northern part of the map area, recumbent F_4 folds are cogenetic with southeast-dipping, ductile-brittle extensional shear zones. These structures are responsible for local unroofing of continental margin units causing a metamorphic overprint (405-370 Ma) and reflect transtensional deformation between the NE-striking, dextral Baie Verte Road and Green Bay faults.

CHARACTERIZATION AND EMPLACEMENT CONDITIONS OF THE GOLD MINERALIZATION OF THE DAISY-MILANO GOLD MINE, MOUNT MONGER DISTRICT, WESTERN AUSTRALIA

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The Daisy-Milano gold mine is located in the Eastern Goldfields Archean superprovince, Yilgarn Craton, Australia. It is owned and exploited by Silverlake Resources since 2007 and the total resources are currently inferred at 1,069,700 t at 18 g/t gold.

The deposit is considered to belong to a gold lode vein orogenic type and is hosted in dacitic porphyries, andesites, komatiites and volcaniclastic rocks in a greenstone belt.

The mineralized vein network is generally oriented 020°/80° and is controlled by N150° sinistral shear zones. Gold is located in quartz carbonate veins and is generally associated with pyrite.

Two stages of mineralization have been defined:

- Stage 1: pyrite, chalcopyrite, galena, electrum, and gold-silver tellurides;
- Stage 2: no economical mineralization

Gold remobilization creates zones with extremely high grades (>1000 g/t) and induces a high nugget effect. Pervasive sericite, chlorite and pyrite haloes due to the hydrothermal alteration surround the mineralized areas.

A microthermometric and RAMAN spectroscopic study of fluid inclusions has been performed in quartz grains. The most common type includes CO_2-dominated inclusions. They are spatially related to two-phase or three-phase H_2O-CO_2 inclusions including a muscovite daughter crystal. Extremely rare CH_4-bearing inclusions can be found with either H_2O or CO_2. Analyses reveal that CO_2 is extremely pure. Homogenization temperatures vary from -21.2 to 29.7°C, indicating highly variable densities (0.572 to 0.938 g/cm^3). Detailed study of the distribution amongst fluid inclusions assemblages suggests that the variable composition and densities of fluid inclusions is due to post-trapping perturbations.

H_2O-CO_2 inclusions, which represent the initial fluid composition and physical properties, show emplacement conditions at 480±100°C and 4.5±1 kbar. CH_4 inclusions indicate a late hydrothermal stage with a significant pressure drop.

DIRECT DATING AND CHARACTERIZATION OF THE POPE'S HILL REE DEPOSIT, LABRADOR

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The Pope's Hill rare earth element (REE) deposit is located approximately 80 km southwest of Happy Valley-Goose Bay, Labrador, along the Trans Labrador Highway. Exploration done by Silver Spruce Resources, Inc. in 2010 led to the discovery of a highly prospective REE-bearing unit with total REE plus yttrium (TREE+Y) as high as 25 wt.% along an open-ended northeast trend approximately 2.8 km in length. Ore, host rock, and country rock samples were collected to 1) quantify which phases contain the REE and their abundances and distribution in the ore; and 2) use *in situ* U-Pb geochronology and *in situ* Sm-Nd isotopes in monazite from the ore and host rock to constrain the timing of mineralization and determine the source of the REE. These data will help develop predictive models for this type of mineral deposit elsewhere.

The Pope's Hill REE deposit host rock is syenitic to monzonitic in composition containing up to 90% Na- and K-feldspar with minor amounts of hedenbergite, hornblende, and biotite and pervasive Na and K hydrothermal alteration. Trace mineral phases include monazite, zircon, and allanite. The REE ore occurs in millimeter- to centimeter-scale segregations and pods that are locally discontinuous. EMPA results demonstrate that apatite-britholite, allanite, and titantite contain the majority of REE+Y in the Pope's Hill deposit. A minor amount of the REE are contained in monazite, fergusonite and an unidentified REE-carbonate. Apatite and titanite are present in both high-REE and low-REE types, where the minerals either conform to their stoichiometric composition or contain chemical substitutions incorporating major quantities of REE and Si, where Si^{4+} + REE^{3+} substitute for Ca^{2+} + P^{5+}. In some REE-rich ore samples high-REE apatite and britholite co-exist.

Monazite in the host rock yields a U-Pb age of ~1060 Ma, while monazite in the ore is ~1000 Ma. A Sm-Nd isochron age obtained from the major REE phases in the ore agrees well with the monazite U-Pb age of the ore, and therefore provides excellent constraints on the timing of REE mineralization. The initial Nd isotopic composition of the REE phases is nearly identical to that of the host rock, permissive of a locally derived source for the REE elements.

REMOBILIZATION AND FRACTIONATION OF RARE-EARTH ELEMENTS DURING POSTEMPLACEMENT EVOLUTION OF CARBONATITES: IMPLICATIONS FOR EXPLORATION

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Carbonatites in orogenic terranes host some the world's most spectacular rare-earth deposits, where rare-earth elements (REE) are concentrated in such primary minerals as bastnäsite ($REECO_3F$) and monazite ($REEPO_4$). Carbonatites found in Precambrian orogenic settings commonly show evidence of post-emplacement deformation involving ductile flow, grain-boundary migration, grain deformation and comminution, and post-deformational recovery. These processes are accompanied by mineral reactions involving primary calcite and accessory REE-host phases. Some of these mineralogical changes (for example, remobilization of REE and their redeposition as a new, syn-deformational mineral assemblage) have profound implications for REE exploration. Our data show that primary calcite and fluorapatite undergoing postemplacement deformation are strongly susceptible to the removal of light REE (leading to LREE concentrations up to 20 times lower than the original levels), whereas heavy REE remain essentially immobile. The remobilization of light REE is not accompanied by any changes in isotopic composition or Y/Ho ratio (i.e. the primary "mantle" geochemical signature of carbonatites is retained), suggesting that the deformation processes under consideration involve a fluid isotopically equilibrated with the primary igneous paragenesis. The remobilized lanthanides are deposited as a late-stage paragenesis of minerals (commonly, monazite, Ca-REE carbonates and allanite), whose composition is largely controlled by the fluid chemistry and local depositional environment. These data imply that postemplacement deformation has a dual effect: on the one hand, it may result in significant dispersal of REE, but on the other, it may lead to the development of an economically viable late-stage light-REE mineralization (e.g., monazite).

PRELIMINARY PETROGRAPHIC CHARACTERIZATION OF IMPACTITES FROM THE POPIGAI IMPACT STRUCTURE

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This study presents the preliminary petrographic results of a suite of impact melt-bearing breccias from the Popigai impact structure, Russia. This petrographic characterization is part of a broader comparative study of impact-induced breccias. The study aims to elucidate the formation and deposition mechanisms of melt-bearing breccias also known in the literature as 'suevites'. The suite of samples presented here is from beneath the coherent impact melt sheet at Popigai and has been classified by others as 'suevite' breccia. The relative "textures" of these samples were semi-automatically and quantitatively analyzed by means of digital image analysis on a macroscopic (hand sample) scale, using ImageJ software. The petrographic investigation was conducted using traditional optical microscopy, Scanning Electron Microscopy (SEM), and Electron Microprobe Analysis (EMPA). Petrographic microscopic investigation agrees with textural macroscopic observations in terms of "textures". At both scales, impact melt particles exhibit complex deformation textures and interaction with both the groundmass and the mineral fragments of the breccia. The glass fragments vary from strongly vesiculated to almost non-vesicular and from "light-coloured" to "dark-coloured". In addition, these glass fragments occasionally exhibit an internal fabric with preferentially oriented mineral clast inclusions that appear to have deformed along with the glass fragment. Most fragments mineral/glass have obvious reaction rims. In addition, present are lithic fragment that appear as angular to subrounded fragments. Of interest are 100µm wide features of mantled recrystallized melt that appears in the form of sheaf-like laths, "coated" with clinopyroxene rims. Preliminary chemical results suggest a mostly

anhydrous aluminosilicate melt. The compositions are mainly quartzo-feldspathic with the presence of Ca-rich pyroxenes. It has been observed that the clinopyroxenes have an extensively more Ca-rich composition compared to that of the melt. In addition, pyroxene aluminum content varies greatly an observation that may reflect crystallization temperature. Generally, however, both impact melt rock and glass fragments have a similar chemical composition. Finally, the groundmass is broadly consisted by similar (but finer) phases as the clastic population of the breccia. Composed mainly by crystallites of plagioclase, quartz, pyroxene and some carbonate.

LATE PALEOZOIC FRACTURE-ZONE OPHIOLITIC BELT IN WEST JUNGGAR, NW CHINA

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West Junggar is located at the east end of the Kazakhstan orocline, in the collisional triple junction where the Siberian, Tarim and Kazakhstan plates are sutured. Two parallel subvertical belts of ophiolitic rocks, principally serpentinite, outcrop in West Junggar: the Darbut and Baijiantan ophiolitic belts. Late Devonian (363.6 Ma) peperitic basalts form the base of a 2 km thick Lower Cretaceous basin fill that occurs in continuous stratigraphic sections distributed regionally over a distance of 100 km on both sides of the Darbut and Baijiantan ophiolitic belts.

The Baijiantan ophiolitic belt (outcrops ca. 5 km long, 1.5 km wide) comprises ultramafic rocks, with lesser gabbro, sandstone, basalt, and tuff, which show block-in-matrix structures and high-angle fault contact with the surrounding basin fill. Nearly all the peridotite is serpentinized and foliated, but some small blocks retain their original mantle lithology of dunite, harzburgite and lherzolite. Detailed field mapping and analysis of stretching lineations, rotation of sheared lenses, S-C foliation and shear fissures show that emplacement of the Baijiantan ophiolitic belt was related to a NE-trending sinistral strike-slip system. The Darbut ophiolitic belt (ca. 105 km long, <5 km wide), 40 km to the northwest, has similar rock assemblages and structural features to the Baijiantan ophiolitic belt.

Detrital zircon U-Pb (LA-ICP-MS) dating of three samples from sandstone blocks in the Baijiantan ophiolitic belt and one sample from Lower Carboniferous basin fill sandstone shows that the four samples have similar age distributions. The sandstone blocks in the ophiolite thus came from the adjacent coeval basin fill; they are not exotic blocks transported by obducting oceanic crust, distinguishing them from conventional ophiolitic belts. The peperitic basalts form the upper crust of a continuous small ocean basin, in which the Darbut and Baijiantan ophiolites originated as oceanic fracture zones, similar to those interpreted from the Troodos (Cyprus) and Bela (Pakistan) ophiolites. They should not be interpreted as evidence of a plate boundary or of subduction or obduction of oceanic crust.

TRACE FOSSIL EVIDENCE FOR EDIACARAN BILATERIAN ANIMALS WITH COMPLEX BEHAVIORS

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Trace fossils provide an important source of information about the behavioral ecology of early soft-bodied animals in the Ediacaran Period (635–542 Ma). We report a group of trace fossils from the Ediacaran Dengying Formation in the Yangtze Gorges area, South China. The Dengying Formation is constrained between 551 Ma and 542 Ma and contains Ediacaran fossils, macroalgal fossil *Vendotaenia* and the tubular fossil *Sinotubulites*.

Here we focus on three types of traces that are often connected with one another: millimeter-sized horizontal tunnels, surface tracks, and vertical burrows. The horizontal tunnels are preserved as full reliefs. They are about 4–7 mm in width, which remains constant along the length of individual tunnels. They typically consist of two raised lateral lobes separated by a central furrow, although the bi-lobed nature is sometimes apparent only along part of burrow length. In transverse cross sections, the tunnels have a bi-lobed and biconvex profile. The surface tracks are comparable in width to the horizontal tunnels, but they are always preserved as negative epireliefs or positive hyporeliefs. They consist of two parallel sets of sharp scratch marks. The vertical burrows are cylindrical, about 5 mm in depth, and 5 mm in diameter. They are always connected to the horizontal tunnels.

Trace fossils are often preserved in a facies characterized by thin-bedded limestone closely associated with microbial mat. The extensive development of biomats may separate two layers of similar lithology and server a plane of splitting, and let to trace fossils can be preserved close to the sediment-water interface. These three types of trace represent animal activities related to under-mat feeding, epibenthic locomotion, and temporary dwelling. Because these three types of traces are connected, indicate these traces were made by the same bilaterian animals that had complex behaviors, lived in association with microbial mats to exploit nutrient and O_2 resources. These animals heralded a new age in ecosystem engineering, animal-sediment interaction, and biogeochemical cycling.

COLLOID-FACILITATED TRANSPORT OF CESIUM-137 IN PARTIALLY SATURATED MEDIA: THE INFLUENCE OF NATURAL ORGANIC MATTER

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Colloid-facilitated transport of contaminants through the vadose zone has important implications to groundwater quality, and has received considerable attention over the last decade. Natural organic matter (NOM) is ubiquitous in the vadose zone, and its influence on mineral colloids and solute transport has been well documented. NOM sorption to colloids and sediment grains increases the mobility of colloids. Meanwhile, NOM either decrease or increase solute contaminant adsorption to colloids and sediment grains, and therefore could increase or decrease contaminant mobility. The overall effect of NOM on colloid-facilitated transport depends on the relatively importance of these mechanisms. The objective of this work is to elucidate the effects of NOM on colloid-facilitated transport of a radionuclide contaminant (^{137}Cs) within partially saturated sediments. Measurements made onto re-packed laboratory columns reveal that either in the presence or absence of NOM, the mobility of ^{137}Cs was limited when colloids were not present. The addition of mineral colloids in the influent slightly increased ^{137}Cs mobility, and effluent ^{137}Cs was dominated by colloid-associated form, indicative of colloid-facilitated transport. When NOM were added to an influent that contained both mineral colloids and ^{137}Cs, the mobility of both mineral colloids and ^{137}Cs significantly increased, although the presence of NOM slightly decreased ^{137}Cs adsorption to colloids. Our experimental results further show that the influence of NOM on colloid-facilitated transport is controlled by the type of transport media and the type of mineral colloids. However, the influence of moisture content of the media on colloid and ^{137}Cs transport seems negligibly small. A mathematical model, which accounts for (i) advective-dispersive transport of colloid and ^{137}Cs, (ii) rate-limited colloid deposition, and (iii) rate-limited ^{137}Cs desorption from colloids and adsorption to sediment grains, was applied to describe our colloid and ^{137}Cs transport data. The model successfully simulated the transport of colloids and ^{137}Cs both in the presence and absence of NOM. Our modeling results show that NOM (i) reduces colloid deposition rate, (ii) reduces the total number of sites available for colloid deposition in the transport media, and (iii) reduces the rate of ^{137}Cs adsorption to sediment grains. The overall effect of NOM is therefore an increase in both colloid and ^{137}Cs transport. Findings from this work demonstrate the importance of NOM in controlling colloid and solute contaminant transport and provide a method to quantify the influence of NOM.

TIMING OF OPHIOLITE OBDUCTION AND REGIONAL METAMORPHISM IN THE GRAMPIAN OROGEN

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The Grampian terrane in the Caledonides of Scotland and NW Ireland is the type locality for Barrovian (regional) metamorphism. It is thought to have resulted from the collision of the Laurentian margin with an oceanic arc and suprasubduction ophiolite during the Early Ordovician. Here we address the timing and P-T conditions of Grampian ophiolite obduction and re-evaluate the link with regional metamorphism.

Magmatic zircons from the Highland Border Ophiolite, Scotland define a 499 ± 8 Ma U-Pb Concordia age. Its metamorphism is dated by a 490 ± 4 Ma 40Ar-^{39}Ar hornblende age, and a 488 ± 1 Ma ^{40}Ar-^{39}Ar muscovite age from a metasedimentary xenolith within it, from which P-T estimates of 5.3 kbar and 580°C relate to ophiolite obduction. Metamorphism of the Irish correlative of the Highland Border Ophiolite is constrained by a 514 ± 3 Ma ^{40}Ar-^{39}Ar hornblende age, while mica schist slivers within it yield detrital zircon U-Pb ages consistent with Laurentian provenance and Rb-Sr and ^{40}Ar-^{39}Ar muscovite ages of ca. 482 Ma. P-T values of 3.3 kbar and 580°C constrain the conditions of ophiolite obduction.

Peak Grampian metamorphism on the Laurentian margin (Dalradian Supergroup) is constrained to c. 475 – 465 Ma. This includes U-Pb zircon ages from Grampian syn-orogenic intrusives and metamorphic mineral ages from Dalradian regions devoid of syn-orogenic intrusive rocks. There is therefore a pronounced time gap between c. 470 Ma mineral ages in the Laurentian margin (Dalradian Supergroup) and c. 490 Ma mineral ages in the Grampian ophiolitic rocks. P-T conditions also differ markedly, with high T - low P metamorphism in the Grampian ophiolitic rocks and high P - low T (blueschist-facies) metamorphic conditions in the subducted Laurentian margin sediments of the Dalradian Supergroup.

It is envisaged that subduction of the leading edge of the Laurentian plate initiated at c. 490 Ma, contemporaneous with the start of ophiolite obduction and resulted in high-pressure metamorphism of the Laurentian margin. The high-pressure rocks were transferred to the hanging-wall plate and thrust back onto the margin, and exhumed by extensional collapse preserving mineral cooling ages as old as ca. 475 Ma close to the margin. Away from the Laurentian margin, collisional thickening created the thick Dalradian nappe stack and associated Barrovian metamorphism, with possibly minimal involvement of obducted oceanic lithosphere. Collisional thickening may have initiated shortly after ophiolite obduction in order to generate the ca. 470 Ma Grampian peak metamorphism in the Dalradian.

VARISCAN INTRA-OROGENIC EXTENSION IN SW IBERIA: INJECTION OF ANATETIC LEUCOGRANITES AND RELATED GOLD-MINERALISATIONS

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In SW Iberia, after a phase of crustal shortening and building of the Appalachian and Variscan Mountains (when the Rheic Ocean between Laurussia and Gondwana close), continental extension and onset of high-medium-grade metamorphic terrains occurred. The high-medium-grade metamorphic terrains in the Ossa-Morena Zone consist of strongly sheared Ediacaran, Cambrian and Ordovician (c. 590–480 Ma) protoliths. The dominant structure is a widespread steeply-dipping foliation with a gently-plunging stretching lineation generally oriented parallel to the fold axes. Despite of the wrench nature of this collisional orogen, kinematic indicators of left-lateral shearing are locally compatible with an oblique component of extension. U-Pb and ^{40}Ar-^{39}Ar geochronology and structural data constrain the Variscan wrenching in the Ossa-Morena Zone. Wrenching is responsible for the developed of ductile extensional shear zones, rapid exhumation of deep crust, metamorphic rocks, partial melting and magma production in the interval c. 356-321 Ma. In the Boa Fé shear zone of the Évora Massif, gneisses were exhumed from a depth of 11–15 km to 6-8 km, indicating a minimum vertical displacement of c. 4-6 km and exhumation rates of 1 to 2-3 mm a^{-1}. In the Évora Massif, the cooling history was complex, with a first stage in the Tournaisian, a second stage in the Visean (lasting 2 to 5 Ma), with a cooling rate of 60-80 to 150-200ºC Ma^{-1}, and a final stage in the Serpukhovian. The spatial distribution of anatectic leucogranites veins/dykes running through a footwall migmatite system, and reaching the Boa Fé extensional shear zone operated under amphibolite to greenschist facies metamorphic conditions. Statistical results show that frequency of thickness and spacing of the leucogranitoid veins/dykes conform to power-law distributions comparable to what is observed in volcanic systems. The fractal geometry of the distribution of leucogranites stress the development of a dense framework of thinner weakly or non-mineralised veins and dykes formed at higher nucleation/growth ratios in the footwall migmatite system that contrast with the emplacement of wider dykes and associated gold-mineralized veins within the shear zone. The volume of injected leucogranites veins/dykes into the Boa Fé shear zone is lower (15-20%) when compared with the footwall (35-45%), and is comparable to an expanding footwall shear zone with non-coaxial flow and volume increase.

CONSTRAINTS TO BASEMENT-INVOLVED FOLDING OF UPPER-CRUSTAL ROCKS IN THE EAST RANGE OF THE SUDBURY BASIN, ONTARIO

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Tilting of crystalline basement rocks associated with folding strain at uppermost crustal levels is difficult to recognize if basement rocks are devoid of traceable marker planes. Here we use the orientation of Paleoproterozoic Matachewan dyke segments complemented by compiled paleomagnetic data to identify tilting in Archean basement rocks associated with kilometer-scale folds of the eastern Sudbury Basin, Ontario. Spatial analysis of the strike of dyke segments is consistent with generation of the NE-lobe and a newly identified anticline, referred to as the West Bay Anticline, in the layered Sudbury Igneous Complex (SIC). This anticline accounts better for the structural characteristics of the eastern Sudbury Basin than a previously proposed anticline with west-plunging hinge line. The West Bay Anticline is characterized by abrupt plan-view thickness variations in the lower SIC and curved faults displaying significant strike separations of SIC contacts. These structural characteristics are consistent with folding strain imparted to the SIC and adjacent Archean rocks during formation of the West Bay Anticline. Sublayer embayments and associated quartz-diorite dykes served likely as zones of mechanical weaknesses, at which the higher-order folds localized. Unfolding magnitudes of the NE-lobe based on primary paleomagnetic remanence directions are significantly smaller than inferred magnitudes that are based on the assumption that the basal SIC contact was initially planar. Thus, the basal SIC contact in the NE-lobe must have had a trough-like geometry at the time of remanence acquisition. We advocate a scenario for the formation of the NE-lobe, in which the trough geometry of the SIC is primary rather than a consequence of tilting prior to solidification of, and remanence acquisition in, the SIC. Finally, we caution the interpretation of photo lineaments in eroded basement terranes purely as a consequence of planar structural elements.

A GEOLOGIST RESIDENCY PROGRAM AT THE EDGE: FOGO AND CHANGE ISLANDS, NEWFOUNDLAND

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Shorefast Foundation is a private, non-for-profit organization based on Fogo Island and Change Islands, off the northeast coast of Newfoundland.

With the people of Fogo Island and Change Islands, we are working to establish a leading geotourism destination built upon the intrinsic physical, creative and cultural assets of this elemental, powerfully remote place. We want to and we will bring together the spirit and energy of visitors and the local community to unleash the creative and economic potential of this special place.

Shorefast Foundation is supporting economic diversification through the development of world renowned geotourism products by creating a unique destination for artistic, cultural, ecological and culinary pursuits at "the edge of the earth". Our projects build on the people, culture and ecology of the islands to create a leading destination for geotourism and to build another leg to the economy of the islands.

On Fogo Island we know that the rocks watched us arrive and we don't forget that they will watch us leave – they know what came before us and they connect us to the people who came before. There are stories in the rocks. We take comfort in the knowledge that these old hills and these old rocks underlie everything.

As part of its Guest Programming, Shorefast is developing a geological outreach and education program for its guests, staff and the residents of Fogo Island and Change Islands. The principal objectives of the program are: (1) To explore the relationships between geology, landscape, culture and art; (2) To provide geological education and outreach through a series of lectures and guided tours on selected trails and shorelines; and (3) To enhance the geological knowledge of the islands and integrate that knowledge with other aspects of our natural and cultural heritage. A key component of the Shorefast Geology Program will be the establishment of a "Geologist in Residence" on Fogo Island, supported by Shorefast in partnership with geologists and professional organizations.

We believe geologists can reveal these untold stories in the rocks, through a residency program anchored on the rocks at "the edge of the earth" and we invite the geological community to partner with us in this program.

GEOLOGICAL HERITAGE, EDUCATION & ECONOMIC DEVELOPMENT

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Fortune Head ECO Friends, a not-for-profit organization, became incorporated in May of 2007 to provide advice and direction pertaining to the ongoing operations of the Fortune Head Interpretation Center located in the town of Fortune, in this Province.

Their mandate is educate and preserve the significance of the Fortune Head Ecological Reserve (located 1.6 km west of the town), which contains the Global Stratotype Section and Point from the Precambrian Era and the Cambrian period. This fossil find has been referred to as the golden spike - making it unique to the entire world because it's accessible, easy to relate to other similar sedimentary rock formations elsewhere in the world, and shows a thick, unbroken sequence of trace fossil types.

The aim of the organization is to develop and implement a strategy to ensure sustainability of the Interpretation Center that will also provide economic benefit to the region by utilizing the Reserve as a resource - an anchor! We have come to the realization in a small area of our small, yet beautiful Province that our unique and geological history can reap benefits! Its preservation and promotion through educating our youth through programs and activities, and of course engaging the general public/tourists, creates an interest to visit - extending facts in the field of geology, extending a stay in the area!

Fortune's proximity to the French Islands of Saint Pierre and Miquelon is a competitive advantage for us - with a steady stream of tourism traffic waiting to board a ferry. Many of these tourists explore the area, and acquire points of interest from the Visitor Information Desk housed in the Center.

The Town of Fortune is investing in providing wages for a full-time Business Development Officer for the Board (Center), whereby professional development opportunities are provided. These opportunities are an asset to developing quality educational programs for school groups as well as interpretation for the general public. This position also is responsible for other initiatives - package market developments, gift shop and coffee bar operations.

As we continue to support information and education programs to promote action in the field of geological heritage conservation we are encouraging an interest for visitation to these sites and are able to capitalize on lengthening the visit in the area, increasing economic development for many small businesses.

STRANGE LAKE: GEOLOGY, MINERALIZATION AND ALTERATION OF QUEST RARE MINERALS' B ZONE

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The Strange Lake alkalic complex, located along the Newfoundland and Labrador and Quebec border, hosts abundant rare earth showings, one historic non NI 43-101 resource (IOC; 52 Mt @ 1.3% TREO) and one NI 43-101 compliant resource (B Zone: @ 0.579% TREO cut-off, 140.6 Mt @ 0.933% TREO indicated; 0.579% TREO cut-off, 89.6 Mt @ 0.882% TREO inferred). The complex is compositionally zoned, with grossly concentrically distributed, progressively REE—enriched phases of granite and localized pegmatite-aplite. The B Zone, controlled 100% by Quest Rare Minerals, is located along the north western contact between the Complex and Proterozoic quartz monzonite and Archean gneiss and occurs in the carapace of the intrusion. REE mineralization is hosted in sheeted pegmatites that vary from several centimeters to over 30 metres of vertically continuous pegmatite. Interpretation suggests that the thicker sheets are continuous over more than 1000 m along strike. Within these sheets, REE-bearing minerals are commonly concentrated in late volatile-rich zones. An important aspect of mineralization at the B Zone is the high proportion of heavy REE, a feature not common to many other REE deposits. B Zone alteration is complex: major Na, Ca and Fe metasomatic events are documented overlapping each other and affecting granite and pegmatite mineralization both destructively and constructively.

Hf ISOTOPE EVOLUTION ARRAYS REVEAL THE LIMITS OF UNIFORMITARIAN PLATE TECTONIC STYLE THROUGH TIME

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Hf isotope evolution arrays revealed from zircons provide a new way to evaluate orogenic- and global-scale geodynamics, and in doing so, provide information on how far back in time "Uniformitarian Plate Tectonic Principles" can be applied. The accretionary Paleozoic Tasmanides Orogenic Zone of eastern Australia is an orogen-scale example. Two features are critical: (1) the complicated sequence of repeated extension-contraction events recorded in the tectono-stratigraphy are mimicked by the Hf isotopic (ε_{Hf}) arrays: Short periods of crustal thickening are associated with strong – ε_{Hf} excursions, and alternate with much longer periods of extension involving reversals to +ε_{Hf} values; (2) the outboard and successively younger orogens become progressively more juvenile with time, which is also reflected in the wholerock Nd isotopic evolution, and is consistent with the interpreted tectonic setting of a protracted retreating accretionary orogenic system.

The long-term (500-250 Ma) progression to more juvenile (+ε_{Hf}) values for the Tasmanides forms part of a larger dataset that encompasses the entire circumPacific orogenic system throughout the Phanerozoic (550-0Ma). Data from the Andes, New Zealand, Japan, and the former Gondwanan margin, all show a remarkably systematic contraction of the Hf isotopic array with time. It indicates the circumPacific orogenic system had Precambrian crust and subcontinental lithospheric mantle (SCLM) permanently removed from beneath nascent active plate margins that formed around the newly formed supercontinent (Gondwana) at ~500 Ma, and that the old crust was progressively replaced with juvenile crust.

By contrast, the collage of sequential Eurasian collisional orogens that young southward through Asia during the Mesozoic have a Hf isotopic array that "fans" with time, so that the ε_{Hf} range increases from ~35 epsilon units at 500 Ma to ~55 units by the Neogene. The array suggests that Precambrian SCLM was successively removed at the active margin of each orogen (during subduction), but was then replaced by similar SCLM during continental collision, as old continental crust was underthrust and remelted at the termination of each Wilson cycle.

The two contrasting Hf isotopic arrays reflect contrasting protracted (500 Ma duration) global-scale, orogenic systems that can be tracked through the Precambrian. They suggest that circumPacific-style tectonics were operating back to 2 Ga, possibly to ~ 3Ga, and that supercontinental assembly associated with Wilson-style tectonics began at least 2.2 Ga ago.

HOW DID TERRANES OF TIMANIAN, CALEDONIAN AND URALIAN AFFINITIES END UP IN THE NORTH AMERICAN CORDILLERA?

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Exotic terranes of inferred Arctic affinity form an outer belt within the North American Cordillera extending from Alaska to northern California. These include Arctic Alaska-Chukotka, Farewell, Alexander, and the Eastern Klamath and Northern Sierra terranes. The geological history, fossil and detrital zircon data for these terranes show strong correlations and linkages among them, and many features in common with the northern Caledonides, the Timanide orogen, and the Urals.

Neoproterozoic successions from a number of these terranes include early Neoproterozoic (ca. 980-920 Ma and ca. 870-850 Ma) magmatism and late Neoproterozoic arc magmatism (ca. 700-540 Ma). These contrast with the western Laurentian margin at that time, which was characterized by epeirogenic basinal sedimentation and rifting related to breakup of Rodinia, but are similar to magmatism in the north Atlantic (Valhalla) and in the Timanides of NE Baltica. In the Alexander terrane, the late Neoproterozoic arc succession is overlain by Ordovician-Silurian arc volcanics and related plutons, and Silurian-Devonian conglomerate and sandstone that are compared with Old Red Sandstone. In northern California, Ordovician-Early Devonian mélanges contain blocks of both Neoproterozoic and early Paleozoic arc magmatic rocks, Ordovician blueschist, and are associated with late Neoproterozoic and Silurian ophiolites. These features have more in common with the Caledonian-Appalachian orogen than with the early Paleozoic passive margin of western Laurentia.

Early Paleozoic faunas from most of these terranes have strong affinities to either Siberia and/or Baltica. Detrital zircon populations from early Paleozoic sandstones in these terranes commonly show a nearly continuous spread of ages between 2.0-1.0 Ga, a pattern characteristic of Baltica. Some samples display healthy populations of late Neoproterozoic (ca. 700-550 Ma) and/or Ordovician-Silurian (ca. 450-420 Ma) zircons; patterns ascribed to Timanian and Caledonian sources, respectively.

Together, these features suggest that Cordilleran terranes of inferred Arctic affinity probably occupied an intermediate position between Baltica, Laurentia and Siberia, in proximity to the northern Caledonides in Neoproterozoic-early Paleozoic time. Westward dispersion of these terranes is interpreted to result from development of a Scotia-style subduction system between Laurussia and Siberia in mid-Paleozoic time – the NW Passage – following closure of the Iapetus ocean. Diachronous Late Silurian to Early Devonian orogenic activity across Arctic Canada records passage of some of these terranes. Westward propagation of a narrow subduction zone coupled with a global change in plate motion, linked to closure of the Rheic ocean, are proposed to have led to initiation of subduction along the western margin of Laurentia.

LAKE SUPERIOR-TYPE IRON FORMATIONS IN THE LABRADOR TROUGH – AN OVERVIEW

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The Labrador Trough in western Labrador and northeastern Quebec hosts numerous world-class iron ore deposits within Paleoproterozoic (2.17 to 1.87 Ga) supacrustal rocks. These deposits have been mined since 1954, with five currently producing mines in Labrador and Quebec and a number of further projects under development. Iron ore deposits are hosted in the Sokoman Formation, a 30-170m thick sequence of cherty iron rich sediments which outcrop continuously for more than 1100km. They are classified as Lake Superior-type iron formations, which formed as a chemical sediment in shallow to deep-water environments. The Sokoman Formation is variably altered and metamorphosed, which has important implications for the economic viability of iron ore deposits.

Four main types of iron ore deposits exist within the Sokoman Formation. The most widespread are weakly metamorphosed sedimentary iron formations (~30% Fe), termed taconites. Although not presently exploited, these deposits represent very large resources of low-grade material. Metamorphosed iron formations (metataconites) are present in the southern part of the region, which was affected by Grenvillian metamorphism and deformation. Recrystallization to coarser-grained magnetite and specular hematite produces material that is higher in grade than the taconites (up to 40% Fe), and considerably easier to beneficiate. Most current iron production in the Labrador Trough comes from metataconite deposits (Carol Lake and Scully Mine in Labrador, Mont Wright and Bloom Lake in Quebec). Soft, friable, fine-grained secondary iron ores with >55% Fe, termed direct shipping ores, are found mostly in the Schefferville District. Enrichment of primary taconites is believed to be related to groundwater circulation and supergene enrichment associated with deep Mesozoic tropical weathering. Direct shipping ores mined in the Schefferville area between 1954 and 1982 amounted to 250 million tonnes, and mining operations have recently restarted. Finally, hard high-grade (~60% Fe) hematite ores have been described from several locations. These deposits are economically unimportant at present, but their origins may be important in the context of genetic models for high-grade iron ore mineralization elsewhere in the Labrador Trough.

Current research is focused on developing genetic models of iron ore deposits in the Labrador Trough, combining detailed fieldwork with geochemical techniques such as fluid inclusion microthermometry and stable isotopes. Combined hypogene-supergene models for the origins of high-grade iron ore deposits in other parts of the world such as Australia and Brazil require further investigation in the context of the Labrador Trough, and may have implication for future exploration.

TOWARDS A NEW ABSOLUTE CHRONOLOGY FOR THE EARLY SOLAR SYSTEM

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The ages of calcium-aluminum inclusions (CAIs) and chondrules underpin our understanding of the timing and nature of critical events in the first ca. 5 million years of solar system formation. We have undertaken a study to determine the Pb and U isotopic compositions of a set of CAIs and chondrules to construct a suite of robust absolute ages for the formation of these inclusions from CV meteorites. Measuring U isotopic compositions of small amount of U (<5 ng) from these inclusions has become necessary due to the recent recognition that the $^{238}U/^{235}U$ is not invariant in all meteoritic materials. Pb from each inclusion is parsed into 10 to 15 aliquots via strategic stepwise dissolution using progressively stronger acids.

One of the CAIs (22E from Efremovka) is mineralogically similar to fine-grained spinel-rich CV CAIs formed by gas-solid condensation from a gas depleted in refractory rare earth elements. As such, it is an ideal candidate to provide a benchmark age of CAI formation and, by inference, the solar system. This inclusion yields an age of 4567.34±0.27 Ma, an age that overlaps 2 other CAIs we have dated from this same meteorite. The concordance of these Pb ages for CAIs is consistent with Al-Mg data that suggest a brief episode of CAI formation. Relative to this benchmark age for our solar system (T0), we find that chondrules from the CV chondrite Allende range from as old as T0 to as young as 4564.8±0.2 Ma. The youngest chondrule age requires that the CV chondrite parent body did not accrete until 2.5 Myr after T0, consistent with the insufficient amount of ^{26}Al to cause widespread melting of the parent body by this time.

The development of U isotopic analyses for sample limited materials was the last technical step required to erect the first assumption free absolute chronometric framework for the first 5 Myr of the solar system. The emerging picture is one of discordance between ages from the U-Pb and Al-Mg systems, an observation that we attribute to an inhomogeneous distribution of ^{26}Al within the inner solar system. There is a better agreement for the Hf-W short-lived chronometer implying homogeneity of ^{182}Hf in the precursor materials to planets and planetesimals within the inner solar system.

KEEPING THE LID ON: THERMOCHRONOLOGY FROM THE MONT LAURIER TERRANE, GRENVILLE PROVINCE, QC

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Convergence during the Grenvillian accretion led to crustal thickening and juxtaposition of the currently shallow southeast-dipping imbricated terranes of the Central Metasedimentary Belt (CMB) in eastern Canada. The Mont Laurier terrane of the CMB (Quebec) is composed of a Mesoproterozoic back-arc sequence metamorphosed to upper amphibolite / granulite facies (at conditions of 6 ± 1 kbar and 650-700°C). Notable peak assemblages include Fo-bearing marbles and Sil + Kfs migmatites, with little to no retrogression. The terrane is further divided into the Marble (west) and Quartzite (east) domains, separated by the easterly dipping Heney deformation zone (HDZ). LA-ICPMS U-Pb geochronology on select migmatites from both domains yielded bimodal U-Pb zircon and monazite age populations at ca. 1230 Ma and ca. 1160 Ma, with mineral ages from the leucosomal portion of the migmatite populating the younger age population. Ar-Ar mineral analyses yielded generally well-behaved age spectra with antithetic Ca/K spectra exhibiting full or near plateaux. In proximity to the HDZ, hornblende and phlogopite ages are ca. 1145 Ma and ca. 1150 Ma, respectively, whereas to the west in the Marble Domain hornblende ages are markedly younger (ca. 970-950 Ma). Biotite ages of 905-885 Ma are similar to the majority of biotite Ar-Ar ages reported across the southern Grenville Province. The Marble and Quartzite domains record similar higher temperature U-Pb mineral ages indicating initial Elzevirian (ca. 1245-1225 Ma) metamorphism followed by Shawinigan (ca. 1190-1140 Ma) high-grade metamorphism with attendant partial melting. Rapid cooling of the Quartzite Domain at the end of the Shawinigan Orogeny together with the complete lack of evidence for any metamorphic overprinting in the Otter Lake region during the long-lived Grenville Orogeny (1095-980 Ma) is consistent with this region residing in the mid-crust, and possibly part of an "orogenic lid" (Rivers 2008, 2009). Cooling of Marble Domain rocks through 500°C nearly 200 m.y. after cooling of the Quartzite domain suggests considerable late normal displacement across the HDZ analogous to that proposed for terrane bounding shear zones like the Robertson Lake and Bancroft shear zones in Ontario, perhaps related to vertical collapse or lateral stretching of the orogenic lid. S- and Z-fold pairs and kinematic indicators in the migmatite packages are consistent with a vertical collapse model. Relatively uniform biotite Ar-Ar ages across the province suggest orogen-wide thermal stabilization at ca. 900 Ma.

THE SVECONORWEGIAN ACTIVITY IN CALEDONIAN NAPPES OF THE MIDDLE ALLOCHTHON SOUTHERN NORWAY

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The nappe stack in the southern Scandinavian Caledonides comprises thrust sheets of crystalline rocks formed predominantly between 1700 and 1500 Ma, with minor components at around 1450 and 1250-1200 Ma. They were all pervasively affected by Sveconorwegian deformation and metamorphism, and some parts also underwent Sveconorwegian magmatism. The intensity of the metamorphism varies in different segments: for example, it reached granulite facies and anatexis in the central Jotun Nappe Complex but it attained a much lower grade in peripheral trust sheets. The metamorphic activity was multiphase and in the Jotun and Lindås nappes it occurred mainly between 950 and 900 Ma. By contrast, in the Espedalen massif, and especially in parts of the Hardanger-Ryfylke Nappe Complex, there is good evidence for an episode of metamorphism at around 1000 Ma, which in the latter case also corresponds to emplacement of a major pluton. Emplacement of anorthosite in the Jotun and Lindås nappes occurred at about 970 Ma, in the latter as a component of a 40 Ma suite that includes mangerites to jotunites. Younger, ca. 960-950 Ma gabbro to tonalite occurs in the Sognefjell complex undeneath the Jotun Nappe Complex. Some of these nappes were only juxtaposed during the Caledonian events, and their distinct features point to a derivation from different crustal domains. However, their broadly similar Late Sveconorwegian history is consistent with a provenance from parts of the Sveconorwegian orogen. Important analogues in the Autochthon are the Rogaland anorthosite complex, the suites of 980 to 930 Ma granites, and the late Sveconorwegian regional metamorphism interpreted by Bingen *et al.* (2008, Norwegian Journal of Geology) to reflect final convergence (Falkenberg phase) followed by gravitational collapse (Dalane phase).

CONTRASTING STYLES BETWEEN THE TRANS-HUDSON AND GRENVILLE OROGEN: SECULAR CHANGES IN TECTONIC PROCESSES OR DIFFERENT EVOLUTIONARY PATHS?

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The Paleoproterozoic Trans-Hudson and Meso-Proterozoic Grenville orogens present quite different parameters in terms of overall crustal thickness attained, amount of crustal reactivation, levels of exhumation achieved, exhumation mechanisms, as well as type of magmatism involved. The Grenville Orogen, in particular, appears to have attained overall greater crustal thicknesses, has more abundant occurrences of exhumed eclogites and hosts large metamorphic core complexes and syn-convergent extensional faults, the latter being quite rare in the Trans-Hudson. From a magmatic perspective, the Grenville orogen hosts unique anorthosite-mangerite-charnockite-granite (AMCG) complexes, which have no know equivalents in the Trans-Hudson orogen except perhaps for minor occurrences of anorthosite, gabbro and related anhydrous granitoid rocks in the Snowbird Tectonic Zone. A valid question to ask is whether these differences are the product of secular changes in tectonic processes between ca 1.90 and 1.11 Ga or simply reflect different parameters affecting both orogens such as duration of convergence, rate of convergence, heat flow, lithosphere thickness, the size and shape of colliding blocks, pre-collisional accretionary tectonics, etc. The similarities observed in accretionary and tectonic processes between the Trans-Hudson and more modern examples (e.g., parts of the Appalachian or Himalayan systems) is striking, suggesting that tectonic processes 1.9 Ga ago were likely more similar than different, to those observed today. This cast doubts in explaining the broad contrasts observed between Trans-Hudson and Grenville orogens in terms of significant changes in tectonic processes through time, and points instead towards more mundane explanations such as variations in specific parameters during orogenesis, with the most important one perhaps being the duration of continent-continent convergence.

SCANNING THE BARCODE USING GEOCHEMISTRY: SUPER-CONTINENT RECONSTRUCTION BACK TO 2.7 Ga FROM LARGE IGNEOUS PROVINCES

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Over the past decade there have been advances in understanding of the geochronological links between igneous rock units on various continents. This “bar coding” of dyke swarms and other parts of large igneous provinces (LIPs) has allowed greater precision in continental reconstructions utilizing the model of mantle plumes and radiating dyke swarms related to continental breakup. As part of the project “Reconstruction of Supercontinents Back to 2.7 Ga Using the Large Igneous Province Record” (industry, university, government consortium; www.supercontinent.org) we are focusing on the geochemistry of LIPs fragmented by plate tectonics. Magmatism from all parts of a single event should be related petrologically, and may share similar mantle source compositions, a differentiation history that varies with distance from proposed plume centres, and a crustal interaction history that varies depending on the age/composition of the intruded crustal block. Several M.Sc. and Ph.D.-level projects are planned. First is the Gunbarrel event, a ca. 780 Ma series of sills and dykes that are exposed from the Slave craton south to the Wyoming craton and is associated with the breakup of Rodinia (Sandeman *et al.*, this meeting). A second project involves globally-distributed magmatism at 1380 Ma recognized in western Laurentia, northern Greenland, the Anabar Shield of Siberia, southeastern Baltica (the southern Urals), Antarctica, the Congo and southern Kalahari craton.

These widespread 1380 Ma extensional magmatic events may mark the final breakup of the Mesoproterozoic supercontinent Nuna (aka Columbia). A third geochemical target is 1890-1870 Ma, mainly mafic magmatism across the Slave craton and its marginal platformal sequences, coeval with the final docking of the Hottah terrrane with the Slave craton. An integrated geochemical and isotopic comparison of all these units with respect to their position and distribution across the Slave craton will investigate the number and distribution of magmatic sources, the extent of lithospheric contamination, and the degree to which subduction related vs. plume and asthenospheric sources were involved. In addition, we plan to investigate the geochemical relationships between the ca. 1.1 Ga magmatism of the Midcontinent Rift of North America (Hollings *et al.*, this meeting) the Umkondo igneous province of the Kalahari craton and other locations. Another focus will be ca. 1750 Ma LIP magmatism now recognized in Canada, Siberia, Baltica and elsewhere. Ongoing projects include circum-Superior province magmatism at 1880 Ma and Matachewan (ca. 2.45-2.49 Ga) events in the Wyoming and Superior cratons and comparison with other regions with matching LIP ages.

SULFUR ISOTOPES REVEAL THAT PEAK OF DECCAN VOLCANISM POST-DATES THE CRETACEOUS-PALEOGENE MASS EXTINCTION

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The Cretaceous-Paleogene (KPg) boundary marks one of the most significant mass extinctions in Earth history, leaving an evolutionary imprint that can be still be seen in the modern biota. The leading hypothesis attributes the extinctions to a bolide impact with sulfate-rich rocks in the Yucatán Peninsula, Mexico. The major competing hypothesis is the emplacement of the Deccan continental flood basalts in western India. Both processes would have released massive amounts of sulfur in the atmosphere. Absolute age measurements for the largest Deccan eruptions and the KPg boundary suggest the two events were contemporaneous, but measurement uncertainties have so far thwarted attempts at resolving the relative timing of these two competing extinction triggers.

We measured whole-rock sulfur content and isotopic composition ($\delta^{34}S$) at a resolution of 2 cm or less across the KPg boundary at the Knudsen's Coulee Section (KCS), near Drumheller, Alberta, Canada. The KCS is among the most complete and best-preserved terrestrial KPg sections in the world and features many key markers, including the boundary claystone, an iridium anomaly, and a fern-spore spike.

Our high-resolution study shows positively-correlated variations in both signals, consistent with sulfur addition to an initially sulfur-poor terrestrial environment. Profile modeling using simple Gaussian functions shows that addition of ^{34}S enriched sulfur to the KCS occurred in three pulses: a pair of overlapping pulses originating at the KPg boundary (one intense pulse restricted to the first ≈2 cm above the boundary, and a second, more moderate, extending over ≈9 cm), and a third pulse, ≈11 27 cm above the boundary. Mixing curves show the ^{34}S enriched sulfur is derived from two distinct sources. Measurements associated with the brief and intense pulse fall on a high $\delta^{34}S$ ($\delta^{34}S$≈18‰) curve, comparable to target rocks, while those associated with the broader pulses fall on a lower $\delta^{34}S$ ($\delta^{34}S$≈8‰) curve, comparable to sulfate aerosols from oxidized volcanogenic SO_2.

The environmental scenario we propose places the onset – not the end, or peak – of a major Deccan eruptive phase, lasting ≈90 kyrs, at the KPg boundary, contemporaneous with a bolide impact. A subsequent eruptive phase started ≈120 kyrs post-impact, and lasted for ≈90 kyrs. The ratio of volcanogenic- to impact-derived sulfur at the KCS is ≈5:1, consistent with independent published estimates of 3:1 to 88:1. Although Deccan eruptions may have delayed the recovery of both marine and terrestrial ecosystems after the KPg extinctions, our results highlight the bolide impact as the primary extinction trigger.

DISTAL EXPRESSIONS OF MINERALIZING SYSTEMS: MAPPING THE THERMAL FOOTPRINTS OF CARLIN-TYPE AU SYSTEMS USING APATITE FISSION TRACK, APATITE (U-Th)/He AND ZIRCON (U-Th)/He DATING

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Targeting Carlin-type Au deposits in northern central Nevada is hindered by a lack of extensive pervasive visual alteration and the disseminated nature and submicron scale of Au mineralization. New methods for better defining the expressions of these hydrothermal systems are needed to aid future exploration for mineral deposits. Heat associated with hydrothermal systems is transferred advectively within the fluid flow path as well as conductively beyond the limit of hydrothermal fluid flow. The conductive thermal halo should be the most distal expression of hydrothermal fluid flow as it will extend beyond the front of fluid-rock interaction necessary for mineralogical and geochemical alteration.

Low temperature thermochronology provides one possible means for mapping out the thermal halo of hydrothermal fluid flow. Here we present apatite fission track and apatite and zircon (U-Th)/He data used to map low-temperature thermal anomalies associated with the mineralizing hydrothermal fluid flow event, defining the limit of heat flow associated with the formation of Carlin-type Au deposits in the northern Carlin Trend. Thermal resetting of apatite fission track ages was observed up to 800 m from mineralization in granodiorite. In surrounding host sediments, however, the complexity of structural and stratigraphic controls and resulting fluid flow network makes a distinct thermal footprint more difficult to define, although a similar sized expression is inferred.

LATE CRETACEOUS EXHUMATION IN NORTHERN CENTRAL NEVADA: EVIDENCE FROM LOW-TEMPERATURE APATITE AND ZIRCON (U-Th)/He AND APATITE FISSION TRACK THERMOCHRONOLOGY

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The western Cordillera of North America at the latitude of northern Nevada has a long history of contraction and crustal thickening through the Late Paleozoic and Mesozoic, culminated in the Late Cretaceous Sevier and Cretaceous to Eocene Laramide thrusting in Utah, Wyoming and Colorado region. Mesozoic shortening was responsible for the thickened crust that ultimately formed the Rocky Mountain ranges that run the length of the North American Cordillera.

We present apatite fission track, apatite (U-Th)/He and zircon (U-Th)/He thermochronology data from vertical deep drill holes in Jurassic stocks from the northern Carlin Trend in north central Nevada. This data shows unequivocal evidence for rapid cooling and exhumation of the this region of the Sevier hinterland in the Late Cretaceous between 80-60 Ma. Total exhumation since the emplacement of the stocks at 158 Ma is estimated at 3-3.5 km. Calculated exhumation rates varied from ~0.01 km/Myr pre- and post- 80-60 Ma cooling to 0.1-0.2 km/Myr during the main period of exhumation.

The Mesozoic evolution of the region influenced ongoing development of topography through the Cenozoic in this part of the Cordillera. Previous workers have proposed that the latest stage of the Sevier thrusting was coincident with crustal thinning and collapse of an overthickened hinterland in Nevada. They cite evidence for mid crustal depressurization and cooling, but note little evidence for surface breaking faults and erosional exhumation. No major low angle faults are known within the study area, precluding tectonic exhumation as a likely cause of the rapid cooling. Instead, erosion is considered most likely cause of exhumation. Although there are no known sedimentary basins of that age in north central Nevada, large drainage systems identified to the far west and east of the hinterland may have transported sediments to more distal

depocentres. Evidence for Late Cretaceous sedimentary input into the Cretaceous to Eocene Sheep Pass Formation in central east Nevada suggests that there was also internal drainage within the Sevier hinterland.

MULTI-ELEMENT HISTOLOGICAL ANALYSIS OF AN ORNITHOMIMID (DINOSAURIA) BONE BED FROM THE UPPER CRETACEOUS HORSESHOE CANYON FORMATION (MAASTRICHTIAN) OF ALBERTA

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Bone beds and bone microstructure can each provide important data from which hypotheses regarding ontogeny, metabolism, ecology, and behaviours of ancient vertebrates can be established. Ornithomimids (or 'ostrich dinosaurs') were a group of small, gracile theropods found throughout the Cretaceous of North America and Asia. Multiple hind limb elements (femora, fibulae, tibiae, metatarsals) from three individuals from the first North American bone bed of late Cretaceous ornithomimids were examined histologically. Each specimen showed fibrolamellar tissue, near-equal spacing of lines of arrested growth (LAGs), and osteon development at outer bone margins, indicating that they were experiencing rapid growth at death. However, this rate was somewhat reduced in the largest individual, possibly indicating the onset of maturation. The two smaller individuals were determined to be two and three years of age at death, while the approximately 10% larger individual was found to be four years old at the time of death. This pattern is similar to that reported for other theropods, but it is potentially different from Asian ornithomimids in showing evidence of growth reduction at a much earlier age. These differences could be related to predator-prey relationships, and could affect our interpretations of the ecology of the late Cretaceous dinosaur communities of western Canada.

Of note is that LAGs and other histological signals remain consistent across the different hind limb elements examined within individuals. This indicates that for at least some small theropods, age at death can reliably be determined from various postcranial long bones. This has the potential to significantly increase the database available for determining growth patterns within various taxa, because isolated limb elements can be used as long as body size at the time of death can be determined.

TECTONICS OF POLYCYCLIC GNEISS DOMAINS OF THE CENTRAL GNEISS BELT (CGB), GRENVILLE PROVINCE, ONTARIO

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An extensive substrate of, thrust-stacked and polycyclic, Laurentian margin domains underlies much of the CGB. In the northern CGB the Britt and Powassan domains comprise polycyclic Paleo- and Mesoproterozoic orthogneiss metamorphosed at ca 1450 Ma and intruded by monocyclic plutons. In the eastern CGB, thrust contacts between polycyclic gneiss sheets are widely exposed in the Algonquin domain but are obscured in the western CGB by overlying monocyclic units.

At their northwestern boundary the imbricated polycyclic domains (Britt and Powassan) overlie a belt of polycyclic but structurally distinct units (Grenville Front Tectonic Zone and Nepewassi domain, GFTZ-ND) which abut the Grenville Front. The south eastern boundary of the GFTZ-ND is irregular with NNW and ENE stair-stepping segments separating the Archean-cored ND from Britt. Late NW motion of the Britt domain across and along this boundary has varied effects. Transpressive overprinting is restricted to the margins of the GFTZ but Nepewassi domain response is more widespread with formation of large scale refolds and shear zones within its interior. NNW sectors of the ND-Britt boundary are strongly sheared.

A current model of CGB tectonics invokes early thickening followed by lower crustal nappe flow allowed by melt-softening in monocyclic rocks. Historically, the structural, metamorphic and geochronological evidence supporting this model is from the western CGB where monocyclic domains dominate. New, and sparse older, geochronological data from the Algonquin domain match key age groupings from the western CGB and together with structural and metamorphic data support a nappe flow model for the polycyclic substrate.

Several intriguing questions remain: are similar processes responsible for producing retrograde eclogites, locally accompanied by anorthosite gneiss, within the polyclic domains (and along polycyclic-monocyclic boundaries) and early tectonic interleaving of monocyclic upper crust (basal Parry Sound domain back-arc deposits) with lower crust (anorthosite gneiss)? Is this process attempted subduction (of, respectively, the Laurentian margin and back-arc lithosphere) or simply related to Himalayan scale thickening?

ANOXIA IN THE TERRESTRIAL ENVIRONMENT DURING THE LATE MESOPROTEROZOIC

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The 1.1 Ga intracratonic Mid-Continent Rift System of central North America reached >2000 km in length prior to rift failure due to the onset of the Grenvillian orogeny. In the Lake Superior region up to 30 km of volcanic and sedimentary rift-fill sequences make up the Keweenawan Supergroup. This succession provides one of the few comprehensive records of early rifting processes. It consists of 20 km of predominantly flood basalts that are overlain by post-rift fluvial and alluvial red beds of the Oronto and Bayfield Groups. The Oronto Group consists of fluvial and alluvial volcaniclastics with one exception; the Nonesuch Formation, a 200 m thick lens of organic-rich grey to black siltstones and shales. Depositional characteristics of the Nonesuch Formation suggest that it was deposited in a restricted lacustrine setting; however, evidence from biomarkers has also suggested that there may have been a marine incursion during Nonesuch deposition.

Organic-rich rocks are important biogeochemical records of surrounding geological and climatic processes, with lacustrine systems in particular providing very high resolution archives. Geochronology of the post-rift sedimentary units is poorly constrained. U-Pb zircon dates constrain the rift-related volcanic units within the lower Copper Harbour Conglomerate (underlying the Nonesuch Formation) at 1087 Ma, thus marking the end of volcanic rift deposition. Here we present new Re-Os geochronology that provides a depositional age for the Nonesuch Formation which is in stratigraphic agreement with the underlying 1087 Ma volcanics of the Copper Harbour Conglomerate. Additionally, Os isotope compositions provide a new line of evidence which strongly suggests that these deposits are truly lacustrine in origin.

Continental paleoenvironmental conditions in the Late Mesoproterozoic are poorly understood. The geochemical signature recorded in the Nonesuch Formation gives an insight into these conditions and the redox chemistry of lake systems at this time. Iron speciation data for 45 Nonesuch Formation samples from core PI-1 show that anoxic ferruginous conditions dominated in this lake system. This is contrary to previous studies which suggested a euxinic depositional setting. These data have implications for the habitats of early eukaryotes and suggest that the terrestrial environment, similar to the oceans, was dominantly anoxic and ferruginous at this time. This contrasts with a recent suggestion that oxygenation of terrestrial aquatic environments preceded oxygenation of the marine realm.

GEOLOGY AND GEOCHEMISTRY OF THE COUBRAN LAKE BASALTS, A MIDCONTINENT RIFT-RELATED SEQUENCE WITHIN THE CENTRAL COLDWELL COMPLEX, MARATHON, ONTARIO

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The Coubran Lake Basalts occur as part of a large, preserved roof pendant of volcanic rocks in the center of the ~28 km diameter Mesoproterozoic Midcontinent Rift-related, alkalic Coldwell intrusive complex near Marathon, on the northern shore of Lake Superior. In one location, basalt is exposed along a thin (3 to 5 m wide), ~350 m long stripped area. Thin (~2 m), amygdaloidal flows appear to be draped over the side of a hill and exhibit ropy flow tops, suggesting subaerial emplacement. The volcanic pile is estimated to comprise five or six individual flows at this locality. The basalts are locally hornfelsed, altered and are intruded by syenite dykes. They likely predate the main phase of syenitic magmatism that produced the central part of the intrusive complex.

Geochemically, the unit comprises two groups (types A and B) distinguished by their incompatible element abundances. Basalt type A dominates the succession and displays light rare-earth element (LREE) enrichment (La/Sm_n = 1.99 to 4.76) and heavy rare-earth element (HREE) fractionation (Gd/Yb_n = 1.96 to 2.30). Basalt type B lies towards the base of the unit, forming the lowermost 10% of the exposed sequence and displays strong LREE enrichment (La/Sm_n = 7.44 to 9.32) with HREE ratios comparable to that of type A (Gd/Yb_n = 2.48 to 2.52). Major element chemistry for both groups displays very little variation, with SiO_2 values ranging from 49.33 to 51.98 wt%, TiO_2 values ranging from 0.78 to 0.99 wt%, and MgO ranging from 4.77 to 7.34 wt%.

Midcontinent Rift-related volcanic rocks have been classified and correlated as five distinct groups (basalt types I through V) based on their major element, trace element and Nd isotopic analyses. Basalt type II represents a reversely polarized group of volcanic rocks deposited during the first phase of magmatism (>1105 Ma). They are characterized by LREE enrichment, HREE fractionation, as well as a negative niobium anomaly. Primitive mantle-normalized diagrams show the Coubran Lake Basalts to be similar to basalt type II, which includes the upper Siemens Creek Volcanics, the central suite of the Osler Group and the recently recognized Devon Volcanics. Further correlative work, including radiogenic isotope analysis and paleomagnetism, is ongoing in order to place the Coubran Lake Basalts in context with other Midcontinent Rift-related volcanic units.

STRUCTURAL STYLE AND THERMAL HISTORY OF THE EASTERN LANCASTER SOUND AND BYLOT ISLAND AREA, NU

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Understanding the structural style and thermal history of the Lancaster Sound-Baffin Bay area is critical for assessing its hydrocarbon potential, which is considered significant, and reducing exploration risk. Contributions to the Baffin Bay Basins project of the GEM-Energy program, including thermal modelling of new Apatite Fission Track data, reinterpreted marine seismic data, primarily from the 1970's, and interpretation of more recent sub-bottom profile and bathymetry data, indicate that crystalline basement in this area is dominantly affected by northwest- and east-striking normal faults. These faults form the bounding structures of an array of horsts and grabens, most of which lie beneath Lancaster Sound and are inaccessible.

One graben, the Eclipse Trough, and its more mountainous bounding horsts (Navy Board High to the southwest, Central Bylot High to the northeast), together with another graben, the North Bylot Trough, and the Liverpool High (farther northeast), are partially exposed on Bylot Island and northeastern Baffin Island. The "Highs" currently form part of the uplifted rim of northwestern Baffin Bay.

Apatite fission track results from the Archean crystalline basement underlying Cretaceous to Tertiary sediments of the Eclipse Trough yielded Early Paleozoic cooling ages suggesting that apatite fission tracks were not completely re-set during the Mesozoic or Tertiary burial. This finding is consistent with the low thermal maturity of the overlying sediments (vitrinite reflectance <0.5% Ro). In contrast, thermal modelling of apatite fission track data for crystalline basement rocks from the adjacent horsts suggests Jurassic to early Cretaceous cooling, followed by Late Jurassic to Early Cretaceous heating (likely due to burial) and Late Cretaceous to Cenozoic cooling. This thermal history is consistent with the conclusion from a provenance study that indicates that Central Bylot High separated North Bylot Trough from Eclipse Trough as early as Maastrichtian time. Latest Cretaceous to Paleocene cooling of the Central Bylot and Liverpool highs was largely due to denudation, as evidenced by the predominantly locally derived sediments found in North Bylot Trough.

PROVENANCE OF CRETACEOUS AND TERTIARY SEDIMENTS, BYLOT ISLAND, NU

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The undeveloped Lancaster Sound-Baffin Bay area is considered to have significant petroleum potential, making it a focus of the Baffin Bay Basins project of the Geological Survey of Canada's GEM-Energy program. Understanding its Mesozoic and Cenozoic depositional history is critical for assessing hydrocarbon potential and reducing exploration risk. Sedimentary rocks of Eclipse Trough (west Bylot Island, northern Baffin Island) and North Bylot Trough (central northern Bylot Island) provide the most complete accessible record of Late Cretaceous to Paleocene fluvial-deltaic sedimentation in the western Baffin Bay area. New detrital zircon U-Pb SHRIMP ages, palynology, and detrital rutile geochemistry for Cretaceous and Paleocene samples from Bylot Island indicate a change in provenance, and progression to distinct source areas for Eclipse and North Bylot troughs as early as the Maastrichtian.

U-Pb detrital zircon age distributions for the Sirmilik formation of Eclipse and North Bylot troughs (informal; Upper Cretaceous) are similar to those of the Proterozoic of Borden Basin, middle Albian to possible Turonian Hassel Formation-equivalent rocks of Eclipse Trough, and Paleocene rocks of North Bylot Trough. These distributions contrast with those of Paleocene strata of Eclipse Trough, which include Silurian to Devonian zircons, indicating a change in provenance, and presumably depositional patterns for Eclipse Trough.

The abundance of Proterozoic? Leiosphaeridia in the lower Upper Maastrichtian and Paleocene of the North Bylot Trough contrasts with their very limited occurrence in coeval strata of similar facies from the Eclipse Trough.

Geochemistry for rutile grains from Hassel Formation-equivalent and Sirmilik formation samples from Eclipse Trough indicates they were in part derived from lower amphibolite- and greenschist-facies rocks, consistent with a distant or recycled source, as rocks of this metamorphic grade have not been exposed in this area since before Paleozoic (possibly Mesoproterozoic) time. Rutile geochemistry for Paleocene rocks of North Bylot Trough is indicative of upper amphibolite to granulite grade source(s), and consistent with a local provenance.

STRATIGRAPHIC ORIGIN OF MARINE VERTEBRATES FROM THE LOWER-MIDDLE TRIASSIC SULPHUR MOUNTAIN FORMATION, BRITISH COLUMBIA

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The Sulphur Mountain Formation (SMF) of east-central British Columbia is highly significant in terms of its abundance and variety of Early Triassic marine vertebrates. However, most strata of the SMF have been tilted to near-vertical and typically weather to produce steep talus slopes. Consequently, loss of stratigraphic context is a serious problem.

Two detailed stratigraphic sections were measured approximately 30 km southwest of Tumbler Ridge, B.C. Rock samples were collected from the three members of the SMF that outcrop in this area: the Vega-Phroso Siltstone Member (VPSM), the Whistler Member (WM), and the Llama Member (LM). Based on field and laboratory observations, the VPSM is dominated by siltstone, shale and silty shale; the fresh surface is nearly always dark grey to greyish black, whereas the weathered surface is dominantly moderate to dark yellowish brown; calcite ranges from 13-30%, quartz from 5-15%, and muscovite from 1-5%; and most siltstone samples have thinly spaced parallel laminations. The WM contains both carbonate rocks and siltstones; the fresh surface colour is nearly always greyish black, whereas the weathered surface may look mottled and can range from yellowish brown to dark grey to olive black to brownish black; calcite is dominant and typically makes up over 50% of the rock; wavy laminations are characteristic; and several samples contain ammonite impressions. The LM is dominated by siltstone, with subordinate shale and sandstone; the fresh surface colour is variable, whereas weathered colour is generally mottled light yellowish brown to olive grey; mineralogy is highly variable, with calcite ranging from 17-30%, quartz from 6-25%, and muscovite from 1-2%; samples are either non-laminated, or have thin, indistinct parallel laminations.

The rock matrices of 20 marine vertebrate specimens previously collected from the SMF were compared to the generalized geologic characteristics noted above. Results indicate that 12 samples originate from the VPSM, 3 from the WM, and 5 from the LM. Based on this hypothesis of stratigraphic placement, early ichthyosaur taxa separate out stratigraphically, with *Utatsusaurus*, *Chaohusaurus*, and *Grippia* cf. *longirostris* restricted to the VPSM, and *Phalarodon* restricted to the LM. The hypothesis presented here agrees with all instances in which the known stratigraphic origin of these specimens had been previously documented. However, in order to develop an understanding of the early radiation patterns of the group, further work is necessary to achieve the stratigraphic precision necessary to assess the relative ages of ichthyosaurs collected from the SMF.

ORPHAN BASIN, OFFSHORE NORTHEAST NEWFOUNDLAND: UNRAVELING THE DEPOSITIONAL HISTORY IN A FRONTIER BASIN

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Based on its proximity to the petroleum-rich Jeanne d'Arc Basin, the minimally explored Orphan Basin to the northeast is becoming an enticing area for oil companies focused on discovering oil and natural gas in offshore eastern Canada. Growing interest in Orphan Basin stems from an unusually attenuated continental crust, deep basin fill, and possible correlations to the lithostratigraphy of neighboring basins. In our study, we aim to unravel the depositional history of Orphan Basin and build linkages to the source-rock-bearing Jeanne d'Arc and Flemish Pass basins by integrating core and cuttings information with biostratigraphy, lithostratigraphy, and seismic interpretations.

Our initial core analyses from the northern Jeanne d'Arc and Flemish Pass basins, denote a depositional change from restricted marine in the ?Middle to Late Jurassic to open marine beginning in the latest Jurassic and continuing through the Tertiary. During times of restricted marine deposition, 100s of metres of sediment accumulated in nearshore settings in the rapidly forming accommodation space. Conversely, open marine units encompass heavily bioturbated strata, reflecting continuous outer shelf to shoreface deposition. This prominent shift from restricted- to open-marine deposition can be attributed to rifting and subsequent drifting between the Grand Banks and Iberia, which opened the area to fully marine conditions as rifting of the North Atlantic propagated northwards. Well-log data from the neighboring basins suggests a similar environmental shift occurred, at least in part, within Orphan Basin. Log characteristics of the lower interval in the Great Barasway F-66 well (located in central Orphan Basin) may indicate a similar Late Jurassic restricted marine package, which we will attempt to confirm through palynological analyses.

One of the major discrepancies between Orphan Basin and Jeanne d'Arc Basin lithostratigraphy is the generally thin nature of Cretaceous and lower Tertiary packages bounded by unconformities. Lack of accommodation space at this time suggests that the basin did not undergo major subsidence to establish bathyal conditions until the middle Paleogene. Nonetheless, the thin Cretaceous packages such as progradational shoreface sands and distal shelf limestones are comparable to those of the Jeanne d'Arc Basin. However, thicker shoreface sandstones are generally confined to wells found in proximity to the Bonavista Platform (a prominent sediment source), whereas the central Orphan Basin is typified by shelfal shales. Our preliminary results above and our planned integrated studies should provide a more comprehensive understanding of the evolution and petroleum potential of Orphan Basin.

ALTERATION MINERALS AND ELEMENTAL ASSEMBLAGES AROUND THE PHOENIX URANIUM DEPOSIT, ATHABASCA BASIN, SASKATCHEWAN

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The Wheeler River Property, host of Denison Mine's Phoenix Uranium Deposit, is situated near the southeastern rim of the Athabasca Basin in northern Saskatchewan. Discovered in 2008, the deposit currently has resources of 39,449,000 million lbs. U_3O_8. The Phoenix Deposit occurs at a depth of approximately 400 m. It occurs both along a shear zone and the unconformity between Athabasca sandstones and the underlying Archaean to Paleoproterzoic metamorphic rocks. The shear structure is named the 'WS shear', which occurs along the boundary between a graphitic pelite and a garnetiferous pelite in the basement and cuts through the overlying Athabasca sandstones. Rocks near the shear structure and the unconformity are commonly altered to form disseminated, very fine-grained secondary minerals.

Bulk rock compositions of drill core were determined at 10 m intervals, comprising of a dataset of over 6700 rock samples. The geostatistical analysis of the data was linked with the mineralogical-petrological observations of samples using a petrographic microscope, SEM, EPMA, XRD and TerraSpec®. The results of the rocks along the shear zone show that the alteration in the basement is characterized by the coeval formation of sulphide (pyrite and chalcopyrite) and dravitic tourmaline. It is accompanied by intensive alteration of kaolinite and illite. The alteration along the shear zone in the sandstones is represented by the formation of kaolinite-group minerals, illite, and dravitic tourmaline. The concentration of U is positively correlated with As, W and Mo but not with S, K, Al, and B within the shear zone. Therefore the introduction of U into the 'graphitic conductor' appears to have taken place as a separate event, most likely after the pervasive alteration.

EXPERIMENTAL FORMATION OF A MICROBIAL DEATH MASK

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This study represents a first attempt to observe soft-tissue decay in association with microbial mats, in order to recreate the 'death mask' model proposed for terminal Neoproterozoic lagerstätte. This model explains the precipitation of authigenic iron sulfide minerals on, and around, decaying carcasses in association with microbial mats, cementing the sediment as a sole veneer and retaining the external morphology of the organism in relief on the upper and lower surface of coarse-grained sandy event beds. Although this model has been substantiated by the discovery of abundant, microbially-induced sedimentary structures (MISS) and pyrite veneers, in close association with Ediacaran fossils, it has not been tested previously by experimental taphonomic studies under controlled laboratory conditions. Arthropod larvae that decayed on top of a cyanobacterial mat demonstrated higher quality preservation of fine-scale anatomy than larvae that decayed in the absence of a mat. Decay experiments involving

bacterial mats and organic-rich sands generated a black ring extending radially from the decaying carcasses. When this precipitate was analyzed using XPS and ESEM-EDS it revealed the presence of likely iron sulfides, or at least spatially associated Fe and S, and localized concentrations of common aluminosilicate elements (Al, K, Fe and Mg) which is a composition that has been documented in association with Ediacaran fossil preservation.

APPLICATION OF NEW MULTI-RESOLUTION TRANSFORMS APPLIED TO WELL LOG DATA ANALYSIS

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The aim of static reservoir characterization is to produce models in particular of the spatial distribution of certain physical properties of rocks and of the contained fluids, constituting a given reservoir. The representative model is a product of multidisciplinary studies which are related to different types of geological, geophysical data and new mathematical methods. In this paper, we first present an overview of emerging applications of wavelet transform in analyzing well log data and it's still active research topics employing wavelet transform framework. Then, we present an overview of emerging signal processing techniques which can be employed in reservoir characterization and well log data analysis. It is shown that both discrete and continuous wavelet transform is successfully implemented in analysis of spatial series of petrophysical well logs. The engineering details of wavelet, cross-wavelet and curvelet transform implementation for these data are provided for further studies. We expect a flurry of new research and technology development activities in the coming years utilizing still promising and almost untapped analog wavelet transform and multi-resolution signal representation techniques.

Well logs of a large number of oil and gas wells in southern Iran were used to demonstrate the applicability of wavelet and curvelet transformations in denoising of well logs, identifying geological boundaries, wellbore fractures and Milankovitch cycles. Correlation and crass-correlations, fractality and multifractality of these data unrevealed using these methods.

AGE OF DIAGENETIC APATITE CEMENTS FROM THE UNCONFORMITY-TYPE BOOMERANG LAKE URANIUM OCCURRENCE, PALEOPROTEROZOIC THELON BASIN, NUNAVUT

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Fluorapatite is a locally common diagenetic mineral within siliciclastic strata of the Paleoproterozoic Thelon Basin. It occurs both as pore-filling cements and as fracture-filling veins. Boomerang Lake is an unconformity-type uranium prospect at the southwestern margin of the Thelon Basin. The uranium mineralization occurs in association with, but post-dates, early pore-filling apatite cement within the host Thelon Formation sandstone. The interstitial apatite cement at Boomerang Lake is moderately enriched in U and has very low Th contents. In situ SHRIMP U-Pb analyses yield a relatively imprecise age of 1688 ± 14 Ma (MSWD = 1.3; n=38) for interstitial apatite cement from a drill core sample previously described by Davidson and Gandhi. Uranium mineralization at Boomerang Lake is in the form of tristramite ($Ca_{0.6}U_{0.3}Fe^{3+}_{0.1}(PO_4)_{0.75}(SO_4)_{0.25}$-$2(H_2O)$, a rhabdophane group mineral. Crystallization of tristramite post-dates, and involves partial resorption of the interstitial apatite cement. The apatite age therefore provides a maximum age for the uranium mineralization. The occurrence of tristramite at Boomerang Lake may in part reflect reaction of uranium-bearing fluids with the earlier diagenetic apatite cements. The age determined for apatite cement at Boomerang Lake is slightly older than the 1667 ± 7 Ma age reported for apatite from several localities in the northeastern part of the Thelon Basin, approximately 300 km northeast of Boomerang Lake. This apparent difference in age may suggest regional differences in the timing of apatite cement formation within widely separated parts of the basin. Although high in U, the diagenetic apatites in the northeastern part of the basin have distinctively low concentrations of most other trace elements including REE and Th. Total REE contents are one or two orders of magnitude lower than is typical in crustal apatites. The very low REE and Th content of the fluorapatite may reflect low concentrations of these elements in the diagenetic fluids and/or their partitioning into other diagenetic phases such as aluminum-phosphate-sulfate (APS) minerals.

MAGNETITE IN HYDROTHERMAL ALTERATION ASSOCIATED TO IRON OXIDE-COPPER-GOLD SYSTEMS IN THE GREAT BEAR MAGMATIC ZONE, CANADA

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Magnetite is a minor to major constituent of veins, breccias and incipient to intense alteration in iron oxide-copper gold systems of the Great Bear magmatic zone, Northwest Territories. Prevalence of magnetite in most of the known IOCG systems makes it a key mineral to understand and monitor their evolution and development. Multiple magnetite paragenesis associated with numerous textures are observed in these magmatic/hydrothermal systems. The macroscopic and microscopic observation of magnetite-bearing paragenesis is used to understand the processes that have generated the spectrum of textures observed. Mineral assemblages and associated textures can be used as exploration vectors to mineralized zones so distinctions between different paragenesis are essential in the comprehension of IOCG systems. To show the numerous aspects that can exhibit magnetite-associated alteration, a protocol for regional to megascopic description of replacements, veins and breccias has been developed to facilitate the description of these rocks in the field and subsequently on stained and unstained rock slabs and thin sections.

Prevailing paragenesis consists of 1) magnetite (Fe alteration), 2) amphibole-magnetite ± apatite ± albite (high temperature Ca-Fe±Na alteration), 3) K-feldspar-magnetite ± biotite or biotite-magnetite(high temperature K-Fe alteration), with common overprint by hematite. Magnetite replacement is preferentially formed around phenocrysts, within vesicules, in groundmass, or replaces fragments in breccias. These habits suggest that magnetite replacement forms where fluids circulate through porous and permeable rocks and/or minerals. In bedded or layered rocks, magnetite alteration can form selective stratabound replacements of specific horizons. Magnetite also crystallize as breccia cement or fill veins. High temperature K-Fe alteration crystallizes magnetite with K-feldspar in felsic and intermediate igneous rocks, and biotite in siliciclastic sedimentary rocks and mafic rocks. In potassic-altered porphyritic volcanic rocks, K-feldspar first replaces the groundmass and then the phenocrysts with increasing alteration intensity whereas biotite replaces selectively pre-existing amphiboles. Replacements and veins of transitional high temperature Ca-K-Fe and subsequent high temperature K-Fe alteration are commonly followed by the mineralization stage, in which a wide variety of metal can be concentrated (e.g. Cu, Au, Ag, Bi, Co, etc.). Each type of paragenesis and textures exert a control on the aspect that will take subsequent alteration. As an example, amphibole-magnetite veins preferentially cross-cut albitized zone at the expense of the unaltered volcanic rocks. Ultimately, the main objective of the project is to produce an atlas of alteration associated to IOCG that will provide exploration tools and a framework for geologists during the exploration of under-explored terranes.

GEOLOGICAL REVISION AND LITHO-STRATIGRAPHY OF THE MATAGAMI (VMS) MINING CAMP

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The Matagami mining camp is located in the north-western part of the Archean Abitibi Greenstone Belt in Quebec, Canada. Some 19 zinc-rich

VMS deposits are currently recognized (production since 1960: 4.6 Mt Zn; 0.494 Mt Cu). Known mineralization occurs along three felsic bands: the historical South Flank and North Flank of the stratified Bell River Complex anorthositic intrusion, and the West Camp. The geology is composed of a bimodal volcanic sequence and the stratigraphy is subdivided in two major groups: the Watson Group, including mostly felsic rocks, overlaid by the Wabassee Group, composed principally of mafic rocks, with some localized felsic units. The groups are separated by a marker horizon called the Key Tuffite, which has been a major exploration tool, as most of the VMS deposits of the camp are found at this stratigraphic level.

In 2008, a multi-disciplinary research program, including 3 PhD and 2 MSc projects, was undertaken in close collaboration with the mining industry (Xstrata Zinc, Donner Metals, SOQUEM and Breakwater), the GSC, and the MRNF, whose mandate was to provide new regional geology insights.

The recent MRNF regional mapping campaign suggests a new geological subdivision of the Matagami region into the North and South Domains, delimited by the ENE-trending Rivière Allard shear-zone. This shear zone passes north of the historical North Flank but truncates the West Camp northwest of the Phelps Dodge VMS deposit. The North Domain shows evidence of intense D2 north-south flattening. The South Domain is affected by moderate to weak D2 flattening, but is mainly characterized by open NE-trending D1 folds, visible in particular between the West Camp and the South Flank. Superposition of D2 over D1 has created a "dome and basin" geometry which has important impacts for exploration.

The PhD project at INRS-ETE, which aims to define the volcanic architecture of the Matagami mining camp using lithogeochemistry and volcanic facies variations, had important impacts on this new regional vision. On the basis of major and trace elements geochemistry, several mafic volcanic units have been defined in certain areas of the camp using primarily drill core information. The different felsic units have also shown chemical differences not previously well constrained. This new knowledge has been applied and extended more broadly during regional mapping. This has lead to a better understanding of the architecture and stratigraphy of the Matagami mining camp, and therefore will help exploration efforts.

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INSIGHT INTO RIFTING BETWEEN NOVA SCOTIA AND MOROCCO FROM AN EXAMINATION OF MAGNETIC ANOMALIES

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Positive magnetic anomalies characterize the rifted margins offshore Nova Scotia and Morocco, and these anomalies were modelled to examine the nature and style of rifting. The margins began forming during the Late Triassic rifting and Middle Jurassic separation of the North American and African plates, and deeper crustal structure, faulting style and basin geometry vary considerably along the lengths of the margins. The margin to the south of Nova Scotia has the clearly recognized characteristics of a volcanic-style rifted margin, including seaward dipping reflector (SDR) sequences that are interpreted as rift-related volcanic flows overlying basement. These SDRs are coincident with a strong linear magnetic anomaly, the East Coast Magnetic Anomaly (ECMA), which shares many characteristics with the West African Coast Magnetic Anomaly (WACMA). Seismic evidence for these reflector sequences is absent along most of the Scotian margin, and the magnetic anomalies on the Nova Scotia and Moroccan margins change character and fade in amplitude, from south to north, midway along the margins. Several researchers have proposed previously that this transition is associated with a change from a volcanic to a non-volcanic style of rifting. New models of the magnetic anomalies along the Scotian margin show good correlation of the ECMA with the seaward edge of thinned continental crust. The observed anomalies can be satisfied with modest amounts of igneous material, emplaced at or near the edge of the thinned continental crust. Beneath the central and northeastern sections of the margin, where the ECMA amplitude is weak, there is a significant decrease in magnetic source material. Margin segmentation may explain both the changes in magnetic signature and the variability in predicted melt volume.

THE OCEANIC CRUSTAL STRUCTURE AT THE EXTINCT LABRADOR SEA SPREADING CENTER

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The SIGNAL cruise (Seismic Investigations off Greenland, Newfoundland and Labrador) was carried out in 2009 to acquire marine refraction seismic data in the area between southern Greenland and eastern Canada. Although primarily focused on passive margins, the SIGNAL experiment also included two refraction lines along and across a segment of the extinct Labrador Sea spreading center. This extinct ridge represents a rare opportunity to study the last stages of accretion of oceanic lithosphere, with a full spreading rate < 1 cm/yr between Chron 20 (45 Ma) and the end of spreading before Chron 13 (36 Ma). Dense airgun shots were recorded by 18 ocean bottom seismometers (OBS) on the 230-km-long line 4 across the spreading center, while 10 OBSs were deployed on the 145-km-long line 5 within the axial valley. Both refraction lines follow multichannel seismic (MCS) profiles. A previous study using fewer OBSs, immediately northwest of the SIGNAL lines, shows a thin oceanic crust (5.5-km-thick reducing to 4-km-thick within the axis), with a substantial decrease of P-wave velocities at the axis. While confirming these first-order results, the preliminary velocity models of SIGNAL lines 4 and 5 also show extreme tectonic extension with evidence for mantle exhumation and serpentinization (mantle velocities decrease to 7.5 km/s). On line 5 in the axial valley, crustal thickness varies from 4 km to 1.5 km. Joint analysis of the SIGNAL refraction velocity models and coincident MCS profiles show evidence for an atypical basement at the extinct axis and around the area of mantle exhumation. In these regions, the basement has a velocity of 4 km/s and is characterized by a series of high-amplitude reflectors. These reflective layers could be interpreted as volcanoclastic material emplaced by a few volcanic centers in the axis that remained active when extension became mainly tectonic. However, the reflectors are not significantly tilted. Another possibility is that the last stages of ultra-slow spreading led to an anomalous crustal structure characterized by a low velocity upper crust and a thin lower-crust. Both situations raise the question of the simultaneity and timing of extension during the termination of crustal accretion.

ALKALINE ULTRAMAFIC DIATREMES OF THE MISSOURI RIVER BREAKS AREA (MONTANA): A COMPARISON WITH CLASSIC KIMBERLITE PIPES

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We conducted fieldwork in the Missouri River Breaks (MRB) area of north-central Montana (USA) where at least 25 diatremes are now exposed due to erosion (Hearn 1968 Science 159:622-625). The diatremes and associated alkaline ultramafic intrusions were emplaced at 52-47 Ma and are part of the alkaline province of central Montana (69-27 Ma). The volcanoes are hosted by a sequence of unconsolidated sediments (sands and muds).

Detailed field and laboratory work were performed on pyroclastic deposits from four diatremes during this study. These four diatremes display more or less the same characteristics such as: the walls of the diatremes are very steep at the level of exposure; there is strong evidence of subsidence of the mostly bedded diatreme fill; the now bowl-shaped beds locally feature indications of deposition by base surges; there are also distinct non-bedded pyroclastic units separated from the bedded ones by sharp contacts; huge slivers of sediments, from known formations, have sunk along the margins of the diatremes. Moreover most pyroclastic rocks contain a large proportion of spherical juvenile pyroclasts (ash to lapilli

size, and more rarely bomb size) and a large variety of them has been identified.

The diatremes from the MRB share some characteristics with classic kimberlite pipes of South Africa, known as class 1 kimberlites, including formation from a low viscosity magma; deep, steep-sided cone-shaped diatremes; the presence of "floating reefs" and mantle xenoliths; sharp pipe margins; cross-cutting pyroclastic units; and spherical juvenile pyroclasts named "pelletal lapilli" in kimberlites. Even though massive volcaniclastic deposits often characterize kimberlite pipes, stratification has also been observed. However, bedding of pyroclastic deposits is better developed in the Montana examples, even at deep structural levels.

We propose an emplacement model for the Missouri River Breaks diatremes. Some features such as bedded pyroclastic units, cross-cutting non-bedded pyroclastic columns and bowl-shaped beds indicate an emplacement by successive explosive pulses and a downward penetration of the locus of phreatomagmatic explosions which leads to the growth of the diatreme (diameter and depth). The pyroclastic material is deposited bed by bed on the crater floor. During subsidence which occurs during the volcanic activity and after, some slivers of soft rocks are detached from the walls of the diatreme and move down. This emplacement model has implications for the origin of class 1 kimberlite pipes, for which the eruptive processes are still debated.

Keynote THE STRENGTH OF THE LITHOSPHERE AND ITS ROLE IN TECTONICS

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A central and critical multi-stranded question of modern tectonics is "what is the detailed rheology and strength of the continental lithosphere with depth in the crust and mantle and how does this control bulk tectonic style in continental extension and shortening. We address the controversy between Watts and Burov who espouse the classic "peanut butter and jelly sandwich" (strong upper crust and upper mantle, and weak lower crust) model of Matthews, and the "crème brulee" (strong upper crust and weak lower crust and mantle). We lean towards Watts and Burov-type models with a strong upper mantle but show that both integrated and detailed vertical strength is immensely varied and complicated in the continental lithosphere. We illustrate this with a large range of "sailboard" diagrams. A strong upper mantle is inconsistent with homogeneous extension/ thinning (McKenzie) and shortening/thickening (Dewey and Burke) of the continental lithosphere and we discard such models in favour of the observed asymmetry of low-angle extensional detachments (Boillot, Manatschal) and thrusts (Snoke, Rutter) that involve mantle rocks. There may be detachment of a weak crust from the mantle with mantle shortening by thrusting. Olivine rheology demands a strong upper mantle. It is inconceivable that plate tectonics could exist without mantle strength, with very thin plates deriving their torsional strength from the upper crust alone.

Old cratons are clearly strong "plums in the continental pudding" that resist deformation. In our view, the mistake in the Jackson view of lithospheric strength is the correlation of strength with earthquakes.

ND ISOTOPE MAPPING OF THE LAC DUMOINE THRUST SHEET: IMPLICATIONS FOR THE LOCATION OF GRENVILLIAN BASEMENT EXHUMATION RAMPS IN THE SW GRENVILLE PROVINCE

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Nd isotope mapping has been performed in the Lac Dumoine region, western Quebec, interpreted as a thrust sheet of the Grenvillian Allochthonous Polycyclic Belt. The thrust sheet has an isotope signature consistent with other terranes of the allochthonous belt, with TDM ages <1.8 Ga in the main allochthon, but ages of 1.8 – 2.0 Ga in an underlying duplex, itself thrust over parautochthonous Archean crust. However, the new data also reveal a salient of Paleoproterozoic ages that bisect the main thrust sheet into two lobes, showing them to be relatively thin-skinned nappes. When combined with new Nd isotope mapping for Algonquin Park, Ontario, these results suggest that the main ramp of the Allochthon Boundary Thrust is located further to the SE than previously thought, with a strong SW-NE linear trend that coincides with dipping reflectors imaged on Lithoprobe seismic line 32 south of Algonquin Park.

OUTER-RAMP CARBONATE PRODUCTION, TRANSPORT, AND DEPOSITION: UPPER ORDOVICIAN WINTERHOUSE FORMATION, LONG POINT GROUP, WESTERN NEWFOUNDLAND

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The Upper Ordovician Winterhouse Group lies exposed along Long Point, Port au Port Peninsula, western Newfoundland, and represents outer ramp deposition that forms the initial regression phase of a greater Caradocian (Turinian-Edenian) T-R cycle within the remnants of a Taconic foreland basin. The formation overlies the the Lourdes Formation that records an overall deepening upward platform succession. The Winterhouse Formation consists mostly of shale and laminated sandstone. However, within the lower half of the succession are metre-scale intervals of skeletal (brachiopod, echinoderm) quartzose limestones and pure limestone that identify temporary reduction to shut-down of siliciclastic transport and accumulation of graded to massive, medium to coarse-grained deposits, often overlying irregular (scoured?) surfaces. These deposits appear to thin upsection, but peculiar to each occurrence are angular to rounded cobble- to block-size (up to 2 metres across) clasts similar in lithology to the host carbonate matrix. Outcrop exposures suggest that these produce, locally, overlapping laterally restricted sheet-like or podiform deposits. Locally, skeletal grains are cemented by radiaxial fibrous to bladed low-Fe calcite, which forms isopachous rims around allochems preserving an uncompacted texture. Syntaxial calcite cement (on echinoderm grains) and intergranular equant calcite form the more common cement types. Previous work has been largely cursory in description, but often emphasized that the carbonate clasts represented reworking of the underlying carbonate platform (Lourdes Fm). Carbonates of these two formations contain distinct facies. Preliminary field and petrographic analyses indicate that lithification occurred in a cool-water marine or modified marine environment at or very near the sediment-water interface; and, that clasts represent marine reworking of a locally cemented seafloor. Ongoing work is examining the geochemistry (trace elements, isotopic: C, O, Sr) and fluid inclusion characteristics of the calcite cement to help characterize the depositional and diagenetic setting of the Winterhouse carbonates. At present, we suggest that the deposits represent sub-thermocline production with local pervasive marine calcite cementation, then reworking and transport.

THE OTTAWA-GATINEAU GEOHERITAGE COMMITTEE ENTERS ITS SECOND DECADE

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The Ottawa-Gatineau Geoheritage Committee (OGGC) was initiated in 2002 to advance public understanding of the geosciences in relation to enjoyment of, and respect for, the natural world. Our local committee swiftly expanded from two members to 12, and has remained at this level, with few changes in composition of the Committee, derived primarily from the Geological Survey of Canada, Carleton University and The University of Ottawa.

Because of imbalance in teaching of the natural sciences within our school system, almost all citizens reach adulthood with a better comprehension of things biological than things geological. Talks, field excursions and displays organized by OGGC members continue to raise awareness of this imbalance, and linkages with other nature-based groups have significantly enhanced expansion of our outreach. Since our report last year, we provided geoheritage guidance during a canoe trip organized

for high-school students by the Ottawa Riverkeeper, contributed to upgrading of the James Wilson displays in the Matheson House Museum in Perth, and prepared a brochure for an outdoor display of local rocks in Perth that we hope to have designated as the second geoheritage park in Ontario. In collaboration with Carleton University, the fifth annual Geoheritage Day in October 2011 drew many new participants to eight key sites where professional and student geoscientists provided educational guidance throughout the day.

We had one minor setback last year. An outdoor display of 30 large rocks in Metcalfe Geoheritage Park, Almonte, created entirely by volunteer effort over several years and officially opened in 2010, was disrupted by the need for sewer repair that required displacement of the specimens. Stoic acceptance of this unexpected problem served to rally considerable local support, and funds from several sources, including the local Mississippi Mills Council, will usher in creation of a more elaborate display in 2012.

OGGC maintains excellent support within the geological community, strengthened by having had our geoheritage initiative adopted as a project of the Canadian Geoscience Education Network; we continue to enjoy widespread support among numerous nature-based groups; and launching of our own website a few months ago will allow us to promote geoheritage with greater impact. We see significant potential for creation of a geopark in Eastern Ontario, and have encouraged several outdoor and tourism groups to consider creation and submission of a geopark proposal. Above all, we will continue to seek greater appreciation of geoheritage by municipal, provincial and federal organizations.

DETERMINATION OF A FORENSIC GEOLOGY AND POLICE SEARCH STRATEGY TO LOCATE SHALLOW BURIALS ASSOCIATED WITH CRIME

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Police searches to locate graves, firearms, weapons and items of value that have been buried at a shallow depth beneath ground as part of a criminal act, no longer need to rely on conventional line searches and the use of cadaver dogs and air observations alone. Over the past 15 years or so geologists' have been increasingly working closely with the police by combining their expertise and resources and the result has been the development of much improved and cost-effective, search strategies. Although there has been a long association of forensic geologists supporting police and law enforcement investigations, which has been document for at least 150 years, only 'recently' have geological methods and techniques been applied to some types of police searches. The objective of this paper is to provide a general appreciation of how forensic geology may enhance police ground searches. Often, this may begin with the collation, review and analysis of geological data and information and case intelligence. This enables the ground conditions, hydrogeology, types and properties of rocks, soils and any 'made ground' to be determined and the likely detectables associated with the target to be estimated. The results of this initial phase may be summarised in the form of a Conceptual Geological Model (CGM) for the burial, which facilitates the communication of complex geological information between the geologist and police officer. Based on this ground-burial model the most suitable choice of search assets may then be determined and a methodology devised to provide a high assurance search, to confirm the presence or absence of the suspected buried target. This paper also provides information on how organisation such as the International Union of Geological Sciences (IUGS), Initiative on Forensic Geology (IFG), has played a leading, pioneering role in the promotion and development of forensic geology around the world, both as a science and as part of some routine police and law enforcement operations.

REGIONAL SEQUENCE STRATIGRAPHIC INTERPRETATION OF THE MARCELLUS SHALE

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The Middle Devonian Marcellus Shale was deposited in relatively shallow water in the Acadian foredeep of the Appalachian Basin and is a proven hydrocarbon source and reservoir. Several regional correlative surfaces have been identified from standard triple combo well log data and interpreted within the Marcellus. Regional correlations, incorporated with core analysis, have led to the development of a sequence stratigraphic framework for the Marcellus.

The Marcellus rests disconformably on the Onondaga Limestone and contains a minimum of two third order sequences and several higher-order, sub-regional sequences. Accommodation space for the sequences is created by subsidence in the foreland basin. The base of each sequence is represented by black, laminated shale with large amounts of detrital shell material, which, in turn, is overlain by transgressive black, organic-rich shale. The black shales grade both upward, and in a proximal direction, into gray shale which is occasionally capped by a shallow water limestone. This sequence is repeated through the deposition of the Tully Limestone, after which Acadian clastics replace the carbonates.

Identification of the systems tracts and mapping their regional distribution has highlighted differences in the nature of the grey and black shales and allowed for the creation of a depositional model. The sequence stratigraphic framework, wireline log data, core data, and petrophysical and geochemical analyses have been integrated to predict key parameters such as porosity, organic carbon content, and mineralogy and then incorporated into a general basin model to determine burial and thermal maturation history.

NATURAL TOXICANT IS NOT AN OXYMORON. EARTH SCIENCE BASED PROBABILISTIC MODELLING OF NATURALLY OCCURRING ARSENIC IN NEW BRUNSWICK DRINKING WATER

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Despite its potential to inform, earth science knowledge and information is slow to be integrated with environmental, ecological and human health protection initiatives. In Canada, we have significantly large areas that contain **natural toxicants** that have the potential to pose health risks to its overlying population. Yet, we are seemingly unaware, uninformed and unprotected.

Far from trivial, these naturally occurring toxicants have the potential to cause morbidity (carcinogenic and non-carcinogenic disease) that exceed those that would develop from 'a pack a day' smoking habit. We present a modelling tool for the natural toxicant arsenic (a semi-metallic, naturally occurring, nonessential trace element and one of the first elements to be recognized for is cancer promoting agents) as an example of how earth sciences can be used to predict, prevent and provide ongoing health protection to Canadians.

PRECIOUS AND BASE METAL MINERALIZATIONS ASSOCIATED WITH THE REGIONAL MORE-TRONDELAG FAULT ZONE, CENTRAL NORWAY

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The Paleozoic-Cenozoic Verran - and Hitra-Snaasa faults, comprise the main sutures of the giant inter crustal More-Trondelag fault zone that can be followed over 900 km from central Norway across the continental shelf

to Scotland. In Norway, it separates Proterozoic gneisses to the north from Caledonian nappe complexes in the south. Many deposits are associated with second order sub-parallel faults or smaller third order faults typically oblique to the dominant NE-SW strike direction. The polymetallic deposits at Flintheia and Skaudalen hold an average grade of 2.5 wt% Cu, 0.64 wt% Zn, 0.59 wt% Pb, and 152 ppm Ag; and 4,0 wt% Cu, 0.83 ppm Au, 29.3 ppm Ag and 266 ppm Mo respectively.

In Flintheia the mineralizations occur as fracture controlled sulfide mineralizations. Ag occurs in small inclusions in pyrite associated with Pb, Cu and Bi minerals, and in larger galena grains. The larger galena grains are selectively altered, sometimes pseudomorphosed, to covelite and other copper sulfides, whereas coexisting chalcopyrite and pyrite remain unaltered. Sphalerite is slightly altered to covelite along fractures. In the larger galena grains, Pb is extracted and Ag remobilized and precipitated in liesegang like textures in Cu-Ag-Pb-Bi-sulfides together with the Cu-sulfides within the original grain during low temperatures and oxidizing conditions. Average Ag content in unaltered galena relicts is 0.91 wt%. The vein quartz is highly recrystallized with abundant chalcedony, often in comb textures in micro brecciated pyrite. Fluid inclusions preserved in coarse-grained quartz are CO_2 dominated. SEM-CL reveals extensive zoning in the quartz with two main types: one blue luminescent with a main peak around 420 nm and a minor peak at ca. 620 nm, and one type with a main peak around 620 nm, giving it a yellow/orange luminescence. The latter also has a markedly higher intensity.

The Skaudalen mineralizations occur as impregnations in amphibolite facies biotite gneiss. The ore mineralogy comprises coarse-grained chalcopyrite with inclusions of magnetite, molybdenite, pyrrhotite and sphalerite. The quartz vein becomes progressively deformed towards the dominating chalocopyrite grains. Small electrum grains accounts for the gold anomaly. Ag is lattice bound in chalcopyrite, and is verified by "corrosion roses" developed during polishing.

The polymetallic nature together with the complex textural patterns imply that multiple sources and several ore-forming episodes formed these deposits over extensive temperature, depth and time intervals. Significant ore grades and unusual mineralization textures make these deposits interesting in both an economical and academic sense.

GARNET AS A TRACERS FOR THE MINERALIZATION IN A BANDED-IRON FORMATION-HOSTED OROGENIC GOLD DEPOSIT; EVIDENCE FROM THE MUSSELWHITE DEPOSIT, NORTH CARIBOU GREENSTONE BELT, WESTERN SUPERIOR PROVINCE

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Musselwhite, an orogenic Au deposit, is located in the central portion of the North Caribou Greenstone Belt (NCGB). Mineralization is hosted within a meta(chemical) sedimentary banded-iron formation (BIF) which is overlain and underlain by regionally continuous ca. 2.9 Ga amphibolite grade volcanics rocks. The NCGB is bounded by ca. 2.72 – 2.87 Ga TTG-granitiods and granites. Samarium-neodynium geochronology of garnet from the ore zone has been reported to yield a 2.69 Ga age, which post-dates plutonism and volcanism in the NCGB. Recent detrital zircon analysis from the metasedimentary rocks overlying the Au-bearing unit returned $^{207}Pb/^{206}Pb$ peaks at ca. 2.87 and 2.60 Ga. Here, we present recent LA-ICPMS trace element and EPMA major element compositions of garnet from Musselwhite. Samples were collected from auriferous garnet - grunerite schist, footwall and hanging wall schist in the mine, as well from auriferous schist outcrops north of Musselwhite. A sample was also collected from the non-mineralized meta-chemical sedimentary bed that is continuous 24 km from the deposit. Major elements of garnet from mineralized rocks show Mn and Mg rich rims and Ca rich rims. Mineralized samples show positive Eu anomalies in the ore zone in the mine, whereas auriferous rocks outside the mine show less prominent anomalies. Low Eu anomalies occur in the non-mineralized sample (Eu/Eu*= 0.706-2.19). The majority of garnet grains show high HREE concentrations with a mean $(Sm/Lu)_{CN}$ value of 1.6 and low LREE ($\sum$HREE/$\sum$LREE = 41). Rims of garnet from mineralized samples show large variations in Ni/MgO from ~ 0.14 to 15.5, and Y concentrations from ~ 0.89 to 198 ppm. The high Ni and low Mg are recorded in the core of these grains from the ore, whereas their rims show low Ni. Trace element zonation in garnet from the non-mineralized rocks is minor compared these samples. The data suggests that garnet growth was contemporaneous with precipitation of pyrrhotite and chalcopyrite; both sulfides are closely associated with the introduction of Au. Gold-bearing fluid was derived from rocks during metamorphism or extensive alteration of mafic rocks as reflected by variably high Eu/Eu* values and Ca- rich rims in the garnet crystals in the mineralized rocks. The origin of BIF-hosted Au deposits remains enigmatic and the source fluids (magmatic or metamorphic) are still in debate. Results here indicate that garnet effectively records the history of hydrothermal activity associated with Au deposits and the data indicates metamorphic fluid as the principle transporter of Au.

HYDROTHERMAL DESILICIFICATION AT DOME/KEEL DETACHMENTS: A KEY ELEMENT IN FORMING HIGH-GRADE MAGNETITE DEPOSITS IN THE MARY RIVER DISTRICT, NORTH BAFFIN ISLAND

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The Mary River District in north-central Baffin Island is emerging as an exciting new high-grade iron ore camp with numerous variably delineated massive magnetite-(martite-hematite) deposits, the largest in excess of 500mt of 65-70% Fe. These deposits are hosted within a prominent Algoma-type banded iron formation, a member of an upper BIF-komatiite-quartzite assemblage capping the Neoarchean Mary River Group. The Mary River Group is preserved in superstructural keels and the massive iron oxide bodies develop where Mary River BIF is juxtaposed against high grade polymetamorphic infrastructural gneiss, within a classic "dome and keel" Paleoproterozoic tectonic framework. The massive magnetite lenses have well developed footwall chloritite schist, and pervasive chloritization extends well into bordering mylonitic gneiss. With loss of silica, the Mary River BIF transits from typical magnetite-quartzite with <45% Fe, to enriched BIF with >50% Fe, into massive magnetite. Remnants of original BIF are occasionally preserved within the coarsely granular magnetite.

Coarse idioblastic garnets overgrowing the multiple-foliated footwall chloritite and randomly oriented cordierite-staurolite-andalusite overgrowing chloritized footwall gneiss clearly demonstrate that desilicification occurred prior to the late thermal peak of the Hudsonian overprint. Randomly oriented grunerite overgrowing granoblastic magnetite ore is attributed to late annealing under the terminal Hudsonian amphibolite facies thermal conditions. The relative timing for hydrothermal retrogression is therefore during regional Hudsonian dome and keel development. Granular martite and platy hematite ores result from post peak metamorphic oxidation of granoblastic magnetite along still active deformation zones accommodating terminal isostatic adjustment.

Wholesale silica removal via hydrothermal fluidization of Proterozoic dome/keel boundaries has not been widely reported in the literature. However, pervasive chloritization of younger detachment faults supplies a modern analogue. Here, meteoric fluids ponding at the brittle/ductile interface of orogenic infrastructures play a formative role. The hydrothermal disaggregation reflects a steep thermal gradient across faults accommodating rapid unroofing. In the case of Mary River it is perhaps more likely that dewatering of the low grade Mary River Group, particularly of serpentinized komatiite members, was the primary fluid source. Other possible analogues for hydrothermal silica removal from background BIF to form residual massive magnetite ores at Proterozoic dome/keel boundaries can be found in the IOCG literature.

NEW SHRIMP U-Pb ZIRCON AND APATITE FISSION TRACK AGES CONSTRAIN THE DEFORMATIONAL HISTORY AND TIMING OF CARBONATE REPLACEMENT MINERALIZATION IN THE WESTERN FORTYMILE MINING DISTRICT, EAST-CENTRAL ALASKA

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Epigenetic base- and precious-metal prospects in the Mount Veta area of the Fortymile district occur in the eastern Yukon-Tanana Upland (YTU), which is bounded by the Tintina and Denali right-lateral fault systems. The YTU is cut by steep NE-trending faults with both left-lateral and dip-slip movement. New SHRIMP U-Pb zircon ages (n=29) in the Mount Veta area document magmatic episodes at ca. 217–210, 188–184, 111–98, and 70 (±2) Ma. Intrusions of 210, 188, and 70 Ma occur within 3 km of the Little Whiteman (LWM) Zn-Pb-Ag-(Cu) carbonate replacement prospect. Sulfide bodies at LWM formed as NE-trending, steeply SE-dipping, chimney-shaped replacements of Paleozoic marble in the hanging wall of the NE-trending Kechumstuk fault and along contacts with steeply dipping feldspar porphyry dikes. Within some dikes, the intensity of quartz-sericite-pyrite alteration increases towards the sulfide lenses. Zircon from one dike yielded a 187.7±4.8 Ma U-Pb age. Secondary sericite from another altered porphyry dike yielded a $^{40}Ar/^{39}Ar$ age of 187.5±2.0 Ma for the most retentive 6 fractions (28% of ^{39}Ar released) with minor gas loss at ~65 Ma (P. Layer and J. Benowitz, written commun., 2011). These ages are consistent with sulfide replacement during 187 Ma magmatism. However, Pb isotopic compositions for sphalerite and galena from LWM drill core are more radiogenic than those for K-feldspar from nearby Jurassic intrusions and overlap with those from Cretaceous plutons. Pb isotopic data allow an alternative interpretation in which the 187 Ma $^{40}Ar/^{39}Ar$ sericite apparent age records initial alteration of the porphyry dikes, whereas disturbance at ~65 Ma records mineralization by fluids at a temperature below the closure temperature of the Ar system in sericite.

Apatite fission track (AFT) ages from igneous rocks (n=27) in the Mount Veta area indicate multiple episodes of Paleogene (40 ± 10 Ma) cooling through the ~110°C AFT closure temperature. However, geologic relations around the 69-Ma Middle Fork caldera 20 km north of Mount Veta suggest that these rocks were near the surface in the Late Cretaceous, and therefore likely were reheated to >110°C sometime in the early Tertiary. The nature of the suggested post-69-Ma reheating is unknown. We interpret the Paleogene cooling implied by the AFT data to indicate uplift, exhumation, and cooling related to far-field movement on the Denali and Tintina faults. Two samples near faults have AFT ages of ca. 19 and 10 Ma, recording local re-heating by fluids in the Neogene.

TURNING WATER INTO WINE: A GEOLOGICAL INTRODUCTION TO LITHIUM-RICH FORMATION WATER IN WEST-CENTRAL ALBERTA

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The idea of a green mining operation—one that extracts minerals from waste oil-field water for eco-friendly products—is appealing. Middle to Late Devonian Beaverhill Lake, Woodbend and Winterburn group formation waters associated with producing oil and gas wells in the Swan Hills area of west-central Alberta contain up to 140 mg/L lithium (1 mg/L = 1 ppm). This value is significant considering the average values of lithium in Alberta formation waters are 10 mg/L (based on 1511 analyses), and a Government led historical lithium resource study of the Swan Hills area estimated some 515 000 tonnes of lithium over an area of 4,000 km^2 (non-NI 43-101 compliant). The high-lithium brines also contain elevated potassium (up to 8000 mg/L), boron (up to 270 mg/L) and bromine (up to 410 mg/L), such that industry is considering the feasibility of a multi-commodity extraction plant.

The occurrence of lithium in the world's oil-field waters is poorly understood and inadequately represented in the literature. The objectives of this presentation, therefore, is to illustrate where lithium-rich formation waters occur in Alberta and to explore the source environment, mobilization and transport of lithium and related minerals to form these unique brines. Industry data forms a valuable contribution to this work and, where applicable, leading edge investigations will be incorporated.

Major ion and Sr, Pb and Li isotopic geochemistry show Alberta's lithium-rich brines form prior to halite precipitation, lack a freshwater source and involve alteration of silicates (particularly Li- and K-bearing minerals). In the Swan Hills area, viable lithium-source models should invoke direct mobilization of silicate-bearing fluids from either the crystalline basement or the immature siliciclastics deposited above the basement (basal Cambrian sandstone, Granite Wash or the Gilwood Member), to the Devonian Swan Hills, Leduc and Beaverhill Lake formation waters. A number of thermal, potential-field and tectonic features in west-central Alberta are reviewed in this introductory investigation of lithium-rich oil-field waters that may one day become an economically viable resource.

DIVERSITY, BIOGEOGRAPHY, AND BIOMINERALISATION OF COLD-WATER CARBONATE PRODUCERS IN CANADIAN WATERS: OVERVIEW AND NEW DIRECTIONS

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Cold-water carbonate producing organisms, sediments and rocks have received limited study in Canada, compared to the cold-water scleractinian bioherms of the northeast Atlantic, the main focus of COCARDE (Cold-water Carbonates in Shallow and Deep time), the eastern US and Gulf of Mexico, or the extensive cold-water carbonate systems of southern Australia, the Gulf of California or the Mediterranean. Canada's climate, oceanography, and glacial inheritance may limit the organisms and their sedimentary products.

Dominant cold-water carbonate producing organisms in Canadian waters include the coralline red algae, bryozoans, bivalve and gastropod molluscs, sponges (indirectly), and corals - similar to the general bryomol assemblage described from other broad cold-water carbonate shelves. Coralline algae, producing magnesian calcite skeletons, are ubiquitous members of Canadian shallow marine hard-substrate communities. Branching corallines produce large amounts of carbonate sediment in some fjords, while compact domal coralline algae may record high-latitude climatic or ecological chaanges. Dominantly calcitic erect and encrusting bryozoans are common epibenthos in shelf-depth waters, and are often found associated with cold-water corals and sponges, but remain vastly understudied. Carbonate-skeletoned cold-water corals include aragonitic scleractinians, aragonitic or calcitic stylasterids, and calcitic gorgonians. Solitary scleractinians have a relatively low diversity, while colonial scleractinians occur mainly as isolated colonies, rather than in bioherms. Stylasterid hydrocorals are common and relatively diverse in some British Columbia waters, but rare in Atlantic Canada and the Arctic. The most common carbonate-skeletoned gorgonian corals include Primnoids in shallow, high-current settings, and Isidids in deeper, calmer settings. Cold-water gorgonians construct "coral forests", whose habitat importance far surpasses their sedimentary production. Sponges, especially demosponges and hexactinellids, make an important contribution to habitat throughout Canadian waters, and build glass sponge bioherms in shelf depth British Columbia waters.

Modern cold-water carbonate sediment deposits appear relatively rare in Canadian waters, perhaps due to dilution by the vast amounts of siliciclastic sediments delivered to Canadian continental shelves by Pleistocene glaciations. Preservation potential of cold-water scleractinians and carbonate-skeletoned gorgonian corals may be relatively high, as evidenced by sub-fossil skeletons several thousands of years old found exposed on the seafloor, but the preservation potential of the environments in which most of these organisms live is generally low. Many areas remain unexplored, however, especially in the Arctic.

Emerging questions surrounding Canadian cold-water carbonates include biomineralisation and skeletal microchemistry, rates of skeletal growth and carbonate production, mineralogy, patterns of distribution and abundance, and sedimentology and diagenesis of mound construction and other habitat formation.

EVENT DEPOSITION AND BIOTURBATION GRADIENTS IN ORGANIC-RICH MUDSTONES - THE LOWER MISSISSIPPIAN BAKKEN FORMATION OF NORTH DAKOTA, WILLISTON BASIN, USA

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Conventional depositional models for organic-rich mudstones typically envision prolonged tranquil sedimentation in overall anoxic marine basins. Although recently this paradigm has shifted towards a more differentiated view based on recognition of bed-load transport structures and erosion surfaces in mudstones, necessitating a thorough "rethinking" of our understanding of the complexity of processes acting in such "anoxic" settings. This study focuses on recognizing depositional events, bioturbation structures and their stratigraphic and spatial distribution within the upper shale member, Bakken Formation, an important source rock and potential unconventional petroleum reservoir, Williston Basin, U.S and Canada.

Facies analysis of the upper shale member reveals that this depositional system is characterized by at least three distinct facies belts with amorphous organic material occurring in all of them. On a transect from proximal to distal these are: (1) a heavily bioturbated mudstone, largely lacking sedimentary structures, (2) a laminated silt-rich mudstone with horizontal and vertical bioturbation features, and (3) a radiolarian-rich mudstone with varying content of silt and clay, and nearly exclusively vertical bioturbations.

Evidence of event deposition exists in all facies belts, in the form of sub-millimeter thick fine silt laminae interpreted as distal tempestites and lag deposits from weak currents. The presence of vertical bioturbation in laminated silt-rich mudstones, which forms the bulk of the sediment in the unit, also argues against continuously anoxic conditions even some millimeters below the sediment-water interface. Only some of the radiolarian-rich facies, devoid of any trace fossils or tempestites, may reflect temporary anoxia, whereas others are rippled indicating bottom current reworking at least during portions of their depositional history.

The upper shale member represents an overall highstand unit, sandwiched between the overlying Mississippian Lodgepole Limestone and siltstones with carbonates of the middle Bakken member. Although the basin center was at its greatest depth during such periods of elevated sea-level, storms episodically influenced Bakken deposition, which points to the Bakken depositional basin having been a relatively shallow trough with maximum depth only slightly below storm wave base, perhaps <100 m. Thus, important source rocks such as the upper shale member of the Bakken can be deposited in relatively shallow water, above storm wave base, with tempestites being a recognizable, common depositional feature.

THE BORING BILLION: IMPROVING OUR UNDERSTANDING OF THE ITS GEODYNAMIC DEVELOPMENT AND ITS MINERAL DEPOSITS

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Understanding and visualizing the geology of multiple domains, particularly those outside of one's own areas of specialty, is usually difficult. Database systems developed for the IGCP 509 project are intended to facilitate this process by allowing users to extract information for user-selected domains and to create time-space correlation charts which illustrate lithostratigraphy, geochronology, geodynamic setting, rock class and depositional setting. It is also possible to illustrate the age and general character of metamorphism and deformation, as well as the timing and style of mineralization and to highlight special features appropriate to individual units.

This approach has been used to illustrate aspects of the geology of the Grenville Province (*sensu lato*) of North America, the Sveco-Norwegian Province of Scandinavia and the Namaqua-Natal Belt of southern Africa. Geochronology for additional domains in Africa, Australia, Antarctica and South America are also shown although the compilation of lithostratigraphic information for these domains is only just beginning. These various data sets will be used to help constrain plate reconstruction models, hopefully building on to information already available from the IGCP 440 project.

Studies of various mineralization styles during the past decade have demonstrated that several associations may be uniquely associated with geodynamic setting. For instance, volcanic-hosted massive sulphide deposits have been classified in several 'clans' which appear to have geodynamic significance, just as porphyry deposits and orogenic gold deposits are formed in settings which are consistently linked to subduction or collisional settings with distinctive vergence polarity at large scales. Utilisation of the age and setting of ore deposits provides another mechanism to help constrain or prioritise possible palaeogeographic reconstruction models.

Investigation of the geodynamic setting of mineralization during the 'boring billion' (~1700-800 Ma) will draw on the information in the DateView and StratDB databases (available online from http://sil.usask.ca/databases.htm), from compiled time-space correlation charts and from palaeogeographic reconstructions, so allowing comparison with time intervals which are better endowed with economic mineralization.

Keynote LARGE SCALE CONTROLS ON THE SETTING OF PALAEOPROTEROZOIC URANIUM MINERALISATION IN THE NUNA SUPERCONTINENT (NORTH AMERICA AND AUSTRALIA)

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Understanding the regional development of Palaeoproterozoic uranium mineralisation has always been hampered by the disseminated nature of information and by a lack of technology to draw together broad regional data in formats suitable for systematic study. Databases developed for the IGCP 509 project have facilitated collation of structured regional and global data and new technologies facilitate reconstruction of past palaeogeographies. Visualizing the development of the Nuna super-continent relative to other cratons and fragments allows one to better investigate broad regional patterns thought to influence fluid flow, fault reactivation and mineralisation in the Athabasca, Thelon and Hornby Bay basins of Nuna.

Reconstructions, performed in a GIS environment, utilise published palaeomagnetic data augmented by regional structural vergence directions which permit the 'explosion' of existing crustal domains at times dictated by geology and geochronology. Known ore deposits, lithostratigraphy and sample localities move with the continental fragments so that one can 'watch' the processes and events as they change in time and space and study regional patterns which possibly controlled fluid flow leading to mineralisation.

Nuna was formed by closure of the Manikewan Ocean and other seaways in the interval 2.2 to 1.78 Ga. From 1.78 Ga to 1.65 Ga, the geological history of Nuna is dominated by peripheral magmatism along its western margin and coeval activity on the still open north-eastern margin of Australia. The locus of orogenic activity changed through time, shifting southwards, triggering reactivation of sympathetically oriented pre-exisiting structures and basinal faults withinthe supercontinent interior. From ca. 1.75 to 1.46 Ga, Nuna exhibits signs of attempted breakup that overlapped with ongoing peripheral orogenesis. IOCG mineralisation at Olympic Dam in Australia, unconformity uranium mineralisation in the Athabasca Basin and Pb-Zn mineralisation in the Sullivan camp all relate

to this phase of Nuna development, with a locus of IOCG and SEDEX mineralisation about a seaway between ancestral North America and Australia. Regional geochronology illustrates zones where post-collisional reactivation and/or uplift was focussed, possibly influencing fluid flow within and around the sedimentary basins.

The style of supercontinent aggregation appears to have had a strong influence on the nature of ore deposits formed and their preservation. Major VMS, Ni-Cu-PGE and Orogenic Gold districts formed during the interior orogenic phase whereas porphyry, sediment-hosted Pb-Zn, IOCG, MVT and unconformity-uranium mineralisation are mostly associated with the peripheral orogenic phase that overlapped with attempted breakup.

PERMANENT 4D ACQUISITION – PAST, PRESENT AND FUTURE

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Permanently installed reservoir monitoring systems enable more frequent 4D monitoring leading to improved reservoir management and increased total recovery. This paper reviews the history of permanent 4D system use offshore from the initial installation in 1995 through to the present permanent 4D system acquisition activity. The current state of the art in permanent 4D technology is presented along with observations on where the acquisition technology may be headed in the future. Two areas for potential joint R&D projects are identified for industry consideration which would be of particular interest to help operators maximise the value of permanent 4D technology for applications in the conditions found offshore Newfoundland.

The history of permanent 4D systems is longer than many in the industry may recognise, starting with the first pilot acquisition project over the Foinaven field in 1995. Over the past 17 years there have been 11 recognised projects undertaken. A brief review of the history and progress from the early pilots through to the current full field installations will be presented.

An overview of the current systems and technology available from the main system/service providers will be presented, highlighting the development and background of the existing technology options. An objective view of the pros and cons of both electrical and fibre-optic based technology for permanent 4D use will be discussed and presented.

The author will present his views on where the acquisition technology may be headed based on the factors currently driving adoption and implementation of permanent 4D systems and the Permanent Reservoir Monitoring (PRM) 4D momentum currently building within the industry. The near-term considerations for both providers and operators will be discussed.

Two specific challenges for maximising the potential for permanent 4D acquisition offshore Newfoundland will be presented, one operational and one technical. Both are proposed as potential subjects for joint R&D collaboration between industry and academia.

On the operational side, a practical solution for the protection of permanent seabed arrays against iceberg scour is required for the offshore Newfoundland environment.

Longer-term, technology development of permanent seabed source solutions to complement permanent receiver arrays will bring a step-change reduction in repeat survey cost allowing a step-change increase in repeat survey frequency, particularly in areas where the operational weather window for conventional source acquisition is restricted.

BASIN EVOLUTION AT THE BEGINNING OF "SEQUENCE B", NORTHWESTERN CANADA

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The Mackenzie Mountains and Shaler supergroups (MMSG and SSG; western NWT and northern NWT, respectively) of northwestern Canada are assumed to be correlative successions in separate epicratonic open-marine basins. This relationship is based on lithostratigraphy and chemostratigraphy of the upper parts of the supergroups; the lower parts of the supergroups remain largely unknown. The lower part of the Mackenzie Mountains Supergroup (<1150?, >845 Ma), newly described from the northwestern Mackenzie Mountains (NWT) and Wernecke Mountains (YT), contains units that are not readily correlated lithostratigraphically between the two areas. The basal unit (Dolores Creek Fm.; YT only; 260 m) lies with angular unconformity on the Pinguicula Gp. and consists of organic-rich black mudstone and siltstone that was deposited under an anoxic water column, interlayered with shallow-water microbial and intraclastic dolostone. The overlying Black Canyon Creek Fm. (YT only; ~285 m) consists of shallow-water cherty dolostone that contrasts compositionally with most of its putative equivalent in NWT, the Tabasco Fm. (formerly "H1 unit"; lowest MMSG unit exposed in western NWT; >485 m), which is dominated by a thick deeper-water stromatolitic succession. Overlying terrigenous clastic units [Tarn Lake Fm. in YT (~265 m); Tsezotene Fm in NWT(~1 km)] were deposited under different conditions (tidal flat to shallow marine, and muddy outer ramp, respectively), but could be lateral equivalents depending on basin configuration. Stable isotope stratigraphy is unhelpful in deciphering among the possible correlation schemes, because no distinctive excursions are matchable. The MMSG basin began with a thin (~260 m), restricted, anoxic, shallow-water phase that probably represents a rift environment, whereas the SSG began with a thick (~1 km) shelf siltstone succession (Escape Rapids Fm.) that probably records an open marine continental shelf. Lithostratigraphic and chemostratigraphic comparison of the lowermost carbonate formations in the MMSG with the SSG (Mikkelsen Islands Fm.) may resolve the problematic relationships among these units. Lithostratigraphic comparison of the lower parts of the supergroups (600-1000 km apart) will illuminate the conditions under which different styles of basin extension first developed in these two areas.

RECENT WORK ON ERNIETTOMORPHS FROM THE SOUTH OF NAMIBIA

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In recent years, a diverse group of researchers has been working on the Nama Group in Namibia. The Nama Group, representing the latest Neoproterozoic and including overlying Cambrian sediments, outcrops extensively in southern Namibia. It consists of a series of sandstone-limestone cycles. Some of the earliest of these cycles outcrop at Aar Farm, near the town of Aus. Work on Aar Farm has substantially extended existing collections. In particular, it has produced remarkable specimens of Pteridinium and Ernietta, two of the more unusual Ediacaran organisms. Ernietta has been studied for over forty years. Among the Ediacaran organisms, it has arguably been among the least-controversial, but we are far from a complete understanding of its evolutionary or environmental significance. The new specimens are representative of the 'Nama-style' preservation, a three-dimensional form of soft-tissue preservation that has interested researchers for some time. Newly discovered fossil features associated with Ernietta may extend our understanding of this organisms morphology during life, but also interesting are examples of multiple Ernietta preserved together. Previous work has established that these fossils cannot be easily related to modern taxa. The prevailing consensus is that they represent a branch of the tree of life with no living descendants. The similarity – and probable relationship – between Ernietta and Pteridinium has been noted by many researchers. How this will ultimately fit in with phylogenies of the Ediacaran fauna remains to be seen.

IS THERE ANY OIL PLAY IN THE CANADIAN LABRADOR SEA BASINS?

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Two very large basins, Hopedale and Saglek, cover the shelf, slope and deep water of the Labrador continental margin. These are extensional basins containing thick Mesozoic to Tertiary sedimentary fill including quality sandstone reservoirs. The area was explored during the seventies and early eighties when 6 gas and condensate discoveries were made. Only one oil show was recorded attributable to an immature source rock. Regional geology, reflection seismic, oil seep and conjectural evidence

point toward the existence of a lucrative oil play within sectors of the Canadian Labrador Sea basins.

2012 EXPLORATION AND PRODUCTION UPDATE ON THE CANADIAN ATLANTIC MARGIN

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The Canadian Atlantic Margin has six areas with significant hydrocarbon discoveries:

1. Sable Subbasin producing gas since late 1999;
2. Jurassic Carbonate Bank containing the Deep Panuke gas field;
3. Jeanne d'Arc Basin, the only offshore East Coast North America oil producing area;
4. Flemish Pass Basin containing the newest Atlantic oil discovery;
5. Hopedale Basin where several gas fields were found, and
6. Saglek Basin containing the Hekja gas field.

Production. During 2011, a total of 97.3 MMbbls of oil were produced from the Jeanne d'Arc Basin, offshore Newfoundland. The production from Hibernia, Terra Nova and White Rose fields and several satellites averaged 266,494 bopd. Lately, the satellite field development has helped maintain the production rate above 250,000 bopd. Over 1.3 billion barrels were produced to date from the area. In the Nova Scotia's offshore, the Sable Offshore Energy Project produced 100 Bcf during the year, with an average production rate of 274 MMcf/d. A total of 1.8 Tcf were produced since the start of the project.

Development. The Deep Panuke gas field, offshore Nova Scotia is planned to start production during the summer of 2012, with anticipated peak production of 300MMcf/d. The next major project offshore Newfoundland is the Hebron field with development stating in 2012, following project sanction. Hebron's first expected oil is planned for 2017 and its peak production is estimated to be 150,000 to 170,000 bopd.

Exploration. Peak production from NL offshore oil fields came in May 2007; Nova Scotia gas production peaked in December 2001. A low level of exploration has characterized the past decade of exploration in Atlantic Canada. No exploration wells have been drilled offshore Nova Scotia since 2005, while a well or two per year was the usual drilling rate offshore Newfoundland. Many basins and subbasins remain unexplored or little explored. Three wells, Ballicatters M-96 and M-96Z and Glenwood H-69 were recently abandoned or suspended in the northern Jeanne d'Arc Basin without proving significant oil reserves. In spite of a successful licensing round in the Hopedale Basin, no drilling in the Labrador Sea is planned yet. Without new discoveries, the Canadian Atlantic Margin petroleum industry is on a declining path with aging fields, shrinking reserves and many remaining undrilled prospects.

Nevertheless, focused exploration efforts and good news comes from:

a) Mizzen oil discovery that brings a new intermediate to a deepwater exploration area in the North Flemish Pass-Southeast Orphan Basin. The Mizzen O-16 significant discovery has also triggered several successful exploration licensing in the adjacent area;
b) Allochthonous Salt and Minibasin Province, southwestern Scotian Slope where four deepwater parcels were won in January 2012 by Shell with a record $970 million work commitment bid.

Research. On the Newfoundland and Labrador sector of the margin, the Provincial Government and Nalcor Energy Oil and Gas initiatives resulted in acquisition of modern high quality regional seismic data coupled with satellite based sea slicks studies and geochemistry analysis of shallow cores. The data and studies will be made available for licensing to the industry. The Province of Nova Scotia's recently released $15 million Play Fairway Analysis (NSPFA) points toward the existence of Early Jurassic oil prone source rocks in the deeper parts of the Scotian Slope. The comprehensive study has been very favourably received by industry and is available free for download.

Minimizing the geological risk is essential to increase exploration activity and to lead to drilling success on the Canadian Atlantic Margin.

GREAT BEAR MAGMATIC ZONE ROCK PROPERTY DATABASE: LINKING GEOLOGY AND GEOPHYSICS WITHIN IOCG SYSTEMS

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The two primary poles of mineral exploration are geological mapping and geophysical surveying. In order to link these two great exploration investments, labs such as the Geological Survey of Canada Paleomagnetism and Petrology Laboratory and the McMaster Applied Geophysics and Geological Imaging Centre have undertaken extensive measurements of physical properties to strategically chosen rock collections: density (bulk and skeletal), magnetic susceptibility and remanence, and electrical impedance spectra for resistivity and chargeability. The Great Bear magmatic zone (GBmz) Rock Property Database provides a useful example of this approach. The current exploration model for the GBmz is iron oxide copper gold (IOCG) mineralization (and affiliated deposits) featuring a six-zone alteration classification of mineral assemblages. From the high temperature-deeper-earlier-core to the cooler-shallower-later-distal alteration indices, the zones are identified as 1:Na(Ca); 2:Ca-Fe(Na); 3:High Temp K-Fe; 4:Skarn (if carbonates are present); 5:Low Temp K-Fe; 6:Low Temp silicification. Analysis of the distributions of physical properties as a function of the lithologies and alteration zones of the range of rocks collected in the GBmz reveals useful patterns to provide new exploration vectors. The geometric mean magnetic susceptibilities [E-3 SI units ± standard error] are: 1: 3.2±40%; 2: 17.7±16%; 3: 12.6±18%; 4: 1.5±83%; 5: 3.9±3.3%; 6: 2.1±15%. Note that the magnetite produced in the higher temperature zones 2 and 3 lead to magnetic susceptibilities 6 to 8 times higher on average than that of zone 6 samples. The iron oxide mineralization leads to high magnetic remanence values which must be taken into account in magnetic survey interpretation. One quarter of rocks identified to be in zone 2 or 3 alteration have Koenigsberger ratios above 1, compared to 10 to 15% of the samples in the other zones. The correlation of high magnetic and density values leads to hybrid density-magnetic potential field models. Current work on resistivity-chargeability properties is motivated by strong unexpected anomalies observed in electromagnetic surveys in the Port Radium region. As of January 2012, rock properties from over 700 samples from the GBmz have been measured and compiled, and several hundred are currently under examination. Through the petrophysical link coupled with clear understanding of the relevant mineralization model, new effective strategies are being developed to target and locate new mineral deposits.

DIFFERENTIAL EXHUMATION AND CONCURRENT FLUID FLOW AT THE NICO Au-Co-Bi-Cu DEPOSIT, GREAT BEAR MAGMATIC ZONE, NWT - A PALEOMAGNETIC AND STRUCTURAL RECORD

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The iron oxide copper-gold (IOCG) mineralization model is offering new exploration possibilities, especially in the Proterozoic Great Bear magmatic zone, NWT. The NICO Au-Co-Bi-Cu deposit, the numerous U-Th-REE±Cu-Mo showings of the Southern Breccia and the nearby Cu-Ag-(Au) Sue Dianne deposit provide well-exposed examples of IOCG-type and IOCG-affiliated mineralization. A paleomagnetism study (39 sites, 318 oriented specimens) was undertaken in this region with the goal of determining the interplay of hydrothermal fluids, deformation and iron-oxide mineralization. Because of the high concentrations of large magnetite grains in these altered rocks, hybrid alternating field and thermal demagnetization was done to clean a large unstable magnetic component from the useful paleomagnetic components. Strong stable magnetic remanence was observed throughout the collection, almost fully carried by

magnetite even in dominantly hematite-bearing rocks. The rich range of lithologies, alteration levels and contact relationships in this small area provided the whole range of paleomagnetic stability tests. Negative conglomerate and tilt tests reveal pervasive remagnetization. The collection almost completely holds downward polarity (but not in the present field direction), as do the reference directions observed in stable Paleoproterozoic formations northwest of the Trans-Hudson Orogeny. While 4 sites retain an untilted Paleoproterozoic direction, most sites hold steeper remanence directions interpreted as variable tilting after remanence was acquired, dominantly down to the south-east. Rare 3-component magnetizations reveal magnetization acquisition during tilting. Five contact tests offer the exotic result that dykes were magnetized at different times than their contact zones, interpreted to be the result of subsequent hydrothermal pathways exploiting the differential permeability pathways. Combined with detailed analysis of polyphase structural evidence, the paleomagnetic remanence may indicate a form of bookcase normal faulting active during late deformation. Along with the complex results revealed from many complementary methods used to examine IOCG deposits, paleomagnetism provides quantitative proof of differential exhumation and concurrent fluid flow in this mineralization setting.

A PROPOSED 725 Ma DOVYREN-KINGASH LIP OF SOUTHERN SIBERIA, AND POSSIBLE RECONSTRUCTION LINK WITH THE 725-715 Ma FRANKLIN LIP OF NORTHERN LAURENTIA

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Along the entire southern flanks of the Irkutsk promontory of the Siberian craton, numerous mafic-ultramafic layered intrusions occur with Ni-Cu-PGE ore deposits. Previous age studies by various methods have suggested igneous emplacement broadly between 800 and 600 Ma. Here we present the first U-Pb (ID-TIMS) baddeleyite ages for two of these intrusions (samples from BHP Billiton). On the eastern margin of the promontory, the large, well-exposed and lopolithic (Yoko-) Dovyren intrusion at the northern end of Lake Baikal contains abundant, fresh baddeleyite and gives an upper intercept age of 724.7 ± 2.5 Ma (5 fractions). Along the southwest border of the promontory, an upper, differentiated gabbroic portion of the Upper Kingash layered intrusion (East Sayan block, Kan belt) yielded only sparse, minute baddeleyite grains (max. 20-30 microns), but regression of the U-Pb data gives a similar age, at 726 ± 18 Ma (4 fractions). Lower intercepts in both cases suggest Paleozoic- and Mesozoic-aged Pb-loss effects, likely due to docking of Phanerozoic terranes of the Central Asian fold belt.

These two dated intrusions are located in widely separated terranes bounding the southern Siberian craton and suggest that the many other undated mafic-ultramafic intrusions (also commonly with Ni-Cu-PGE potential) along the 1100 km distance of these bounding terranes may also have a ca. 725 Ma age. Moreover, dykes and sills within the Irkutsk promontory of the Siberian craton have yielded Ar-Ar ages similar to our dated intrusions. This suggests that ca. 725 Ma mafic-ultramafic magmatism is widespread in the Siberian craton and adjacent terranes, and constitutes a 725 Ma large igneous province (LIP).

This 725 Ma Dovyren-Kingash LIP of southern Siberia is an age match to the ca. 725-715 Ma Franklin LIP which covers an area of >1 Mkm^2 in northern Canada and western Greenland. It consists dominantly of a radiating mafic dyke swarm with an arc of about 90°, converging to an inferred mantle plume centre near Banks Island. Additional Franklin components include the Coronation sills and the Natkusiak volcanic rocks and associated sills of the Minto Inlier of Victoria Island. The temporal equivalence between the Dovyren-Kingash and Franklin LIPs lends support to a nearest neighbour relationship between southern Siberia and northern Laurentia. That the 725 Ma Dovyren, Upper Kingash and related intrusions of southern Siberia have significant Ni-Cu-PGE mineralization enhances the intrinsic metallogenic potential of Franklin magmas providing that northern Laurentia and southern Siberia can be demonstrated to have been adjacent at this time.

INTRAPLATE MAGMATIC 'BARCODE' RECORD OF THE CONGO CRATON (ANGOLA PORTION): NEWLY DATED DOLERITE EVENTS AT 1502 AND 1110 Ma AND IMPLICATIONS FOR NUNA AND RODINIA SUPERCONTINENTAL RECONSTRUCTIONS

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Positions of the large Congo craton in Precambrian supercontinent reconstructions remain poorly constrained. New evidence from ongoing geochronologic and paleomagnetic studies of widespread Proterozoic mafic dykes and sills now permits some first-order magmatic 'barcode' comparisons with other continental blocks.

In Congo craton's Angola portion, the only well-dated Proterozoic intraplate event to this point is the 1370-1380 Ma Kunene Intrusive Complex. We report new, precise U-Pb ID-TIMS dating of dolerites that reveals two unanticipated additional Meosproterozoic intraplate events: at 1502 and 1110 Ma (details below). Identification of these three Mesoproterozoic magmatic events (ca. 1380, 1500 and 1110 Ma) define an initial magmatic 'barcode' for the western portion of Congo craton, which can be compared with the record in other crustal blocks to identify former nearest neighbours important to Precambrian supercontinents Nuna and Rodinia.

A 1502±5 Ma U-Pb baddeleyite age has been obtained for the prominent Humpata sill, potentially part of a broad dolerite sill province. The combined presence of both 1500 Ma and 1380 Ma magmatism in the Congo craton represents a critical match with similar ages published for two suites of mafic dykes and sills in northern Siberia. This magmatic 'barcode' match suggests a nearest-neighbour relationship between northern Siberia and the Congo (+ formerly attached São Francisco craton) in the supercontinent Nuna. Intraplate magmatism at 1380 Ma is also found on other blocks and is interpreted as heralding a final, widespread breakup phase of Nuna.

A prominent NNW-NNE trending dolerite swarm (Huila dykes) in southeastern Angola has yielded a precise U-Pb TIMS baddeleyite age of 1110±3 Ma. This age is currently unknown in Siberia, suggesting that breakup of Congo-São Francisco craton from Siberia may have happened in association with the 1380 Ma event. This 1109 Ma age is, however, an important and precise match with existing U-Pb ages for the Umkondo Large Igneous Province (LIP) of the Kalahari craton, and also with intraplate magmatism on other blocks such as the Amazonian craton (Hamilton *et al.*, this meeting) and the Bundelkhand craton (India). Based on this equivalence, we consider whether all these blocks (Kalahari, Amazonia, and India) could have been nearest neighbours to the Congo-São Francisco craton during the Mesoproterozoic, and shared a 1110 Ma magmatic event in the Rodinia supercontinent. Although the latter also represents an age match with the early phase of interior Laurentia's Keweenawan event, on paleomagnetic grounds, Mid-Continent Rift magmatism is likely to have been distant and unrelated.

Keynote THE CAMBRIAN CONUNDRUM: THE CONSTRUCTION OF ANIMAL BIODIVERSITY

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A diversity of bilaterian clades first appear in the fossil record within a few million years during the early Cambrian, and a variety of environmental, developmental, and ecological causes have been proposed as explanations. Molecular clock data indicate that Metazoa arose about 780 Ma, followed by the origination of sponges and cnidarians. The basic metazoan developmental toolkit arose by 700 Ma, demonstrating a macro-

evolutionary lag between the establishment of the tools necessary to generate complex animals, and their later ecological success during the Ediacaran, after 579 Ma and Cambrian (541 to 488 Ma) periods. We argue that this diversification involved new forms of developmental regulation, as well as innovations in networks of ecological interaction particularly through ecosystem engineering of environments that facilitated increased metazoan diversity.

A 3D EVALUATION OF RESERVOIRS ASSOCIATED WITH THE BREAK-UP OF ALASKA AND ASSESSMENT OF THE IMPACT OF MANTLE PLUMES

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The North Slope of Alaska is an established petroliferous region with vast amounts of data, much of which is now in the public domain, thereby facilitating a comprehensive review of its geological history and its petroleum systems. The tectonic history of North Slope is complex and has had a profound influence on the deposition of both reservoir and source rocks. Key unconformities that can be correlated to major tectonic events are recognised in the stratigraphy. One such major feature is the Lower Cretaceous Unconformity, or the Break-Up Unconformity, caused by Northern Alaska rifting away from Arctic Canada.

The trigger for this break up is uncertain, although we propose it may be related to the presence of a hot spot plume in the vicinity of Arctic Alaska and the Canadian Arctic Islands during the Early Cretaceous. The break-up caused very rapid uplift along the line of the Barrow Arch across the North Slope and US Chukchi regions although the expression of the resulting unconformity varies along this region. Following the uplift event, subsurface data shows a very pronounced, but rapid subsidence phase in the region leading to a return to deep marine conditions. This series of events is consistent with the passage of a mantle plume and led to the deposition of sandstones during the transgressive phase associated with the rapid subsidence. The sandstones form important proven and potential reservoir facies although they are relatively localised.

Here we show how we have used a comprehensive data set derived from the public domain to address the distribution of petroleum elements across the North Slope. The data set has been interpreted within a proprietary global sequence stratigraphic model and used to build a set of gross depositional environment maps that illustrate the changes in palaeo-environments associated with the break-up event. By placing these maps within a regional 3D model and applying proprietary palinspastic reconstructions, we have gained much improved insights into the causes of the major tectonic events as well as the potential extents of petroleum elements relating to the Lower Cretaceous Unconformity. Results from this approach to interpret data in the North Slope should also provide good analogues for the neighbouring US Chukchi and Beaufort Sea regions.

A REVIEW AND UPDATE OF GEOLOGICAL MODELS AND MINERALIZED ENVIRONMENTS FOR THE VOISEY'S BAY Ni-Cu-Co DEPOSITS, NL

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The Voisey's Bay Ni-Cu-Co sulphide deposits occur within troctolites and olivine gabbros of the 1.34 Ga. Voisey's Bay Intrusion. The Voisey's Bay Intrusion is a member of the Nain Plutonic Suite and straddles the ca. 1.85 Ga. suture between Archean orthogneisses of the Nain Province to the east and Paleoproterozoic paragneisses of the Churchill Province to the west.

The Voisey's Bay intrusion consists of troctolite to olivine gabbro rocks in two large magma chambers connected by an east-west trending horizontal to sub-vertical conduit system. The Ovoid, Mini-Ovoid, Discovery Hill and Reid Brook and the Eastern Deeps deposits are hosted within or adjacent to the sub-horizontal portion of the conduit system. New drilling and 3D reconstruction of the conduits highlights the continuity of the conduit from both west to east and vertically between the two chambers. The conduit forms a structural corridor which is one of the principal exploration target domains for additional zones of mineralization.

A number of geological features provide additional information that help to identify sites where mineralisation is trapped in the conduit-chamber system within spaces created by structures that were reactivated at the time of magmatism. A range of silicate and silicate-sulphide textures, inclusion content and type coupled with host rock type underpin an understanding of the pathways that controlled the emplacement of the sulphide and its location in the conduit.

Exploration continues to follow targets along the trend of the conduit. Examples where the model has evolved include the Reid Brook Zone where reactivated structures in the wall rock have created space for massive sulphides to migrate into the hangingwall and footwall; these sulphides were likely emplaced at the time of formation of the conduit-hosted ores as they have similar compositions. Within the Southeast Extension, a detailed understanding of coinduit morphology and sulphide metal tenor has helped identify discrete domains of sulphide that have been emplaced from multiple conduit entry points into the Eastern Deeps chamber. These ideas are critical to success as exploration of the deeper extensions of mineral in the Reid Brook and Eastern Deeps is undertaken.

Lightfoot, P.C., Keays, R.R., Evans-Lamswood, D.E., and Wheeler, R., 2011. Crustal contamination and multiple S-saturation events in Nain Plutonic Suite magmas: evidence from Voisey's Bay, Labrador, Canada. Mineralium Deposita **47**, 23-50.

Evans-Lamswood, D.M., Butt, D.P., Jackson, R.S., Lee, D.V., Muggridge, M.G., Wheeler, R.I., and Wilton, D.H., 2000. Physical Controls Associated with the Distribution of Sulfides in the Voisey's Bay Ni-Cu-Co Deposit, Labrador. Econ Geol **95**, 749-769.

GEOLOGY OF THE VOISEY'S BAY DEPOSIT: STATE OF UNDERSTANDING OF THE DIVERSITY IN ROCK AND ORE TEXTURES AND SIGNIFICANCE TO PROCESS MODELS

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Extensive exploration and mining activity at Voisey's Bay has provided unparalleled opportunity to assemble a geological understanding of the mineral system that underpins the ongoing search for extensions to mineral zones and new domains of mineralisation. We present a series of samples that document the diversity in petrology, mineralogy, and textures found in the Voisey's Bay Deposit. The Ovoid Deposit comprised a historic reserve of 32.0 Mmt at 2.75% Ni, 1.59% Cu, and 0.137% Co that has now been mined for 7 years at the rate of 2.2 Mmt pa. The ongoing mining activity has provided unparalleled access to samples which document a spectrum in sulphide types that record changes in composition from Po-Cpy-Pn-rich loop-textured pegmatoidal massive sulphides with po grain sizes of 10cm-2m which grade inwards towards small domains of Cubanite-rich ore. The transition between these ore types is recorded in changing proportions of magnetite and sulphide minerals that support the idea of inwards differentiation of one of at least two discrete pulses of sulphide magma with differing Ni tenors - one of these comprises a large part of the Mini-Ovoid and the other represents the majority composition of the Ovoid. The basal breccia sequence rocks are now understood to be complex coarse-grained intergrowths of silicate and sulphide minerals as well as breccia sequence rocks which are typically associated with mafic and ultramafic fragments proximal to the entry point of a dyke into the Ovoid. We show the variations in samples from different parts of the Mini-Ovoid and Ovoid Deposit and show how these are linked to a facies model proposed by Evans-Lamswood *et al.*, 2000.

Exploration activity SE of the Ovoid has provided a new understanding of the geometry of the conduit system, and now shows that different sulphide types are present at the entry point of the Ovoid conduit dyke relative to the Eastern Deeps conduit dyke. Representative samples from each of these environments are shown in the context of the internal stratigraphy of this complex environment. We show these features in relation to samples from holes VB10910 and VB03582 from the Southeastern extension. We also document some of the detailed internal

stratigraphy of the Eastern Deeps Deposit which is consistent with emplacement of a weakly mineralised magma that formed the variable-textured troctolite and a pulse of fragment-laden magma with abundant immiscible sulphide which formed the economic heart of the Eastern deeps deposit. We show these features using samples from drill core VB96-266.

We propose a model for the formation of the sulphide ores that involves S-saturation and upgrading of the sulphides at depth and then emplacement of multiple different batches of sulphide over a limited period of time (Lightfoot *et al.*, 2011).

Lightfoot, P.C., Keays, R.R., Evans-Lamswood, D.E. Wheeler, R., 2011. Crustal contamination and multiple S-saturation events in Nain Plutonic Suite magmas: evidence form Voisey's Bay, Labrador, Canada. Mineralium Deposita **47**, 23-50.

Evans-Lamswood, D.M., Butt, D.P., Jackson, R.S., Lee, D.V., Muggridge, M.G., Wheeler, R.I. and Wilton, D.H., 2000. Physical Controls Associated with the Distribution of Sulfides in the Voisey's Bay Ni-Cu-Co Deposit, Labrador. Econ. Geol. **95**, 749-769.

TRANSPRESSIONAL DYNAMICS AND THE ROLE OF CRUSTAL HETEROGENEITIES IN THE LOCALIZATION OF THE DESMARAISVILLE BASIN (ABITIBI): GEOPHYSICAL STUDY AND ANALOGUE MODELLING

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The Abitibi Subprovince contains many late Archean, 2685 and 2670 Ma sedimentary basins in the southern Abitibi that host several major gold deposits. Their association with terminations or flexures in regional E-W faults, e.g. Destor-Porcupine and Larder Lake–Cadillac faults, as well as their pronounced subsidence and molassic infill, abrupt facies changes and asymmetry have collectively evoked comparisons with transtensional basins.

The Desmaraisville basin, situated in the Abitibi Greenstone Belt about 120 km WSW of Chapais, is characterized by a volcano-sedimentary assemblage, mafic and felsic intrusions, and regional NE-SW faults. The Auger and Lac Bachelor sedimentary sequences respectively occur SE of the Coniagas mine and NW of the Bachelor mine (Métanor Resources Inc.). The Lac Bachelor sedimentary rocks belong to the Haüy Formation dated at 2692 ± 3 Ma in the Chapais region which represents the northern Abitibi equivalent of the Timiskaming sequences. The Desmaraisville basin can therefore be included as a Timiskaming-type basin.

It however differs to other such basins in its position within a NE-SW deformation zone and enhanced TGI-3 Abitibi Project aeromagnetic images do not reveal *en relais* faults that could have formed a trans-tensional basin. The σ schistosity trajectory around a pluton suggests a dextral movement along an E-W deformation zone and en echelon NW-SE faults with dextral offsets are consistent with a transpressional Riedel system during N-S shortening. Bouguer gravity data demonstrate the presence of a denser block to the west of Desmaraisville and a less dense domain east of the town. The "stair-step" shape of the block suggests the presence of E-W dextral shear zones, one of which passes through Desmaraisville.

Analogue tank models incorporating sand layers that simulate brittle upper crust upon silicone-modelling clay that incorporates crustal heterogeneities as identified from gravity data, floating upon a glucose substrate were used to test our interpretations. Shortening of models produces a basin located exactly in the Desmaraisville area. Some faults formed during this experiment correspond to major structures in the field such as de Wedding-Lamarck fault.

The formation of the Desmaraisville basin does not fit the currently accepted model for "transtensional Timiskaming-type" basins, but it could have developed at the interface between crustal heterogeneities during a late N-S shortening phase in the Abitibi. Forthcoming studies will analyze the relationships between transpressional dynamics and gold mineralization in this basin.

ORGANIC AND INORGANIC PORES: THEIR NATURE AND RELATIVE SIGNIFICANCE IN ORGANIC-RICH MUDSTONES OF THE UPPER JURASSIC KIMMERIDGE CLAY FORMATION, OFFSHORE UNITED KINGDOM

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Organic-rich shales of the Upper Jurassic Kimmeridge Clay Formation (KCF), offshore United Kingdom, are at varying levels of thermal maturity in a suite of 9 cores, and samples from these core provide a unique opportunity to evaluate the nature of the organic material and to document changes in organic porosity as a function of thermal maturity. The KCF, which is at depths ranging from ~6,100 ft to ~15,300 ft (subsea), is thermally immature in the shallowest core samples, where TOC contents are as high as 10 wt%, Ro values are ~0.35%, and hydrogen indices (HI) are high (>400). In contrast, it is thermally mature in the deepest core (Ro values ~1.2%), with high TOC contents (as much as 8 wt%) but low HI values (<30).

Detailed petrographic study and SEM analyses reveals the presence of at least four distinct types of organic macerals. Similar organic macerals were observed in all cores across the study area, and include, include, in decreasing abundance: 1) bituminite admixed with clays (deposited as "marine snow"); 2) elongate (< 500 µm) lamellar masses (alginite or bituminite) with small (<0.5 µm) quartz, feldspar, and clay entrained within it (microbial mats); 3) discrete terrestrial grains (e.g. vitrinite, fusinite); and 4) Tasmanites microfossils.

Organic pores, observed on ion-milled surfaces, vary as a function of maceral type, but, importantly, do not increase systematically with increasing thermal maturity (comparison of low vs high maturity samples). Pores in lamellar masses are irregularly-shaped and typically small (<0.1 µm across), whereas regularly shaped pores (<1 µm across) occur in terrestrial macerals. Irregularly-shaped pores (<0.3µm) exist in bituminite admixed with clay. Other pores (inorganic pores), particularly interparticle (i.e., between clay platelets (~1-2µm in length)), and intraparticle (i.e., in partly dissolved K-feldspar and dolomite (<2µm across), as well as framboidal pyrite (<0.1µm across) are present and noteworthy because they compose much of the observable porosity in the Kimmeridge mudstones in both immature and mature samples.

The absence of a systematic increase in organic porosity as a function of either maceral type or thermal maturity and the relatively small size of organic pores indicates that such porosity was unlikely to be related to hydrocarbon generation. Instead, much of the porosity within KCF mudstones must be largely interparticle or intraparticle so the petroleum storage potential in these organic-rich shales largely resides in inorganic pores.

ORIGIN OF THE REGOLITH AT THE IMPACT CRATER AT MISTASTIN LAKE, LABRADOR – IMPACT EJECTA OR GLACIAL TILL

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The purpose of this study was to determine the origin of the regolith at Mistastin Lake, northern Labrador, Canada (55º53'N, 63º18'W), a mid-sized (~28km wide) complex crater formed by a meteorite impact event 36± 4 million years ago. The crater is located in granodiorite, mangerite and anorthosite of the Mistastin Batholith.

The regolith may have formed as glacial till or impact ejecta or a combination of the two; in particular, the lowermost unit may have been derived as impact-derived ejecta from the shocked breccia of the crater. If so, the spectroscopic properties of the mineralogy of the unit may serve as a test target for remote sensing studies.

A sample of each of four regolith units was studied using scanning electron microscopy (SEM) with mineral liberation analysis (MLA)

software to determine mineralogy; X-ray fluorescence spectroscopy (XRF) and solution nebulization inductively coupled plasma mass spectro-metry (ICPMS) to determine bulk chemical composition; and laser-ablation ICPMS to determine dominant zircon age populations.

Results showed that the major minerals present in the samples are the same as those present in the country rocks, which are quartz, plagioclase, perthite, alkali-feldspar and biotite. Garnet, cordierite and aluminosilicate are present in the samples, but not in the country rocks. XRF and ICPMS showed that concentrations of SiO_2 (65.1-69.5 wt %), Al_2O_3 (14.0-15.8 wt %), TiO_2 (0.5-1.6 wt %) and Fe_2O_T (3.5-7.4 wt %) are similar to those in previous measurements for the granodiorite and mangerite (SiO_2: 66.0 and 61.4 wt %; Al_2O_3: 14.4 and 13.7 wt %; TiO_2: 0.66 and 1.3 wt % and Fe_2O_T: 4.8 and 8.1 wt %, respectively). The samples had a dominant zircon population age of approximately 1.4 billion years, the age of the previously dated country rocks.

The data indicate that the major component of the regolith was glacial till derived from the Mistastin Batholith, particularly granodiorite, with some mangerite. There is no evidence of impact ejecta in the regolith or incorporation of the underlying shocked anorthosite breccia into the lowermost unit. Another, less prominent, metamorphic source contributed to the regolith, which may be from the western contact aureole of the Batholith.

LOCATING BURIED REMAINS USING GROUND PENE-TRATING RADAR IN CANADA

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Ground penetrating radar (GPR) is a non-invasive, geophysical tool used for the detection of clandestine graves. GPR operates by detecting density differences in soil by the transmission of high frequency electromagnetic (EM) waves from an antenna. A 500 Megahertz (MHz) frequency antenna is typically used for forensic investigations, as it provides a suitable compromise between depth of penetration and sub-surface resolution. This presentation will discuss a forensic research project conducted in contrasting soil types in Ontario followed by police and forensic case examples.

Domestic pig (Sus domesticus) carcasses were used as human analogues for the decomposition research. Carcasses were clothed and buried at consistent depths at three field sites of contrasting soil type (silty clay loam, fine sand and fine sandy loam) in southern Ontario. GPR was used to detect and monitor the graves for a period of fourteen months post burial. Analysis of collected data revealed that GPR was able to detect clandestine graves containing remains in silty clay loam and fine sandy loam soils, but remarkably was not suitable for detection in fine sand soil. The results of this research have applicability within forensic investigations involving decomposing remains by aiding in the location of clandestine graves. Several successful case examples will be presented.

Keynote PORTRAIT OF A MOUND BUILDING DEEP-WATER CORAL

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With increasing multibeam mapping of continental margins, driven by the evaluation of mineral and biological resources within the exclusive economic zones, some hundred-kilometre-long chains of up to 350-m-high mound clusters became visible. Such examples were found around the rims of the Rockall Bank and Porcupine Bank during the past 15 years. A 400-km-long mound chain was discovered offshore Mauritania and similar impressive structures are currently under research off southeast Brazil as south as to Patagonia. Clusters of mounds also exist in the Florida Strait and on Blake Plateau. All these structures exist in 500-1000 m water depth but when viewed on a local focus, in much narrower bathymetric ranges. Ground thruthing with ROV and manned subs and an IODP drilling campaign revealed the nature of these mounds: coral carbonate mounds. In the Atlantic and their associated marginal seas (Caribbean, Gulf of Mexico, Mediterranean), the azooxanthellate scleractinian Lophelia pertusa and its allies, Madrepora oculata, Enallopsammia rostrata and Solenosmilia variabilis, are the main acters. Best ecological knowledge exists for Lophelia pertusa. This azooxanthellate coral thrives under low temperatures (4-14°C) and can withstand low oxygenated conditions and therefore is even able to expand into oxygen minimum zones of upwelling zones. The self-defense properties of the coral facilitate growth in high particle-laden bottom-water currents and under severe current regimes. Lophelia quickly responds to nutrient and food pulses which are advected from fertile surface waters to the deep. Experiments have analysed the "reef effect" by studying the carbon cycle of corals and the proportion of utilized dissolved organic material. Within a single tidal cycle, up to 40 % of dissolved organics are soaked by the reef community so that the remaining water body is largely depleted. This observation goes in hand with another peculiarity of cold-water reefs which are dominated by suspension feeding organisms. Benthic systems in the bathyal zone generally are driven by deposit feeding communities. The sedimentary matrix of coral mounds shows a bimodality in the grain-size spectrum. The coarse coral fragments (and other internally produced shelly material) is embedded within silt and clay sized material of pelagic and locally of terrigenous origin (eolian, riverine). In many of the Atlantic mounds, remains of coccolithophores and planktonic foraminifers contribute to the bulk of the sedimentary matrix - both became important sediment producers during the advent of the Cretaceous. To conclude, corals without particle-laden bottom waters would hardly be able to build a mound.

ROLE OF SELF-INCURRED RADIATION DAMAGE IN DEVELOPMENT OF TUBULAR AND GRANULAR MICRO-TEXTURES IN SUBMARINE VOLCANIC GLASS: IMPLI-CATIONS FOR MARS EXPLORATION

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The elucidation of microtextures developed during the natural corrosion (dissolution and palagonitization) of basaltic glass by seawater has broad implications for microbial ecology on Earth as well as for the future Astrobiological exploration of Mars. On Earth, such microtextural features have commonly been interpreted as vestiges of microbial activity. As a result, the "biocorrosion" of basaltic glass has emerged as a putative biosignature for the most geographically vast, deep, and long-lived microbial ecosystem on Earth, having been observed in modern glasses of the in situ oceanic crust worldwide as well as in ophiolites and greenstone belts dating back to ~3.5 Ga. If such features were discovered in Martian basaltic glass, either by remote robotic instruments or in terrestrial laboratories after a sample is returned from Mars, such an interpretation would have profound implications for the origin of life (multiple origins? panspermia?). Evidence of bioalteration of basaltic glass along fractures is typically divided into two distinct microtextural varieties: 'tubular' and 'granular'. We propose that these tubular and granular microtextures can form abiotically at the glass-palagonite interface simply as a result of preferential dissolution of radiation-damaged basaltic glass by seawater. Our abiotic (U-Th-Pb-radiogenic) paradigm is based on (1), optical petrographic and Scanning Electron Microscopic (SEM) observations of partially palagonitized basaltic glass pillow margins of the in situ oceanic crust, (2), determination of U and Th concentrations in fresh basaltic glass by Inductively Coupled Plasma – Mass Spectrometry (ICP-MS), and (3), state-of-the-art theoretical modelling of alpha-recoil track and fission track areal densities (i.e., accumulation of radiation damage) in basaltic glass. Numerical modelling of radiation damage based on the known age (~108 Ma) and measured concentrations of U (42 ppb) and Th (132 ppb) in these glasses suggests that they are absolutely riddled with radiation damage (134 million alpha-recoil tracks per cm^2; 1,183 fission tracks per cm^2) amenable to preferential corrosion/dissolution by seawater during palagonitization along fractures. Calculated track areal densities suggest that complex networks of 'tubular', elongate, branching, meandering nanoscopic tunnels (typically ~100-200 nm wide) at the glass-palagonite interface are the result of alpha-recoil track etching. These are interconnected with rare, larger tunnels (~1-2 microns wide by ~8 microns long) that are the result of fission track etching. Incipient palagonitization of dense concentrations of alpha-recoil tracks is also common, resulting in characteristic 'granular' microtexture.

LITHOLOGICAL DISCRIMINATION AND ALTERATION RECOGNITION USING MULTIVARIATE STATISTICAL ANALYSIS ON DRILL CORE MEASUREMENTS, MATAGAMI VMS DISTRICT, ABITIBI GREENSTONE BELT, QUÉBEC

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The Matagami mining camp in the northern Abitibi Greenstone Belt (Superior Province) contains numerous volcanogenic massive sulphide (VMS) deposits, many of which have been mined, and the camp has good potential for additional discoveries. However, only limited information is available on the 3D physical and mineralogical properties of the host rocks for the Zn-Cu-Ag-Au mineralization; this hinders attempts at 3D geophysical modeling, for example. In this context, the Ministère des Ressources naturelles et de la Faune du Québec (MRNF) has commissioned INRS to conduct high-resolution multi-parameter analyses of drill cores from the area over the 2010-2012 period, using the multi-sensor core logger contained in our new mobile laboratory. We have collected more than 30,000 measurements for gamma density, volumetric magnetic susceptibility, visible light and infrared spectrometry (alteration mineralogy) and XRF geochemistry distributed over about 7,000 metres of drill core, at a sample spacing of 20-30 cm.

The vast amount of data and the diversity of measured parameters make it possible to use various approaches to analyze and interpret the data:

- Lithogeochemistry: Measurements made with the portable XRF analyzers, in conjunction with existing lithogeochemistry, can facilitate protolith identification using mostly ratios of immobile elements such as Ti, Al and Zr. Measurements of mobile elements such as Fe and Si are useful to assess hydrothermal alteration.
- Mineralogy: Hydrothermal alteration minerals (abundance, mineral chemistry) can be used as an exploration guide. However, complete petrographic study encompassing several thousand samples is simply not possible. Infrared and visible light spectroscopy thus makes it easier to identify and characterize these minerals.
- Multivariate statistical analysis: Those techniques may be used to group data and/or measurement points based on responses for each parameter.

This third strategy is particularly useful for simultaneously interpreting the entire database. We propose here an approach based on statistical methods, mainly Principal Component Analysis (PCA) and clusters analysis. PCA is initially used to determine the variables dependant of the alteration and those dependent of protoliths. Cluster analysis is then used to separate the data points based on their mineralogical, physical and geochemical signature. Interpretations can be verified on the line-scan images that are also acquired during logging.

By combining statistical and conventional approaches, we aim to use the data acquired with the multi-sensor core logger to achieve a fairly detailed resolution in the spatial discrimination of lithologies and alteration related to the emplacement of ore deposits.

APPLIED REFLECTANCE SPECTROSCOPY AND MINERALOGICAL STUDIES OF GOSSAN HILL, VICTORIA ISLAND, NORTHWEST TERRITORIES, CANADA

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Iron-oxide and sulfate-rich alteration halos were discovered surrounding exposed and sub-surface pyrite deposits in an area of positive relief known as "Gossan Hill" on Victoria Island, Northwest Territories. This site provides an excellent example of iron-sulfide and native sulfur deposit alteration processes in an arctic environment where the permafrost exists at shallow depth. Samples of surficial material were sieved into coarse (500u ìm-1410 ìm, >1410 ìm) and fine (<500 ìm) fractions for spectral reflectance and X-ray diffraction analysis at varying grain-sizes. Finer grain sizes typically yielded greater absolute reflectance and enabled a more direct comparison of samples with different initial grain size. Sieved samples were analyzed with an ASD Inc. Terraspec Examiner VNIR/ SWIR spectrometer to characterize the spectral reflectance of each zone of mineral alteration. X-ray Diffraction analysis was used to identify minerals within the surficial alteration halo and the underlying source material. Mineral assemblages were characterized by comparison with a library of mineral spectral reflectance using The Spectral Geologist (TSG) software. The spectral reflectance data was then smoothed and processed with TSG and ENVI EX applications. Hull quotient, derivative and other spectral profile correction techniques have been considered; however, care was taken in order to avoid destruction of the faint SWIR spectral characteristics produced by cations such as ferrous iron present in the structure of pyrite and some ferrous iron oxides. Over-processing of laboratory data was avoided to allow for direct comparison with remote sensing imagery. Laboratory reflectance of each sample was averaged into a weighted linear mix, with weighting placed on greater surficial volume, finer grain sizes and greater absolute reflectance. The mixed spectral profile was tuned to LANDSAT-7 and SPOT-5 multispectral images of the study site by creating a limited profile of specific bands at 500-590nm, 610-680nm, 780 -890nm and 1580-1750nm. The results of the study provide a test of remote predictive mapping techniques for gossans related to ore bodies based on remote multispectral data.

IN SITU ELEMENTAL AND ISOTOPIC MICROANALYSIS OF INDIVIDUAL MINERAL GRAINS: THE KEY TO UNRAVELING COMPLEX GEOLOGICAL PROCESSES

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The petrographic microscope first provided geologists with the ability to delineate mineral growth, alteration, and paragenetic sequences in rocks exhibiting evidence of complex and often multi-stage histories. While the ability to visibly recognize these temporal complexities has allowed detailed relative chronologies of events to be determined, the lack of complete chemical characterization at correspondingly small spatial scales has often led to incomplete or erroneous interpretations with respect to mineral or rock genesis.

Modern microbeam analytical systems, such as laser ablation inductively coupled plasma mass spectrometry, can now provide multi-element, high-sensitivity major, minor, trace, and ultra-trace chemical analyses of minerals within petrographic thin sections and at the scale of petrographic observations. Because the analyzers in these systems are often mass spectrometer-based, these microbeam techniques can also be used to obtain high-precision isotopic data. These data can be used to further elucidate the origins and significance of the chemical complexities we have been able to observe in geologic materials since the adaptation of microbeam techniques to these applications. These techniques are particularly well suited to the study of mineral deposits and their formative processes, which can produce minerals with extreme compositional variations over exceeding small spatial scales.

The fluorspar deposits associated with the St. Lawrence Granite of southeastern Newfoundland provide an excellent example of the power of these new in situ microbeam techniques. Mapping the trace element chemistry continuously across growth zones within a single fluorite crystal demonstrates the complexity of the compositional evolution of the hydrothermal system, particularly the changing anomalous behaviour of Y relative to the heavy rare earth elements (HREE). It is clear from the changing magnitude and temporal relationship of the Y anomaly with concentration variations of Y compared to REE, such as Ce and Lu in the growing fluorite crystal, that Y geochemistry is 'decoupled' from that of the REE and that the change of chemistry in the hydrothermal fluid from which the fluorite crystallized is complex and varies rhythmically with time. Adding *in situ* isotopic data for Pb and Sr will provide information on the source of the chemical changes, e.g., magmatic fluid evolution versus interactions with external fluids derived from the country rock the granite has intruded.

THE CRUSTAL STRUCTURE OF THE EIRIK RIDGE AT THE SOUTHERN GREENLAND CONTINENTAL MARGIN

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In 2009, the SIGNAL (Seismic Investigations off Greenland, Newfoundland and Labrador) experiment was carried out to acquire marine refraction seismic data in the area between southern Greenland and Canada. Two lines were located on the Eirik Ridge off the southern tip of Greenland where two different continental margin styles merge. The SW Greenland continental margin is characterized by non-volcanic rifting associated with the opening of the Labrador Sea. Here, wide continent-ocean transition zones with serpentinized mantle are observed. In contrast, the later opening of the NE Atlantic formed volcanic-style margins off SE Greenland. The Eirik Ridge is a 300-km-long sediment drift and the SIGNAL experiment was designed to study the underlying crustal structure. SIGNAL line 3 is a 295-km-long refraction seismic line located on the top of the Eirik Ridge and extends into the Labrador Sea. Line 2 (225 km) crosses the ridge and continues into the NE Atlantic. Dense airgun shots were recorded by 24 and 20 ocean bottom seismometers (OBS) on lines 3 and 2, respectively. Preliminary velocity models indicate the presence of volcanic rocks, up to 4-km-thick on the ridge, which form a basement high beneath the ~2-km-thick sediment drift. A high-velocity lower crustal layer (7.1 to 7.5 km/s) with a thickness of up to 8 km underlies the ridge. Moho shallows from 17 km just off the shelf break to 13 km at the feather edge of the ridge. Seaward of the ridge, 4 to 5-km-thick oceanic crust is observed in the Labrador Sea, while initial oceanic crust in the NE Atlantic has a thickness of 10 km. The models suggest that the ridge formed on transitional and initial oceanic crust created during the opening of the Labrador Sea. This crust was then modified by intrusions and extrusions associated with the volcanic style margin formation in the NE Atlantic around 56 Ma. Coincident reflection seismic data along the two SIGNAL lines indicate the presence of inner and outer seaward-dipping reflection sequences separated by an outer basement high. This suggests a subaerial formation of the lavas on the ridge. Cooling and loss of dynamic support by the Iceland plume resulted in the subsidence of the ridge.

INSIGHTS INTO THE STABILITY OF CRYSTAL STRUCTURES

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The general failure to make reliable crystal structure predictions from chemical composition has been identified as the major problem in Crystallography. A new approach that scrutinizes the atomic factors affecting the stability of crystals, and how these factors can be turned into predictive tools that gives insight into the atomic-scale reasons for structure stability or instability is presented. A four-step methodology is developed, addressing issues of (1) bond topology and ideal bond-valences; (2) the assignment of atoms to vertices in the bond-topology graph, and the resulting ideal bond-lengths; (3) 3-D distance-least-squares refinement; and (4) energy evaluation. The result is a better understanding of the connection between bond topology and site populations in crystals from a priori considerations. In the first step, bond topologies are represented as graphs and the mathematical approaches of Graph Theory are used to represent structures in a simple and irreducible form. Following the construction of a topology, a set of ideal bond-valences (the weights of the graph) is calculated from the valence-sum and loop equations of the topology and its associated vertex charges. The question then becomes whether there is a specific combination of cations and anions that can adopt this arrangement. The International Crystal Structure Database (ICSD) enables comprehensive evaluation of the bond-valence ranges that atoms may adopt by surveying the database for the dispersion of bond-lengths for all combinations of atoms, oxidation states and coordination numbers. This, combined with the sets of ideal bond-valences calculated at step 1 allows assignment of atoms to the vertices of the graph of the structure, where the ideal bond-valences must fall within the bond-valence range of the atoms derived from the ICSD analysis. The bond-length bond-strength correlation of Bond-Valence Theory is then used to convert the topology into a set of ideal bond-lengths to be satisfied in three dimensions for the structure to be physically feasible. A distance-least-squares refinement in step 3 yields a structure in Cartesian space, while step 4 evaluates the structure in terms of energy. Different applications of the methodology ensue from various approaches, such as the determination of all possible chemical substitutions within a structure type, the substantiation of the inexistence of certain charge arrangements within a structure type, a stability study of "ad hoc" topologies and the probing for the predicted level of symmetry and order/disorder in "ad hoc" topologies.

PETROGRAPHY AND FLUID INCLUSION ANALYSIS OF AURIFEROUS AND BARREN VEINS FROM THE EAST BAY TREND, RED LAKE, ONTARIO, CANADA

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The East Bay Trend is a large structural corridor that parallels the East Bay of Red Lake, Ontario and is interpreted to be a manifestation of the regional D1 structure that crosscuts this complexly folded greenstone belt. The southernmost 8 km of this corridor is host to a variety of small gold deposits that demonstrate an assortment of mineralization styles. This study aims to: (1) better define the styles of veining and characterize the mineralizing fluids through the use of petrography, fluid inclusions, geochronology and stable isotopes, (2) compare barren and auriferous vein systems from deposits along the East Bay Trend, and (3) compare the fluid history of the East Bay Trend to the nearby Campbell-Red Lake gold deposit. There are four types of auriferous veins throughout East Bay, including quartz, quartz-carbonate, quartz-tourmaline, and quartz-actinolite veins. There is also abundant carbonate veining that generally predates the auriferous system. These veins are typically hosted in the 2.9 Ga mafic volcanics that have significant silicification, carbonatization and biotite/chlorite alteration adjacent to veining.

Carbonic, aqueous, and aqueo-carbonic (three-phase) are the three main types of fluid inclusions, occurring in barren and auriferous veins throughout the trend. The carbonic inclusions are the most abundant with aqueous inclusions representing a smaller proportion and three-phase inclusions as the least common. The homogenization temperatures of the carbonic inclusions range from -13.2°C to 26.3°C. The homogenization temperatures of aqueous inclusions range from 164°C to 345°C and have salinities of 8 - 23 wt% NaCl equiv. The homogenization temperatures of aqueo-carbonic inclusions range from 192°C to 398°C with salinities of 10 - 24 wt% NaCl equiv.

Fluid inclusions with variable liquid-vapor ratios dominate throughout the auriferous veins in the East Bay trend. The most prospective gold areas in this trend (McMarmac and Chevron) stand out because three-phase (H_2O+CO_2+liquid) inclusions dominate over the other types. These data suggest that immiscibility and effervescence play an important role in gold precipitation. In addition, fluid mixing may also play a part in precipitating gold as primary aqueous fluid inclusions from Chevron and Abino yield wide ranges in salinities and homogenization temperatures. Although three-phase inclusions and variable liquid-vapor ratios occur in barren veins, they represent a small percentage of the inclusions. These data will help refine genetic models for deposits located in the East Bay Trend and will improve our understanding of the fluid history associated with gold mineralization throughout the Red Lake area.

VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS OF THE PALEOPROTEROZOIC FLIN FLON DISTRICT: THEIR RECONSTRUCTION AND POST DEPOSITIONAL MODIFICATION

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The Paleoproterozoic Trans-Hudson Orogen (THO) is well known for its contained volcanogenic massive sulphide (VMS) deposits that are

restricted to juvenile arc assemblages that were structurally juxtaposed with VMS-barren back-arc, ocean-plateau (floor) and ocean island assemblages during accretion resulting from initial closure of the Manikewan Ocean (circa 1883 Ma). Assemblage boundaries are faults, often former thrust faults, which are consistent with allochthonous construction of the THO. The Flin Flon District (circa 1889 Ma) contains the Flin Flon, Callinan and 777 deposits, which total more than 92.5 million tonnes at 2.21% Cu, 4.25 % Zn, 2.11 g/t Au and 27.22 g/t Ag, and is the THO's premier VMS district. The Flin Flon District occurs within an oceanic arc assemblage that was amalgamated into the Flin Flon-Glennie Complex during an interoceanic accretion event (1910–1870 Ma). At Flin Flon, the VMS deposits are interpreted to have formed during rifting of a basalt-dominated oceanic arc and the deposits are localized within a volcanic –tectonic subsidence structure or cauldron defined by: 1) a thick but aerially restricted package of predominately mafic megabreccia deposits containing blocks up to 50m in size; 2) internal angular unconformities; 3) basaltic and rhyolitic dike swarms and vents localized within the presumed core of the cauldron; 4) numerous synvolcanic faults; and 5) high-temperature epidote-quartz alteration. The VMS deposits are associated with proximal coherent rhyolite and more distal rhyolitic volcaniclastic facies that occur in distinct fault blocks within the larger cauldron.

Structures that are most significant to the reconstruction of the Flin Flon District and to ore modification include: 1) D1 and NNW-striking D_2 folds and faults that formed during accretion of the Flin-Flon Glennie Complex, prior to deposition of the Missi Group (1847-1842 Ma), a successor arc basin assemblage that unconformably overlies the volcanic rocks; 2) Post-Missi, west verging D_3 and north verging D_4 thrust faults that formed during final accretion of the Flin Flon-Glennie Complex and collision of the amalgamated complex with the Sask craton; and 3) a strong SE-plunging stretching lineation that formed during D4 thrusting and deformed the ore lenses into their present flattened cigar shape.

COMPUTATIONAL MECHANICS AND THE DETECTION OF INNOVATION IN EARTH SYSTEMS

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Many Earth systems consist of myriads of local interacting subsystems. Intuitively one might expect the effects of these interactions to disappear into chaos; we find instead that highly ordered structure often arises on a global scale. We call such order "emergent properties". The mechanisms by which such emergent properties arise from local-scale interactions is not understood and they may change despite a lack of observable changes in local conditions. Such changes may appear as reorganizations of the system on a global scale, which we refer to as "innovation". Possible examples of such innovation include the proposed change(s) in character of plate tectonics during the Archaean; Neoproterozoic glaciations; and magnetic pole reversals. Recognizing innovation in Earth systems on the basis of geological time series is difficult due to our natural tendency to interpret new observations in terms of our current understanding. Computational statistics can be used to provide insight by characterizing the complexity of Earth system behaviour from which we may recognize changes in organization of Earth systems. The change in dynamics of global glaciations during the Mid Pleistocene transition may be an example of innovation.

MAJOR AND TRACE ELEMENT GEOCHEMISTRY OF BIOTITES FROM THE VOISEY'S BAY AND MUSHUAU TROCTOLITES, LABRADOR, CANADA

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The Voisey's Bay troctolite is the main host to nickel-copper-cobalt sulphide mineralization at the Voisey's Bay deposit in northern Labrador, Canada. The troctolite is present in three main environments, viz.; a) as the dominant phase in large layered magmatic chambers, b) as feeder dykes beneath the chambers and c) as chilled margins adjacent to the chambers and feeder troctolites. Biotite, a hydroxyl-bearing phase, accounts for up to ten modal percent of troctolite from chambers, feeders and chills. Through petrographic observations of biotite, primary and secondary biotite could be distinguished in the troctolites. Scanning electron microscopy and mineral liberation analysis (SEM-MLA) was used to define the modal mineralogy of troctolite samples and more specifically to map mineralogical associations of biotite with respect to other mineral phases. Biotite is modally more abundant and coarser-grained in brecciated feeder troctolites (vs. chamber troctolites), preferentially rimming blebby and disseminated sulphides and oxides. Electron probe microanalyses (EMPA) were completed to determine major and trace element geochemistry for biotites from a variety of troctolites. There is a notable variation in the fluorine content of biotites between the Eastern Deeps, Western Deeps, Ashley-Floodplain, and Mushuau chamber zones. The highest fluorine and chlorine values are observed in biotites from Ashley-Floodplain and the lowest in biotites from the Mushuau troctolites. Furthermore, EMPA geochemical data indicate that although biotite is present throughout the Voisey's Bay and Mushuau troctolites, the Western Deeps and Discovery Hill troctolites contain phlogopite (the magnesian end member of the biotite-phlogopite mineral group), not biotite. Major and trace element geochemistry also indicates the existence of two chemically distinct biotite phases throughout the Voisey's Bay troctolites: those in chilled troctolites and those in chamber and feeder troctolites.

Keynote A HIMALAYAN TOP-DOWN PERSPECTIVE INTO A MID-CRUSTAL FLOWING OROGEN

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The Nepal Himalaya offers an excellent top-down view of an active thermo-mechanical continental collision orogen. This presentation offers a synthesis of key observations and interpretations made over 15 years that contribute to our understanding of continental collisional orogenic systems, from a top-down perspective. Nonetheless, the understanding of this prototypal system has significant limitations and need to be complemented by observations made in deeper-exhumed orogens such as the Grenville-Sveconorwegian system.

The Himalayan orogenic core in central Nepal exposes two lithotectonic elements, separated by crustal-scale faults. The uppermost orogenic superstructure package, the Tethyan sedimentary sequence (TSS), is a Paleozoic-Mesozoic weakly-metamorphosed sedimentary sequence originally deposited on the northern margin of the Indian craton. The subjacent Greater Himalayan sequence (GHS), representing the infrastructure, comprises amphibolite to granulite metamorphic facies rocks and extensive granitic melts and migmatites. The TSS/GHS interface, the South Tibetan detachment system, acted as a Miocene normal-sense décollement zone during southward extrusion of the GHS, coeval with slip along the Main Central thrust at the base of the GHS.

Our research documents significant thickening (>150%) of the TSS early in the orogenic evolution, which is interpreted to have instigated burial and metamorphism of the GHS in Eocene-Oligocene. This first orogenic phase was then followed by extensive Miocene melt-weakening and southward extrusion of the infrastructure, and decoupling of the superstructure along the South Tibetan detachment system.

Based on microstructural, geochronological, and thermobarometry studies, the GHS can be divided in two domains. The lower domain contains peak metamorphic assemblages yielding a metamorphic field pressure gradient that increases up structural section from 8 to 11 kbar, whereas the upper portion of the GHS records a metamorphic pressure gradient that decreases up structural section from 10 to 5 kbar. During the extrusion phase, the GHS underwent almost equal coaxial and noncoaxial strain at temperatures ranging between ~450°C to >700°C, similar to peak metamorphic temperatures determined by thermometry. This flow style was diachronous, occurring earlier in the upper part of the GHS, and propagated structurally downward and toward the foreland. The extrusion strain accommodated significant vertical thinning and horizontal stretching in the hinterland part of the orogen, which was counterbalanced by vertical thickening and horizontal shortening in the foreland. This hinterland-foreland transition, coinciding with the boundary between the upper and lower portions of the Greater Himalayan sequence, highlights the

complementarity of deformation processes between orogenic cores and forelands.

EVIDENCE FOR COMPLEX SEDIMENT TRANSPORT PATHWAYS IN THE WESTERN CANADA SEDIMENTARY BASIN DURING THE EARLY AND MIDDLE TRIASSIC

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U-Pb dating of detrital zircons in clastic sedimentary rocks can provide insight into the source of the sediment, and also the timing of tectonic events that control sediment distribution. The Western Canada Sedimentary Basin contains sediment of Early and Middle Triassic age that was deposited in relatively deep water, on what is thought to have been a passive margin. In northeastern British Columbia, these rocks belong to the Toad and Liard formations at the surface, and to the Montney and Doig formations in the subsurface. These subsurface formations are important source and reservoir rocks for tight gas and shale gas plays in B.C. As such they have received a large amount of attention, but the tectonic environment they were deposited in is still unresolved. Although previous models have involved a quiescent margin during the Triassic with terrane accretion occurring only in the Jurassic, structural studies and detrital zircon analyses from the Yukon have produced data that conflicts with this scenario. Instead, collision between ancestral North America and the Yukon-Tanana terrane may have occurred as early as the Late Permian. If this is the case, then a large foreland basin would have been present during the Early and Middle Triassic, and sediment would have been derived from both the North American craton and from the terranes to the west. Although evidence for this has been found in the Yukon, data from B.C. is still sparse. Previous work in B.C. has not found any zircon grains in Triassic sedimentary rocks that can unambiguously said to have been derived from the west. However, detrital zircons with ages from the Devonian and the Mississippian have been found in collections from Williston Lake and the Alaska Highway. Igneous rocks of this age are not common on the craton, but neither are they confined to the pericratonic terranes. Possible source areas for these zircons include the Innuitian orogenic wedge to the north and the Exshaw Formation to the east. The samples have been dated using conodont biochronology and span a period from the Smithian to the Ladinian. These results imply that during the Early and Middle Triassic, the sediment transport pathways were more complex in B.C. than has previously been thought, although no definitive evidence for terrane accretion has yet been found. This may be due to the presence of the Peace River Embayment at this time, which could have prevented the alongshore movement of detrital zircons from terranes that had accreted to the north.

A MINERALOGICAL STUDY OF HEXAGONAL PYRRHOTITE ALONG THE COPPER CLIFF OFFSET, SUDBURY

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Pyrrhotite, present as both hexagonal (HPo) and monoclinic (MPo) polytypes, is a common mineral present in Fe-Ni-S ores occurring in quartz diorite of the Copper Cliff Offset (CCO), south range, Sudbury. While MPo dominates in most Sudbury ores, those present in the CCO show variable but high HPo:MPo ratios. This study addresses the mineralogical, chemical and geological controls that could play roles in stabilizing high HPo concentrations.

Modal mineralogy and quantitative HPo:MPo ratios were determined through Rietveld analyses of powder XRD data. Combined image analysis and application of magnetic colloid to polished thin sections (PTS) confirmed the results obtained by Rietveld analyses, both in terms of the bulk mineralogy and obtained HPo:MPo ratios. Optical microscopy of PTS identified textural relationships present, including crystallographically controlled lamellae of MPo and varying degrees of boxwork intergrowths. Since MPo shows a strong ferromagnetic behaviour, unlike HPo, magnetic susceptibility measurements were taken to empirically determine areas with high concentrations of HPo; systematic trends were observed and are currently being characterized.

The major and minor element chemistry of MPo and HPo were determined by SEM-EDS. Results show that there are no significant variations in Fe:S ratios or minor element (Ni, Co) concentrations. MPo and HPo were found to have virtually identical average compositions of Fe0.85-0.86S, with ranges in Fe:S for the two directly overlapping. These observations appear to contradict results from previous studies of the Fe-S system. The average minor element contents are also virtually identical, with 1.02 wt.% Ni and 0.23 wt.% Co in MPo, and 1.09 wt.% Ni and 0.26 wt.% Co in HPo.

To evaluate the role that trace element concentrations could have in the stabilization of HPo, LA-ICP-MS analyses were carried out on select samples. The data indicates that the samples are devoid of Os, Ir and Pt while Ru, Rh and Pd are present in low, but statistically similar concentrations within both MPo and HPo. The average PGE concentrations in MPo are 0.42ppm Ru, 0.01ppm Rh and 0.1ppm Pd, while HPo was found to have similar average values of 0.53ppm Ru, 0.04ppm Rh and 0.05ppm Pd; the total PGE range for both MPo and HPo is 0-1.26ppm.

Research into potential HPo stabilization factors is ongoing and possible controls, such as textural relationships, modal mineralogy and associated mineral chemistry, will be discussed.

SIMULTANEOUS *IN SITU* DETERMINATION OF BOTH U-PB-TH AND Sm-Nd ISOTOPES IN MONAZITE BY LASER ABLATION USING A MAGNETIC SECTOR ICP-MS AND A MULTI-COLLECTOR ICP-MS

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Monazite is a common and resilient orthophosphate accessory mineral found in a wide range of rock types, and is commonly used to constrain the timing of geologic events (U-Pb-Th isotopes) and source materials (Sm-Nd isotopes). We present a method which exploits these virtues of monazite by simultaneously measuring its U-Pb-Th and Sm-Nd isotopic compositions *in situ*, using a laser ablation system coupled to both magnetic sector and multi-collector inductively coupled plasma mass spectrometers (i.e., the ablated material is split using a baffled glass Y-connector and simultaneously transported to the two mass spectrometers). In addition, the MC-ICPMS is also configured to measure relative Ce, Nd, Sm, Eu, and Gd contents. This approach offers the advantage of obtaining both age, tracer isotope, and trace element data, in the same ablation volume, thus reducing sampling problems associated with fine-scale zoning and other internal structures. At the same time, this approach maximizes the amount of data that can be obtained from a single analysis, making it ideal for detrital monazite studies in which a large number of grains need to be analyzed. Owing to the high concentration of target elements in monazite (e.g., light rare earth elements, Th, U, Pb), the sample can be precisely analyzed using a 20 μm laser spot size which typically allows many analyses to be done on a single grain. The accuracy and precision of the U-Pb data is demonstrated using six well characterized Geological Survey of Canada monazite reference materials (three of which are currently used as SHRIMP standards) and agree well with previously determined ID-TIMS dates (Stern and Berman, 2000). Accuracy of the Sm-Nd isotopic data are assessed relative to TIMS determination on a well-characterized in house monazite standard.

JURASSIC TO CRETACEOUS (POST-RIFT) TECTONICS OF THE EASTERN MARGIN OF THE CENTRAL ATLANTIC (MOROCCO)

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The application of quantitative methods to constrain vertical movements along the Morocco Central Atlantic margin (subsidence analysis for sedimentary basins and low-temperature geochronology for exhuming domains) has documented surprising displacements during Jurassic to Cretaceous times, that is, following Central Atlantic oceanic spreading. Basins located along the Moroccan coast (Doukkala, Essaouira-Agadir and Tarfaya) subsided during Triassic to early Jurassic rifting but continued to do so also after the appearance of oceanic crust. The observed magnitude of subsidence cannot be explained by uniform thinning models compatible with the regional geology. Largest discrepancies occur during the 170-100Ma time frame when thermal subsidence models can justify <50% of the documented subsidence. The area to the E of the subsiding domain experienced km-scale exhumation during Jurassic-Cretaceous times. The exhuming domain stretched from Rabat in the N to, at least, the Reguibate shield for a distance of >1200km roughly parallel to the Atlantic margin. The width (in E-W direction) of the area is poorly constrained. Kinematic and fully dynamic models of rifted margin evolution are able to justify only <30% of the observed upward movements. The subsiding and the exhuming domains were not separated by any significant faults and the transition between the two regions occurred by progressive W-ward tilting of the substratum. Outcrop-scale observations suggest that this tilting and the associated vertical movements were caused by crustal shortening, roughly oriented E-W. The exhumation of large areas of Morocco allowed for the onset of widespread erosion and the production of large amounts of terrigenous sediments which were transported towards the Atlantic margin by fluvial systems and were deposited in the subsiding basins. These terrigenous deposits contrast with the otherwise monotonous and fine-grained character of the Jurassic to Cretaceous offshore sediments of Morocco.

The deformation style, the vertical movements and the sedimentary succession of the margin bear significant similarities with the evolution of the conjugate Central Atlantic margin, that is, North-East US and South-East Canada suggesting non-orthodox connections between the two margins during their post-rift stage.

AN UPDATE ON DIAMOND DRILLING AT THE MURRAY BROOK VMS DEPOSIT

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The Murray Brook deposit is a polymetallic, volcanic hosted, massive-sulphide deposit and is the fifth largest in the Bathurst Mining Camp. Kennco produced an indicated resource of 21.5 million tonnes at 0.48% Cu, 0.66% Pb, 1.95% Zn and 31.4 g/t Ag (Perusse, 1958). The deposit is located on the northwest margin of the Cambrian to Middle Ordovician, Bathurst Supergroup. The deposit is hosted by shale, siltstone and lithic tuff assigned to the Mount Brittain Formation that is gradational into feldspar crystal, lithic-lapilli tuff and flows.

Votorantim optioned the property from Murray Brook Minerals following a review of the digital database and due diligence that included a three hole drill program to twin historical drill holes. The Phase I exploration program started in early 2011 and consists of diamond drilling of the Murray Brook deposit to confirm previously reported massive sulfide widths and grade. The Phase II drill program is designed to further delineate the deposit in areas of low drill density, follow-up higher grade intercepts, drill test the margins of the known massive sulfide body. A total of 66 DDH have been completed by Votorantim for 11,000 meters and an additional 18,000 meters of drilling is planned in 2012. An economic evaluation of the resource will be based on the drill results.

HYDROTHERMAL REMOBILIZATION OF HFSE/REE: THE ROLE OF F-RICH FLUIDS AT STRANGE LAKE, QUÉBEC, CANADA

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The mid-Proterozoic Strange Lake pluton, which consists of peralkaline granite intrusions and associated pegmatites, is host to a world-class rare earth element (REE) and high field strength element (HFSE) deposit. Previous studies have provided extensive evidence for the hydrothermal remobilization and mineralization of the REE and HFSE. Similar observations have been made for other alkaline and peralkaline igneous bodies, notably, the Tamazeght (Morocco) and Khan Bogd (Mongolia) complexes. These complexes have in common a high enrichment in fluorine, which is known to enhance the solubility of the REE and HFSE in fluids and melts. In this study, we focus on the F-rich alteration observed in altered subsolvus granites and pegmatites located in the northwestern part of the Strange Lake pluton. Field relations indicate that the pluton experienced multiple F-rich fluid infiltration events, which lead to the formation of veins and breccias, and pervasive alteration of the granites. These infiltrations were largely confined to a narrow zone dominated by pegmatites, which we suspect formed a porous corridor of focused fluid flow. The mineral textures indicate strong interaction of the granites and pegmatites with F-rich fluids. The co-precipitation of secondary HFSE/REE minerals with hydrothermal fluorite suggests that this interaction caused a change in physico-chemical conditions leading to immobilization of the HFSE and REE. Preliminary observations indicate that zirconosilicates and possibly pyrochlore were the most important primary sources for the rare metals, and suggest that dissolution of these minerals lead to the complexation of the rare metals with F^- present in the fluid. Other potentially important complexing ligands are Cl^- and CO_3^{-2}, which, published fluid inclusion studies have shown, are present in high concentrations in the fluid. We have investigated the capability of such fluids to leach rare metals from the primary rock and their role in remobilizing and concentrating the REE and HFSE. A key finding of this investigation is that fluoride activity (a_{F^-}) and in turn REE/HFSE mobility is controlled by the availability of Ca in the environment. The development of a robust model for the genesis of REE/HFSE deposits such as that at Strange Lake will require a better understanding of the evolution of these F-rich fluids from the magmatic-hydrothermal transition to the final stages of fluid-rock interaction.

CRETACEOUS-PALEOGENE INVERTEBRATE FAUNAS FROM BYLOT ISLAND, NUNAVUT PROVIDE DIRECT LINKAGE WITH WEST GREENLAND STRATIGRAPHIC SEQUENCES

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Cretaceous-Paleogene strata exposed on Bylot Island and the north coast of Baffin Island, northeast Nunavut, Canada, serve as reference stratigraphic successions for the Baffin Shelf, a region of significant petroleum resource interest. Coeval successions with demonstrated petroleum shows are known from offshore areas of West Greenland. Accurate correlation between these regions is thus of vital interest for petroleum exploration, as well as for interpreting the tectonic and depositional history of circum-Baffin Bay basins.

Cretaceous-Paleogene strata of Bylot Island accumulated in a variety of depositional environments, from fluvio-deltaic to deeper-water shelf settings. Strata show locally abundant sulfur which may be responsible for the poor preservation and low abundance of foraminiferal, calcareous

nannofossil, and radiolarian microfossils; where present, foraminifera are of benthic agglutinated nature and indicate a deep water setting. Mollusks and other macroinvertebrate groups are also relatively uncommon in the strata and intrabasinal biostratigraphic correlation has thus relied primarily on palynology, principally dinoflagellates and pollen and spores. Although some palynological assemblages recognized in Bylot Island strata are also recognized on the Newfoundland and Labrador Shelf and the western Canadian Arctic, direct correlation with the succession of West Greenland has not yet been fully established.

Paleogene strata of Bylot Island contain the gastropods *Fusinus* sp., *Nekewis* sp., and cf. *Levifusus* and cf. *Vanikoropsis*, as well as the branching coral *Faksephyllia* sp., of Danian age; similar faunas are known from the Agatdal Formation of West Greenland. Stratigraphically lower strata of Bylot Island have produced sparse aporrhaid and nerinacean gastropods, indicating a Maastrichtian age and suggested correlation with the Kangilia Formation of West Greenland. Stratigraphically still lower fossils from Bylot Island include turritellid and aporrhaid gastropods, as well as possible sphenoceramid bivalves, indicative of a probable Campanian age and suggesting correlation with the upper Atane and possibly Itilli formations of West Greenland. Oldest macroinvertebrate remains from Bylot Island include inoceramid bivalves assignable to a likely Albian-Cenomanian age, and their containing strata are thus correlative with the lower Atane Formation.

No stable isotope record spanning Late Cretaceous-Early Tertiary time presently exists for the Canadian Arctic region. Ongoing bulk stable organic carbon isotope studies of strata on Bylot Island will hopefully refine local correlations, improve correlation with other basins in the circum-Baffin Bay region, and provide a reference for paleoenvironmental change across the northern Baffin Bay region during the Late Cretaceous and Early Tertiary.

SYNTECTONIC DEEP-WATER CARBONATE MOUNDS: IMPLICATIONS FOR THE EVOLUTION OF THE MESOPROTEROZOIC BORDEN BASIN, NUNAVUT

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The Mesoproterozoic Borden Basin, host of the Nanisivik Pb-Zn deposit, is one of the tectonostratigraphically complex Bylot Basins. Deposition of syntectonic, deep-water black shale of the 1.1 Ga Arctic Bay Formation, low in the stratigraphic succession, was accompanied by accumulation of large, isolated carbonate mounds of the Ikpiarjuk Formation. The mounds are centred along and elongate parallel to syndepositionally active extensional faults, and are several kilometres in diameter, and several hundred metres thick. This syndepositional fault activity at ~1.1 Ga may have been related to tectonic stresses during assembly of Rodinia rather than the much older Mackenzie igneous event (~1.27 Ga).

The Ikpiarjuk Formation mounds lack "normal" features of Mesoproterozoic reefs and have an unusual origin. Some mounds contain a faintly clotted to massive texture in outcrop. The clotted texture is defined by variably connected, irregularly shaped voids. The voids are filled by several generations of isopachous carbonate cement, by internal mud-grade sediment, or both. Intraclast debrites on mound flanks indicate that at least some mounds were gravitationally unstable and had relief from the seafloor, or were eroded after deposition. In two locations, smaller "moundlets", <100 m wide and tens of metres high, are stratigraphically below the larger mounds. In one location a moundlet is overturned within flat-lying Arctic Bay shale, indicating that the fault which it was centred on was active during deposition. Each mound has a different growth history. Of the two mounds examined thus far, the "clotted" texture is significantly different in each location. The size of voids in the "clotted" texture, generations of isopachous cement, and abundance of internal sediment is different among locations.

The mounds are interpreted to represent fossilised cold seeps of unknown fluid composition, and to have accumulated where fluids entered seawater through seafloor fissures associated with active intra-graben faults. The clotted texture is similar to thrombolitic textures present in late Neproterozoic reefs. This texture suggests that the formation of mounds may have been influenced by microbial activity. The depositional environment of the Ikpiarjuk Formation mounds was deep-water and anoxic, which explains why the mounds are not analogous to "normal" Mesoproterozoic reefs.

THE PORT HOPE SIMPSON RARE EARTH ELEMENT DISTRICT – FELSIC VOLCANIC AND PEGMATITE HOSTED MINERALIZATION IN SOUTHEASTERN LABRADOR, CANADA

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The Port Hope Simpson rare-earth element (REE) district is located on the southeastern coast of Labrador, Canada. The recognized extent of the district is 135 km along strike and 4 to 12 km wide. Nine prospects have been announced by Search Minerals Inc., the current owner of the mineral exploration rights for the entire district. The prospects were discovered in 2010 during a follow-up exploration program to a regional airborne magnetic/radiometric survey. We have studied the geology and geochemistry of the REE mineralization in order to understand its genesis and distribution.

The regional geology of the Port Hope Simpson REE District is extremely complex as it straddles three separate lithotectonic terranes within the eastern Grenville Province, Labrador. The terranes include the Lake Melville terrane, Mealy Mountain terrane and the Pinware terrane, from north the south, respectively. Differing lithologies, structures, metamorphic facies, along with multiple crystallization and metamorphic events distinguish these terranes.

The Lake Melville terrane is characterized by the Alexis River anorthosite, biotite-bearing granite, granodiorite, and quartz diorite-to-diorite gneiss. The Mealy Mountain terrane is characterized mostly by biotite granitic gneiss, K-feldspar megacrystic granite gneiss, quartz diorite to dioritic gneisses, and pelitic to semipelitic sedimentary gneisses. The Pinware terrane consists of felsic to intermediate intrusions and older intercalated quartzofeldspathic supracrustal rocks. Intrusions consist mainly of granite, K-feldspar megacrystic granite, quartz monzonite, granodiorite, and felsic hypabyssal to volcanic rocks.

Most previous work has been dedicated to large-area regional mapping during which stage the terranes were defined. The nature of the protoliths of the host rocks for the REE mineralization, however, had not been established. Based on detailed geological mapping in the Port Hope Simpson area, together with approximately 25,000 lithogeochemical samples, and the petrologic logs of 21,000 m of drill core, two main types of REE mineralization are distinguished. One is highly evolved REE-Zr-Y-Nb felsic volcanic rocks found within a highly sheared and metamorphosed bimodal, previously unrecognized mafic-felsic volcanic package. The second consists of heavy REE (HREE)-Zr-Y-Nb enriched pegmatites that are both cross cutting and complexly deformed in places. This second type has many subtypes, all of which are pegmatitic. In both types of mineralization, the REE-enriched minerals are allanite, zircon and fergusonite.

CENTURY-SCALE VARIABILITY OF CORALLINE ALGAL CALCIFICATION RATES IN THE NORTH PACIFIC AND NORTH ATLANTIC

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Ocean acidification may inhibit calcification pathways of marine plants and animals. Recently, it has been suggested that aragonitic tropical corals and other marine calcifiers already exhibit declining calcification rates. Greater oceanic CO_2 uptake at mid-to-high latitudes may result in greater inhibition of calcium carbonate secretion in subarctic organisms than in those at lower latitudes. Such inhibition may be particularly evident in the metabolically expensive high Mg-calcite skeletons of the shallow-water,

habitat-forming coralline algae. It has been shown that biogenic high Mg-calcites exceed the solubility of aragonite at approximately 12 mol% $MgCO_3$. Here we present the first century-scale records of calcification rates in the coralline alga Clathromorphum sp. from the North Pacific/Bering Sea region and the subarctic NW Atlantic. Clathromorphum forms annual growth increments in its massive skeleton and is known to have a lifespan of up to several centuries. The seasonal $MgCO_3$ range in Clathromorphum from our subarctic collection sites fluctuates between 10-15 mol%. Century-long time series of calcification rates - the product of skeletal density and linear extension - were generated at submonthly resolution using Micro Computer Tomography. Results indicate that coralline algal calcification rates display multidecadal cycles that covary with regional climate indices such as the Pacific Decadal Oscillation. Unlike studies of other marine calcifiers, this study has not detected a significant decline in calcification rates during the past decades. This is likely attributable to Clathromorphum calcification being metabolically driven, with the organism maintaining significant physiological control over both placement and dissolution of carbonate. Most carbonate in Clathromorphum cells is deposited along an inner wall embedded in an organic matrix of small, radially-placed high magnesium calcite crystals.

THE MANUELS RIVER HIBERNIA INTERPRETATION CENTRE: A NEW GATEWAY TO THE GEOLOGICAL TREASURES OF THE RIVER IN CONCEPTION BAY SOUTH, NL

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A 7 km length of Manuels River provides access to Late Proterozoic volcanics, Cambrian sediments, including a world-famous trilobite fauna, and modern geological processes along the river and at its outlet into the sea in Conception Bay. The Manuels River Natural Heritage Society (MRNHS) has created a linear park along the river and has provided tours of the river to the public, school classes and visiting community groups for 16 years or so. In collaboration with the Rotary Club of Avalon Northeast (RANE), a new 1200 sq. m. interpretation centre is under construction to facilitate access to the river. The new centre will have exhibits focussing on the river's geology, its flora and fauna, and its human history. Of particular interest will be a recreation of the river's bedrock geology, with interpretation, and exhibits on the trilobite fauna, honouring the work of Dr. Riccardo Levi-Setti, who has donated to MRNHS his collections from many years spent on the river. The centre will also provide rentable audio-guides to the river. Funding for the centre is coming from the Town of Conception Bay South, the Hibernia Management and Development Corporation, the Atlantic Canada Opportunities Agency, the Government of Newfoundland and Labrador, RANE and MRNHS. In addition to funding of the building, additional sponsorship is being sought for trail enhancements and other features of the 'Manuels River Experience'. The centre should be open early in 2013.

A GAS HYDRATE RESOURCE INITIATIVE FOR NEWFOUNDLAND AND LABRADOR

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WITHDRAWN

STRATIGRAPHIC FRAMEWORK OF THE LOWER FIFTEENMILE GROUP IN YUKON AND IMPLICATIONS FOR EARLY NEOPROTEROZOIC BASIN EVOLUTION AND CHEMO-STRATIGRAPHIC SYNTHESIS IN NORTHWEST CANADA

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Recent mapping, chemostratigraphy, geochronology, and sequence stratigraphic analysis of Neoproterozoic strata in the Ogilvie Mountains motivate redefinition and revised correlation of the early Neoproterozoic (Tonian) Fifteenmile Group across Yukon. These results demonstrate that subsidence in the Fifteenmile basin initiated prior to 811 Ma as a result of north- to northwest-side down normal faulting that rotated and truncated portions of the underlying Pinguicula and Gillespie Lake Groups. In the Coal Creek inlier, where the lower Fifteenmile Group is most completely preserved, these strata seal synsedimentary faults and mark the onset of thermal subsidence. The basal Gibben formation fills localized half-grabens and is widely capped by a distinct shoaling-upward carbonate sequence bound above by a subaerial unconformity. The overlying Chandindu formation records incipient stromatolite reef development over bathymetric highs in the basin, which resulted in significant facies variations along strike. Relict basin highs persisted through deposition of the Basinal assemblage. Large stromatolite-cored reef systems developed on these paleohighs and prograded to the north-northwest in a series of highstand systems tracts, shedding reworked carbonate into and gradually filling deepwater, shale sub-basins.

In the Hart River inlier, most of the Basinal assemblage and overlying Craggy dolostone are missing beneath a major low-angle unconformity at the base of the Callison Lake dolostone. In the Coal Creek inlier, the Craggy dolostone records final filling of sub-basins and progradation of a broad, shallow-water carbonate platform. The spectacular exposure and mappability of contrasting depositional environments through the lower Fifteenmile Group, from back-reef supratidal flats and lagoons to fore-reef and deepwater settings with abundant organic-rich shales, provide an exceptional opportunity to assess spatial and temporal variability in chemostratigraphic proxies. For example, carbonate $\delta^{13}C$ profiles spanning the inferred onset of the Bitter Springs negative carbon isotope anomaly show significant variability between sections. When viewed within the sequence stratigraphic framework, it is apparent that this variability is attributable to differences between depositional environments, with higher $\delta^{13}C$ values corresponding to more restricted, back-reef settings and the lowest values belonging to interspersed carbonates encased in relatively organic-rich shale in deeper water settings. Despite the complication of the synoptic variability in the carbon isotope values, temporal seawater trends can be extracted from these rocks and applied to interregional and global correlation.

PRECISE, MATCHING U-Pb AGES FOR THE RINCON DEL TIGRE MAFIC LAYERED INTRUSION AND HUANCHACA GABBRO SILL, BOLIVIA: EVIDENCE FOR A LATE MESO-PROTEROZOIC LIP IN SW AMAZONIA?

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The SW margin of Amazonia in Bolivia and Brazil preserves a polycyclic record of tectonic evolution, through successive accretion of arcs, ocean basin closure, and an oblique microcontinent – continent collision (Paraguá terrane to the rest of Amazonia) to form the Rondonian-San

Ignacio Province (1.56-1.30 Ga). Between this time and the eventual Sunsás collisional orogen at ca. 1100-1000 Ma, which culminated in Amazonia's amalgamation into supercontinent Rodinia, this region developed as a passive margin to foreland basin (Sunsás and Vibosi sediments), locally with systems of aborted rifts developed in the foreland (e.g. Huanchaca–Aguapeí basin). Here, we report two new identical, precise U-Pb ID-TIMS ages for widely separated and important ultramafic-mafic units that intrude these sedimentary sequences, and speculate on regional intraplate magmatic equivalents that collectively may define a previously unrecognized large igneous province (LIP).

The Rincón del Tigre (RdT) intrusion was emplaced as a very thick, layered, differentiated, mafic-ultramafic sill between the Sunsás and overlying Vibosi metasedimentary sequences, in the southeast tip of the Sunsás belt. The intrusive RdT rocks, which carry important Ni-Cu-PGE potential, vary from ultrabasic harzburgites and olivine bronzitites to gabbros and granophyres. The intrusion has been deformed along with its sedimentary envelope by upright fold structures related to Sunsás orogeny. The most reliable published age for the complex is a Rb-Sr age of 992 ± 86 Ma determined on granophyre. We have recovered abundant, fresh baddeleyite from a middle mafic (gabbro) unit of the RdT, which yields a well-constrained primary age of igneous emplacement and crystallization at 1110.4 ± 1.8 Ma. Approximately 500 km to the NW, platformal Aguapeí sediments unconformably overlie Paraguá crystalline basement, are flat-lying, undeformed and unmetamorphosed, and are intruded conformably by a series of gabbroic sills. In the Huanchaca type area, two principal sills occur up to 200 m thick, emplaced within Aguapeí Group sandstones and pelites. Baddeleyite from a representative Huanchaca gabbro sill documents an igneous crystallization age of 1111.5 ± 1.9 Ma.

This 1110-1112 Ma age matches LIPs on other cratons, including Congo (Ernst *et al.*, this meeting), Kalahari and Indian. We consider whether all these cratons were nearest neighbour to Amazonia during the Mesoproterozoic, and shared a ca. 1110 Ma LIP in the Rodinia supercontinent. The new ages also coincide with the early phase of interior Laurentia's Keweenawan (Mid-Continent) event; however, on paleomagnetic grounds, as shown previously, Mid-Continent Rift magmatism is likely to have been distant and unrelated.

THE MESOZOIC ORPHEUS RIFT BASIN, OFFSHORE NOVA SCOTIA AND NEWFOUNDLAND, CANADA: THE INFLUENCE OF BASIN ARCHITECTURE ON SALT TECTONICS AND BASIN INVERSION

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The Orpheus rift basin is the part of the Mesozoic rift system of eastern North America that formed prior to the opening of the North Atlantic Ocean. The Cobequid-Chedabucto fault system (CCFS) bounds the Orpheus and Fundy rift basins on the north; thus, it is likely that both basins have a common tectonic evolution. Our study area, imaged by a grid of 2D seismic-reflection profiles, covers the eastern part of the Orpheus basin. Based on data from nearby wells, comparisons to the Fundy basin, tectonostratigraphic packages bounded by unconformities, the presence/absence of growth beds, and cross-cutting igneous intrusions, we recognize four major tectonic episodes for the Orpheus rift basin: Triassic to Early Jurassic rifting, Early Jurassic basin inversion during the transition from rifting to drifting, Early Cretaceous uplift and erosion, and Oligocene/Miocene uplift and erosion. In the study area, the Orpheus basin has two distinct basin architectures based on the geometry of basement-involved extensional faults. In the eastern part of the study area, most basement-involved faults dip toward the south. In the western part of the study area, however, the basement-involved faults dip toward the south and the north, producing a horst-and-graben geometry. The synrift Argo salt is thicker in the full grabens near the CCFS and in the fault blocks far from the CCFS; thus, the fault geometries controlled the initial thickness/distribution of the Argo salt. In areas with thinner salt, basin inversion reactivated the basement-involved extensional faults below the salt, and produced supra-salt compressional structures such as salt-cored buckle folds and detached thrust faults. Thus, the salt layer decoupled the shallow and deep deformation. In areas with thicker salt, salt structures developed during rifting, producing salt walls/columns and wedged-shaped mini basins. Basin inversion reactivated the basement-involved extensional faults below the salt. In response, the salt columns narrowed, accommodating most of the supra-salt shortening. Our work shows that the style of post-rift basin inversion on the passive margin of eastern Canada depends, at least in part, on the basin architecture and the distribution of salt within the basin.

RECRYSTALLIZATION AND NEW GROWTH OF EXTENSIVELY RADIATION-DAMAGED NATURAL ZIRCON

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This study was undertaken to investigate the physical and chemical changes that occur in zircon when heated over a range of temperatures (600°C to 1400°C), and times ranging from one hour to 36 hours, in order to better understand how heat treatment leads to an improvement in the precision and accuracy of isotope dilution thermal ionization mass spectrometry (ID-TIMS) analyses of zircon. The zircon samples chosen for these experiments are nearly completely metamict cm-sized crystals from the Saranac Prospect in the Bancroft District of Ontario.

Approximately 10 grams of these zircon crystals were combined by breaking into small pieces and ground under ethanol to a fine ~1 micrometer powder in an agate mortar and pestle in order to make enough homogeneous material for several powder X-Ray and diffraction scans and high-resolution transmission electron microscopy (HR-TEM) measurements. While these large zircon crystals ground to a powder are not the same physical state as what is typically analyzed in single zircon ID-TIMS U-Pb analysis, the physical and chemical changes that occur during the heat treatment used in chemical abrasion (CA)-TIMS should be a similar process.

Aliquots of the ground powder were heated *in situ* using a Pt sample holder-furnace in a Rigaku Ultima IV powder diffractometer in which time simultaneous powder diffraction patterns were collected. Other aliquots of the zircon powder were heated in a Pt crucible in a Deltech $MoSi_2$ vertical tube furnace and then analyzed with X-ray powder diffraction using a conventional sample stage. The powder X-ray diffraction results indicate that below ~900°C the recrystallization of the zircon powder is incomplete, even after 36 hours, with diffuse low intensity diffraction peaks. At 900°C the zircon powder shows significant recrystallization, and the ingrowth of tetragonal ZrO_2, within one hour at that temperature. At 1200°C, the recrystallization is essentially complete in one hour.

Samples of the unground zircon, the unheated powder, and the powder heated at 900°C for 36 hours, were also investigated using HR-TEM. The unground zircon and the unheated ground zircon powder contain a mixture of amorphous and crystalline zircon material with extensive porosity in the amorphous regions. The sample heated at 900°C for 36 hours consists primarily of well crystallized zircon but also contains small islands of tetragonal ZrO_2 (zirconia) often adjacent to amorphous material. Also associated with the tetragonal ZrO_2 are areas of porosity that may also be contain SiO_2 but that was not possible to verify.

PRISTINE MELT INCLUSIONS IN QUARTZ PHENOCRYSTS FROM THE 2.7 Ga PAYMASTER PORPHYRY, TIMMINS DISTRICT, ONTARIO

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We have characterized primary melt inclusions from a porphyry stock in Timmins, Ontario, in order to evaluate the level of preservation of inclusions that are hosted in intrusive rocks within Archean greenstone

belts. The Paymaster porphyry is one of a series of oligoclase-quartz, tonalitic to quartz dioritic intrusions of volcanic arc affinity within the Porcupine Group (2.69 Ga). Recrystallized melt inclusions in the porphyry occur within growth zones in quartz phenocrysts and do not show petrographic evidence of significant post-entrapment modification despite recrystallization, and the considerable age and post-solidus history of the host rock. Melt inclusions were homogenized in a piston cylinder apparatus (900°C, 5 kbar) and analyzed by EMP and LA-ICPMS for major/trace elements.

Trace elements show a systematic ~ 1 order of magnitude increase in concentration from the earliest to latest growth zones, reflecting primary fractionation. The only element that becomes depleted in the melt is Sr, which shows a strong positive correlation with Ca, reflecting the crystallization of large amounts of plagioclase during progressive melt entrapment. Surprisingly, with the exception of Cu and some HFSE, the most evolved melt inclusions are nearly identical in major/trace element composition to the host porphyry bulk composition. Concentrations of Cu in the melt inclusions are 2-3 times higher than in the bulk porphyry. This may reflect the mobility of Cu during post-crystallization alteration and deformation. However, given that other highly mobile trace elements are not depleted (Ba, Rb, Cs, Pb), it is more likely that Cu was removed from the original magma by a magmatic volatile phase, a suggestion that is supported by the existence of associated Cu porphyry-style mineralization. The bulk rock also shows an enrichment in Zr and Hf that is not observed in the inclusions, reflecting the accumulation of zircon in non-equilibrium crystallization proportions.

Aside from these minor inconsistencies in bulk rock vs. trapped melt composition, the results of this study show that melt inclusions can offer some insight into the evolution of very old intrusive systems, and cannot be assumed to have been compositionally modified based solely on the age and extent of deformation/alteration of their host rocks. On the other hand, the chemistry of these ancient porphyry rocks has not experienced any significant modification either, highlighting the importance of melt inclusion studies in evaluating the level of chemical preservation and representivity of bulk rocks that may or may not be suitable for petrogenetic interpretation.

ANIMAL-SEDIMENT INTERACTIONS ON THE EARLY ORDOVICIAN MUDDY SEAFLOOR: THE IMPORTANCE OF NON-STEADY SEDIMENT ACCUMULATION

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Classic diagenetic facies models conceptualize near-shore marine sediments as one-dimensionally accreting sediment piles in which the reactivity of organic carbon steadily declines with depth. More than 60% of all organic debris discharged to world's continental shelves, is however mineralized via non-steady diagenetic processes. The most important conceptual foundation of non-steady depositional environments is that (1) sediment accumulation is pulsed, (2) particle residence times in the suboxic zone are very high, and (3) bottom sediments are frequently re-worked and re-oxidized before being incorporated into the rock record. Common routines for the characterization of organic-rich mudstone facies rarely recognize this depositional environment from the rock record, because characteristic grain size distributions, sedimentary structures, and bioturbation styles are rarely defined at the appropriate scale. We present a combined sedimentological-ichnological facies model for mud-dominated shoreface and shelf facies members in the Cambro-Ordovician Bell Island Group (Newfoundland). Normal-marine, mud-dominated shoreface and shelf sediments capture sedimentary products of wave- and current-dominated mud deposition and their characteristic macrofaunal colonization styles. 27 m of mud-dominated sections were logged and described in cm-resolution, comprising at least five sedimentological facies. The studied section exposes well-bioturbated sand- and siltstones that are interbedded with decimeter-thick packages of unbioturbated mudstones. We record well-preserved mud-on-mud erosion surfaces, decimetre-spaced combined flow structures and abundant mud ripples at millimetre to decimetre-scale. Microstratigraphies and grain size trends within mudstones and siltstones demonstrate a combination of current-dominated and wave-advected sediment transport, generating turbidites, wave-enhanced sediment gravity flows, and fabrics originating from post-storm suspension fall out. In facies dominated by fluid mud deposition, benthic macrofaunal communities exhibit significant reduction of trace sizes, low bioturbation depth (<5cm) and rarely any cross-cutting relationships. Abundant escape traces and sediment fabrics resembling disruption due to fluid-sediment-swimming activity of macro-organisms dominate intervals with high sedimentation rates. Preliminary geochemical results reveal overmature organic matter with rather low total organic carbon (TOC) values of approximately 0.7% throughout the succession. TOC values above 2% were measured in intervals dominated by microbial mats. Based on high-resolution sedimentological/ichnological analysis, previous interpretations placing this facies into a sub-tidal and periodically salinity-stressed depositional environment are refuted. Instead, we propose that the water-column was fully oxic and of normal-marine salinity, and that bioturbation intensity and colonization style were primarily controlled by storm recurrence frequency, availability of organic matter as a food source and time available for colonization.

WHAT DO GAMMA RAY LOGS TELL US ABOUT SEQUENCE STRATIGRAPHY IN MUDSTONES?

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High gamma log signatures are typically interpreted in sandy clastics sequences as indicators of marine transgressions, because high clay content is commonly associated with distal marine facies. This model is based on the potassium contribution to gamma ray logs, since potassium contents are typically elevated in smectitic and illitic clays.

This association has also been used to develop sequence stratigraphic models in mudstone successions, but here the underlying logic can be problematic. In many mudstones, for example Upper Devonian shale formations in North America, high gamma log is related to uranium content and total organic carbon (TOC) content, not to potassium and clay content. In these cases, for the gamma ray log to be useful for interpreting stratigraphic sequences, TOC enrichment must occur during transgressions or at maximum flooding surfaces. Is this necessarily the case?

The Woodford Shale, Permian Basin, west Texas, provides a good test. Based on spectral gamma ray data, the total gamma log is dominated by uranium and closely matches TOC; contributions from potassium and thorium are minimal. The cyclic occurrence of carbonate turbidites provides another model for interpreting stratigraphic sequences, based on 'high stand shedding'. In parts of the section, peaks in TOC do coincide with transgressive systems tracts; but in other parts, TOC peaks coincide with high stands. This result suggests that in clay-poor mudstones, TOC enrichment is complex and not related in simple ways to sea level cycles; therefore simple sequence stratigraphic models based on gamma ray logs must be regarded with caution.

APPALACHIANS TECTONIC MAPS

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Tectonic maps have been employed to portray the relationships between large and small tectonic units for many decades. A 1961 USGS–AAPG tectonic map of the U.S. portrayed the Appalachians in a pre–plate tectonics context. King's 1969 North American tectonic map appeared at the dawn of infusion of plate tectonics theory into geoscience, and at the threshold of extensive detailed geologic mapping in the Appalachian internides. Because of this, while most of King's boundaries in western North America survived into Muehlberger's 1996 tectonic map, those in the Appalachians internides mostly did not. King's 1970 tectonic map of the southern and central Appalachians improved his 1961 and 1969 tectonic maps, but it also suffered from a lack of new data on the internides.

Williams' monumental 1978 Appalachian tectonic map was the first modern tectonic map covering the entire orogen and portrayed the Appalachians at convenient scales (1:1M and 1:2M), showing state-of-the-art details, and the clear differences between the northern and southern-central Appalachians. Throughgoing elements also became more obvious. It became the basis for the first application of the suspect terranes concept

to the orogen in the early 1980s, and is still useful. Keppie's 1982 map of the New England and Canadian Maritime Appalachians delineated most of the tectonostratigraphic terranes and plutons that we still recognize, except those added recently. The Hatcher *et al.*, 1989, U.S. Appalachians tectonic map attempted to integrate the terranes concept and accurately depict the shapes of plutons and known tectonic units. The 2006 Hibbard *et al.* tectonic map updates the 1978 map and attempted to interpret Appalachian components in terms of tectonic kindred, to apply an updated Williams' 1970s Newfoundland model throughout the orogen, and to accurately depict the shapes of plutons and other elements.

Prior to the 1989 Thomas *et al.* paleogeologic map of the subsurface Appalachians and the 1991 Horton *et al.* terrane map of the southern and central Appalachians, few attempts were made to portray the modern geology beneath the Gulf and Atlantic Coastal Plains. Today it is possible to produce tectonic maps of the entire Appalachians (e.g., 2010 Hatcher) that interpretat subsurface geology from these data.

Doubtlessly, future tectonic maps will greatly improve these maps as new techniques are invented, new data become available, and more of the internides throughout the orogen are mapped in detail.

GAS HYDRATES IN SACKVILLE SPUR?

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Gas hydrates in shallow marine sediments represent a potential hazard to deepwater hydrocarbon drilling and production. The presence of gas hydrates along Canada's Atlantic margin has been inferred from the observation of bottom simulating reflectors (BSRs) on seismic reflection profiles. Given that BSRs can also be caused by the diagenesis of siliceous sediments, additional geophysical data such as seismic velocity and well log data are necessary to positively identify hydrate deposits. On industry acquired 3D seismic data from offshore Newfoundland, a discontinuous phase reversed BSR with a shingled appearance crosscuts Cenozoic drift deposits of the Sackville Spur. This possible hydrate deposit occurs in an area of active hydrocarbon exploration. The objective of this study is to determine the origin of the Sackville Spur BSR, by comparing its mapped occurrence with methane hydrate stability calculations in addition to assessing well log responses through the shallow sediments. Preliminary results show a strong correlation between the BSR and depth to the theoretical base of the gas hydrate stability zone. A low velocity zone below the BSR is suggestive of free gas trapped below hydrate bearing sediments. However, a lack of significant increases on the resistivity log through the sediments overlying the BSR, suggests that sediment-hosted gas hydrate within the formation is not abundant.

Plenary Address FROM PRESERVATION OF FIRST CONTINENTAL CRUST TO ULTRA-HIGH-PRESSURE (UHP) METAMORPHISM IN <1 BILLION YEARS - IMPLICATIONS FOR EARLY ARCHEAN PLATE MARGIN PROCESSES, CRATON FORMATION AND STABILIZATION

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Nearly fifty years after it was first formulated for the modern Earth, the question of how and when plate-tectonics began continues to stir considerable debate. A survey of the literature reveals a full spectrum of opinions amongst researchers placing its beginnings from as far back as the Early Archean to as late as the Neoproterozoic, or even later. Nonetheless, most agree that Earth's tectonic style must have evolved over time from an early regime, dominated by numerous small plates or platelets, to the more organized regime, characterized by larger plates, that may be referred to as modern-style plate tectonics. An answer as to when this transition occurred should ultimately come from the Precambrian geologic record, and much emphasis has been placed therefore on establishing "diagnostic" criteria that may be indicative for the presence or absence of plate margin processes. Such criteria usually include ophiolites, taken as evidence for sea-floor spreading, or high-pressure (HP) and ultra-high-pressure (UHP) metamorphic belts, interpreted as paleo-subduction scars. Regarding the earliest evidence for UHP metamorphism, defined by the occurrence of diamond and/or coesite in demonstrably supracrustal assemblages, a major disconnect exists between information from the surface record and that obtained from the well-studied world-wide kimberlitic upper mantle sample. As UHP metamorphic terranes are restricted to <1 Ga rocks, it is generally assumed that UHP metamorphism is a Neoproterozoic or younger process that was not possible in a much hotter Archean Earth. Yet a convincing case can be made that coesite and diamond eclogites from UHP melanges and coesite- and/or diamond-bearing mantle eclogite xenoliths from kimberlites are complementary end products of the same tectonic process. Both began their UHP metamorphic history in subduction zones, but the former were exhumed together with other, non-subductable crustal assemblages soon after continental or microcontinental collision. The latter were part of the oceanic slab subducted prior to collision. It may have continued its downward journey, but parts of it were accreted to the roots of microcontinental nuclei and could be exhumed only when picked up by younger igneous transport media (e.g. kimberlites). As shown by ~2.9 Ga ages of the oldest known eclogitic diamonds with subduction signatures, occurring in host rocks with even older mantle extraction ages, deep subduction was alive and well in the Mesoarchean, producing lithospheric roots sufficiently thick and cool to reach into the diamond stability field. The required local lowering of hotter Archean geothermal gradients was likely achieved by large-scale tectonic imbrication as has now been imaged in reflection seismic profiles on several Archean cratons. A range of Proterozoic ages for eclogite xenoliths and eclogitic diamonds, also with subduction signatures, has now been recognized in kimberlites and/or lamproites of most diamond-bearing cratons, suggesting that underplating of UHP metamorphic assemblages continued periodically throughout the Proterozoic and may have contributed to craton stabilization.

RESULTS FROM SYSTEMATIC STUDY OF SOME BUZZARD COULEE METEORITES

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Samples of the Buzzard Coulee chondritic meteorite (fell November 20, 2008) were obtained by the National Meteorite Collection of Canada. The masses ranged over an order of magnitude (from 109.14 to 8.8 grams), were fully to almost-fully crusted, and were collected before the winter of 2008-2009. They afforded an opportunity for systematic study, to help define a protocol and methodologies for examination of new meteorite falls and finds, or for specimens from sample return missions to space.

Non-destructive laboratory work commenced. Digitized data were preserved for archival and curatorial purposes, and in anticipation of further research. Each fragment was examined, weighed, and photographed on acquisition and as research proceeded. Average bulk density by 3 independent methods was 3.44±0.03, 3.46±0.03, and 3.49±0.06 g/cm^3, while average porosity was 6.14±1.5%, and grain density was 3.69±0.03 g/cm^3 by helium pycnometry. All these values are similar to those reported for H chondrites. The mass magnetic susceptibility ($\boldsymbol{X}$) of each sample was calculated using results from different laboratories and different machines; the average log of $\boldsymbol{X}$ was 5.2±0.056 × 10^{-9} m^3/kg, also typical of an H chondrite. Up to this point, the only recognized special feature of any sample was apparent shock veins revealed in one mass with missing crust.

The majority of the samples were subjected to X-ray Micro-Computed Tomography (Micro-CT), providing one of the means for calculating bulk volume and density, and information that is being used to define metal concentrations and to calculate bulk metal contents. A fully crusted sample revealed an essentially metal-free interior region invisible from the exterior; this discovery method is probably unique in meteorite studies.

The two variant samples (one with shock veins, one with a metal-poor inclusion) were cut with a diamond-wire saw. The features defined by

the systematic non-destructive work were present in slices. Polished thin sections were made to allow textural and analytical follow-up studies to be reported here.

SEISMOGENIC DEFORMATION OF A CARBONATE PLATFORM STRADDLING THE PRECAMBRIAN-CAMBRIAN BOUNDARY, KARATAU RANGE, KAZAKHSTAN

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The "Lower Dolomite" of the Ediacaran-Cambrian Chulaktau Formation straddles the Precambrian-Cambrian boundary in the Lesser Karatau Mountains of southern Kazakhstan and immediately underlies some of the world's largest sedimentary phosphate deposits. It is not a stromatolitic bioherm, as previously identified in the literature, but a carbonate platform which was regionally and complexly deformed while in a semiconsolidated state. Three subdivisions are recognized: The lower section, approx. 3-5 m thick, is regionally shortened by flexural folds on a meter-scale and also shows thrusting and imbrications of underlying siliciclastic units; local extension is accommodated by soft-sediment boudinage. The middle section, approx. 2-5 m thick, largely consists of a megabreccia of angular and subrounded dolomite clasts up to m-size. The upper unit, approx. 0-3 m thick, consists of microbially laminated dolobindstone, dolorudstone and slab conglomerate cut by syndepositional low-angle normal faults. Channelization and bank margin slumping at the top of the Lower Dolomite was followed by karsting, prior to establishing a high-energy, shallow-water, carbonate-phosphatic coastal environment. A prominent unit of black chert at the top of the dolostone represents an early diagenetic overprint, recognizable by silicified slump folds, lithological boundaries trending oblique to bedding, the absence of reworking, and the partial silicification of overlying basal phosphorites.

We interpret the Lower Dolomite as an example of an unevenly lithified carbonate platform deformed by one or several large seismic events. The lower unit deformed by local sliding, imbrications, and folding while deformation in the overlying middle unit occurred by *in-situ* disaggregation due to extensive shaking. Coseismic or early postseismic uplift, possibly above sea level, led to rapid erosion, widespread extensional gravitational normal faulting of soft sediment piles, drainage incision and their fill by bank collapse and conglomeratic wedges. Our documentation of a major regional seismic event at the pC-C boundary calls for comparable investigations of this critical but typically incompletely preserved contact in Earth history.

CRYSTAL CHEMISTRY OF THE MOUNTAIN RIVER BERYL (EMERALD VARIETY), MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES

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Emerald at the Mountain River occurrence in the Mackenzie Mountains, Northwest Territories, is associated with extensional quartz-carbonate veins hosted in organic-poor deepwater sandstones and siltstones of the Neoproterozoic Windermere Supergroup. The section hosting the veins is found within the hangingwall of a thrust fault that emplaced the Neoproterozoic siliciclastics above Paleozoic carbonates. Emerald occurs as euhedral milky green hexagonal crystals 1 to 5 mm in diameter and up to 4 cm in length. Backscatter electron and cathode luminescence imaging shows the crystals are rhythmically zoned with distinct cores. Substitution of V^{3+} and Cr^{3+} for Al^{3+} in the beryl crystal structure ($Be_3Al_2Si_6O_{18}$) imparts the green colour typical of emerald and the Mountain River emerald contains high concentrations of both chromophores (2846 ppm V, 1430 ppm Cr). High concentrations of Sc (up to 0.31%) and Zn (exceeding 1%) in the emeralds are quite unusual, and do not occur in other emerald deposits.

Hydrogen isotope compositions of water extracted from emerald range between -65‰ and -49‰ (V-SMOW). The $\delta^{18}O_{V\text{-}SMOW}$ values for emerald and quartz range between 16.2‰ and 17.2‰, and 17.9‰ and 18.9‰, respectively. One dolomite sample returned a $\delta^{18}O_{V\text{-}SMOW}$ value of 18.1‰. Temperature of mineralization was determined by mineral pair $\delta^{18}O_{V\text{-}SMOW}$ equilibration to be in the range 379 to 415°C. Fluid inclusion analyses indicate saline (>22 wt% NaCl equivalent) CO_2-bearing brines and homogenization temperatures between 200 and 250°C. Combining fluid inclusion isochores with isotope equilibration temperatures indicates fluid pressures on the order of 2.0 to 4.5 kbar, corresponding to depths of 6 to 12 km. Euhedral pyrite intergrown with emerald yields a 5 point Re-Os model 1 isochron age of 345 ± 20 Ma and an elevated initial $^{187}Os/^{188}Os$ ratio of 3.2, indicating a crustal fluid source.

Emerald formation resulted from the circulation of hydrothermal brines through organic-poor sedimentary rocks, which scavenged the metals necessary for mineralization. The fluids involved and age of the occurrence are synchronous with extensive base metal mineralization (carbonate-hosted lead-zinc, sedimentary exhalative, and volcanogenic massive sulphide) and the Manetoe Facies dolomitization event throughout the northern Cordillera, supporting the argument for a large-scale hydrothermal brine movement event during the Late Devonian to Mississippian. The Mountain River emeralds are genetically most similar to the Colombian-type mineralization model, with two exceptions: 1) the host rocks are organic-poor, hence inorganic thermochemical sulphate reduction was likely involved in mineralization; and 2) mineralization occurred during a period of tectonic extension rather than compression.

THE BREVITY OF HYDROTHERMAL FLUID FLOW REVEALED BY THERMAL HALOES AROUND GIANT Au-DEPOSITS

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Hydrothermal fluid flow is responsible for significant heat transfer in the Earth's upper crust, and is an important process in the formation of ore deposits. The duration of hydrothermal fluid flow episodes is poorly constrained. Active continental geothermal systems are thought to last for at least 20 - 500 Kyr. For extinct hydrothermal ore systems, estimates for the duration of hydrothermal fluid flow are largely constrained by the precision of the U-Pb and $^{40}Ar/^{39}Ar$ geochronometers and are thought to be as short as ~100 - 500 Kyr. Here we demonstrate that thermochronology data, coupled with thermal modeling, can be used to constrain the duration of hydrothermal fluid flow. We present apatite fission-track (AFT) data that define a conductive halo to the Eocene hydrothermal system responsible for >1100 tonnes of gold in the Goldstrike property on the northern Carlin trend, Nevada. Thermal modeling of conductive heat flow and the ensuing AFT annealing provide first-order estimates for the duration of hydrothermal fluid flow responsible for mineralization. Our results indicate firstly that hydrothermal fluid flow was short-lived, comprising one or more hydrothermal pulses < ~10 - 50 Kyr in duration, and secondly, that large hydrothermal ore-deposits can form from geologically brief episodes of fluid flow.

EVALUATING CRUSTAL SULFUR SOURCES IN MAGMATIC Ni-SULFIDE DEPOSITS: APPLICATION OF A NEW MULTIPLE S ISOTOPE METHOD TO THE VOISEY'S BAY NI DEPOSIT

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It is generally accepted that crustal contamination is required for the formation of significant magmatic Ni-Cu-PGE sulfide deposits. Either the addition of external S or SiO_2 promote early sulfide saturation. The most direct indicator of the S source is S isotopes. However, the traditional use of $\delta^{34}S$ values is inadequate in deposits where sedimentary sulfides of Archean age in the footwall might not have significantly different $\delta^{34}S$ values from those of mantle S. Even where sediments have variable $\delta^{34}S$ values, $\delta^{34}S$ signatures can be reset to magmatic values by equilibrating large amounts of silicate magma with initial sulfide melt. We used new multiple S isotope methods to constrain the relationship between $\delta^{34}S$ and $\delta^{33}S$ values, which is helpful to differentiate between high-temperature

equilibrium fractionations found in magmatic S, and low-temperature kinetic fractionations found in sedimentary S.

The Voisey's Bay Ni-sulfide deposit, Labrador is hosted by a troctolitic conduit system connecting two subchambers of the Voisey's Bay intrusion. The Voisey's Bay intrusion is a part of the Nain plutonic suite and intruded at approximately 1.3 Ga along the boundary between the Proterozoic Tasiuyak Gneiss of the Churchill province and Archean gneisses of the Nain province.

Several models for the formation of this deposit have been presented, but there is still significant controversy over the cause of S saturation in the magma to form the deposit. The general model suggests that assimilation of an unknown silica-rich rock, likely in a mid-crustal magma chamber, was followed by assimilation of a large amount of sulfidic Tasiuyak gneiss, leading to sulfur saturation prior to emplacement. However, the Tasiuyak gneiss does not have a high concentration of sulfur (typically <<1 wt%), and traditional $\delta^{34}S$ analysis cannot distinguish between mantle and crustal sources in this deposit.

High-temperature equilibrium relationships are not preserved in our measured $\delta^{33}S$ and $\delta^{34}S$ values. Instead they indicate that a kinetic process is responsible for S isotope fractionations in the mineralization, troctolite, and Tasiuyak gneiss. The observed slope of the data on a $\delta^{33}S$ vs. $\delta^{34}S$ plot is consistent with bacterial sulfate reduction, suggesting a marine sedimentary protolith to the Tasiuyak gneiss. This signature has apparently been inherited by the troctolite and the mineralization during assimilation of the Tasiuyak gneiss, despite the equilibration of the sulfide melt with a very large amount of silicate magma, resetting the $\delta^{34}S$ values in the deposit to magmatic values.

PROVENANCE OF CLASTIC METASEDIMENTARY ROCKS OF THE PALEOPROTEROZOIC AILLIK GROUP, MAKKOVIK PROVINCE, LABRADOR: INSIGHT FROM NEW U-Pb GEOCHRONOLOGICAL DATA

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The Makkovik Province of Labrador is part of a Paleoproterozoic accretionary belt that developed on the southern margin of the North Atlantic craton during the ca. 1.9-1.7 Ga Makkovikian-Ketilidian orogeny. The Aillik domain represents one of three domains that characterize province. The Aillik domain largely comprises: a) the Aillik Group (previously termed the Upper Aillik Group), a supracrustal assemblage consisting of metasedimentary and metavolcanic rocks; and, b) abundant, syn- and post-deformation Paleoproterozoic intrusive suites which intrude the Aillik Group.

The ca. 1883-1856 Ma Aillik Group comprises polydeformed, upper-greenschist to lower-amphibolite facies, bi-modal volcanic rocks and sedimentary lithologies and hosts abundant base-metal and uraniferous showings. The Allik Group is composed of interbedded sandstone and siltstone, conglomerate, tuffaceous sandstone, felsic tuff, rhyolite, volcanic breccia, and lesser basalt that has been intruded by numerous suites of variably deformed Paleoproterozoic granitic intrusions and swarms of mafic and felsic dikes. The lithological units of the Aillik Group are laterally discontinuous and strained, having complex local structures resulting in repetition of the stratigraphy. Depositional basement of the Aillik Group has not been identified, it cannot be coincident with present-day basement, as folding and shearing during Makkovikian orogenesis transported these Aillik Group rocks northwestward.

A sample of a polylithic conglomerate from an eastern exposure of the group, contains a simple detrital zircon population of Paleoproterozoic aged grains, with a dominant peak between 1870-1930 Ma, and no Archean ages. A deformed granite clast at the base of the conglomerate yielded a U-Pb ID-TIMS age of ca. 1880 Ma. The conglomerate is contained with a section of the ca. 1850 Ma Aillik Group, and the detrital zircon population indicates a restricted local source of older (ca. 1880 Ma) Aillik Group sediments being recycled was the main source for the younger (ca. 1850 Ma) Aillik Group sediments.

A sample from metasandstone which is stratigraphically lower then the conglomerate sample and located some 20 km to the west, was also analyzed for detrital zircons. The metasandstone yielded a more complex detrital zircon distribution with abundant Paleoproterozic and Archean zircon, characterized by equally prominent age peaks at 1930 to 2100 Ma and 2500 to 2600 Ma. The abundance of Paleoproterozoic and Archean ages indicates a more complex source for the lower stratigraphic units with the Aillik Group. The abundance of the Archean ages indicates a significant source of Archean age detritus, possible basement, that is yet unrecognized in the region.

Keynote CANADA'S PARTICIPATION IN PLANETARY MISSIONS

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This talk will present an overview of the first decade of Canadian Space Agency planetary mission contributions, and discuss future opportunities and directions.

Around August 6th 2012, NASA's Mars Science Laboratory is anticipated to land in Gale Crater in Mars equatorial region. At the end of its robot arm is the Alpha-Particle X-Ray Spectrometer experiment contributed by the Canadian Space Agency. Principal Investigator Ralf Gellert from the University of Guelph leads a team of Canadian and US scientists who will use APXS data to assess the elemental composition of soils and rocks. This will be the second Canadian experiment in 5 years to land on the surface of Mars, following the Phoenix MET lidar in 2008. The CSA is also collaborating with NASA on the MATMOS instrument on the 2016 ExoMars Trace Gas Orbiter Mission, and contributing the OLA instrument on the OSIRIS-REx mission to asteroid 1999 RQ36, Canada's first involvement in a sample return mission. CSA's Exploration Core program with additional investment in Canada's space industry through Canada's 2009 Economic Action Plan is developing robotics and science instrument prototypes for potential future contributions.

PALEOLATITUDE OF WEST AVALONIA FROM PALEOMAGNETISM OF CA. 600 Ma VOLCANIC ROCKS OF THE HARBOUR MAIN GROUP NEAR COLLIERS, AVALON PENINSULA OF NEWFOUNDLAND

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The Harbour Main Group near Colliers on the central Avalon Peninsula includes the Blue Hills Basalt conformably overlying the Peak Tuff which has yielded a U-Pb zircon age of 606 ± 3 Ma. We sampled seven sites from oxidized flow-tops in the Blue Hills Basalt and one site from welded ash-flow tuffs in the Peak Tuff. On thermal demagnetization, the Peak Tuff site and five of the Blue Hills Basalt sites yielded stable hematite-borne remanences that predate folding (most of which occurred before the Early Cambrian). We also sampled basalt boulders in a conglomerate that unconformably overlies the Blue Hills Basalt. Basalt boulders with stable hematite remanence were magnetized in directions that were scattered from boulder to boulder as expected from primary remanence. Similar results were obtained from rhyolitic boulders in an intraformational conglomerate in the Peak Tuff. Hence, the tilt-corrected stable hematite remanence at six of our volcanic sites is likely primary and provides a 39 ± 10° paleolatitude estimate for the Avalon Zone of Newfoundland at ca. 600 Ma. This paleolatitude can be compared with those based on published primary paleopoles from other well-dated Ediacaran units in the Avalon Zone of Newfoundland – namely, 34 ± 8° for the ca. 580 Ma Marystown Group of the Burin Peninsula, and 19 ± 11° for the ca. 570 Ma Bull Arm Formation of the Bonavista Peninsula. Taken together, these data indicate that West Avalonia drifted at mid to low paleolatitudes through the 600-570 Ma period. This may also help constrain the location of the Amazonia-West Africa landmass (which lacks primary paleopoles) because geological evidence suggests that West Avalonia lay nearby during this period.

THE 1.1 Ga MIDCONTINENT RIFT SYSTEM IN NORTH AMERICA: PASSIVE OR ACTIVE RIFTING?

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The Midcontinent Rift (MCR) of North America comprises ~1,500,000 km^3 of basaltic sheets, flows and intrusive rocks emplaced in the Lake Superior region during the Mesoproterozoic. Traditional models for the MCR invoke formation as the result of impingement of a mantle plume under the Superior Province, similar to those invoked for active rift systems. However, recent geochronological studies have shown that magmatism associated with the MCR may have extended for at least 60 m.y., considerably longer than is typical for Large Igneous Provinces (LIP) (e.g., <1 m.y. for the bulk of Deccan magmatism). Many ancient, plume-related LIP have been identified by the presence of extensive radiating dike swarms. However, to date, no radiating swarm has been identified in the MCR. Rather, the majority of dikes preserved around the rift are broadly rift arm-parallel and restricted to within a few tens of kilometres of Lake Superior. Furthermore, dykes within the Logan basin, which spans the area from Thunder Bay to the Minnesota border, are grouped into three lithological units based primarily on their orientation: the east-northeast- to northeast-trending Pigeon River dykes; the east-northeast-trending Mt. Mollie dyke; and the north-northwest- to northwest-trending Cloud River dykes. This implies a variation in the stress field/extension directions over time and suggests a more complex rifting history. Geochemical and isotopic data for the MCR, including variable ε_{NdT} values over time, have been interpreted as evidence for a complex petrogenetic model in which the influence of plume-related mantle waxed and waned throughout the history of the MCR. This could suggest that the plume signature of the magmas is a result of the remelting of underplated material left by earlier mantle plumes.

These lines of evidence, taken in conjunction with the presence of an angular unconformity beneath the basal member of the Osler Volcanic Group (the oldest volcanic sequence recognised on the north shore of the rift) are permissive of a passive rifting model for the MCR, rather than the traditionally accepted active model. Alternatively, the MCR may represent a hybrid model where the plume itself impacted at some point beneath the Superior Craton and the magma channelled to the paleocratonic margin where it initiated rifting.

PERI-LAURENTIAN VOLCANOGENIC MINERALIZATION WITHIN NORTHERN IRELAND: AN EXTENSION OF THE BUCHANS ARC SYSTEM

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The Caledonian–Appalachian orogen is one of the best preserved and most intensely studied examples of a long-lived collision zone within the geologic record. Early Paleozoic closure of the Iapetus Ocean resulted in the accretion of a diverse set of arc terranes, ribbon-shaped microcontinents and oceanic tracts to the Laurentian margin during Grampian–Taconic orogenesis. Within central Newfoundland, Canada, a complex tectonic collage of peri-Laurentian, Cambro-Ordovician tracts is preserved, many of which host significant VMS mineralization. For example, the Annieopsquotch Accretionary Tract is host to the world-class Buchans deposits (e.g. 16Mt mined at 14.5% Zn, 7.6% Pb, 1.3% Cu, 126g/t Ag and 1.4g/t Au), as well as smaller VMS deposits such as Pilley's Island, Gullbridge (3 Mt at 1.1% Cu), Lake Bond and Shamrock. New resources include: Lundberg (20.7 Mt inferred at 2.78 % Cu+Pb+Zn), Clementine West and Little Sandy.

The Tyrone Igneous Complex (TIC) of Northern Ireland is broadly equivalent to the Annieopsquotch Accretionary Tract of Newfoundland, and represents a tectonically dissected arc-ophiolite complex accreted onto an outboard segment of the Laurentian margin during the early Ordovician. The potential for VMS mineralization within the TIC has been recognized for some time, although individual prospects were not forthcoming. Gold and base metal mineralization is most prevalent within the upper part of the volcanic sequence. Through a combination of detailed field mapping, U-Pb geochronology, extensive geochemistry and high-resolution airborne geophysics, several key stratigraphic horizons were identified which were ideal for the formation and preservation of VMS deposits. Specific petrochemical assemblages indicative of rifting and high temperature magmatism were targeted for detailed prospecting and follow up drilling in 2011, particularly around areas with intense hydrothermal alteration. Prospecting identified new occurrences of outcropping hydrothermally altered volcanics which host Zn-Pb(Cu)-Au mineralization coincident with geophysical and geochemical anomalies. VMS-style mineralization is primarily restricted to rhyolite flow/dome complexes and felsic volcaniclastics often associated with auriferous silica-flooded (crackle-brecciated) rhyolites. Targets have been defined for a new regional drilling campaign in 7 key areas. Drilling has commenced.

GEOLOGICAL/HERITAGE WONDERS OF THE BONAVISTA PENINSULA: THE DISCOVERY GEOPARK PROJECT

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The Bonavista Peninsula is located on the eastern coast of Newfoundland. The rocky peninsula, which juts out into the North Atlantic, caught the attention of the early European explorers who made landfall there, discovering our New founde land. For generations, the environment has shaped a resilient people who have made their living off the cold, harsh but vibrant fishing grounds. Until recently, no one knew that for more than half a billion years, the bedrock of the peninsula has held important secrets. These landscapes and seascapes provide a unique glimpse of a crucial stage in the ancient history of the Earth, including nature's earliest experiments with evolution of animals.

The geological significance of the Bonavista Peninsula was not revealed until 2003, when the region was first mapped in detail by the provincial geological survey. These rocks, part of an ancient ocean long since vanished, preserve some of the earliest multi-cellular life after "Snowball Earth." In addition to recording a crucial period in Earth history, the region provides a glorious, readily accessible outdoor laboratory. In 2011, the provincial government formally recognized the significance of several paleontological (fossil) sites within a number of communities, including the Ediacaran fauna in Trinity Bay North and Elliston.

A regional steering committee is working to explore and educate the public about the coastal geological heritage of the peninsula's assets. The committee receives support and advice from various levels of the provincial and federal government. They have worked with geoscientists and a consulting firm to create a development plan and interpretative framework. Participation in two Best Practice Missions provided operational and management models of established Geoparks. In 2009, a visit to the Copper Coast and Marble Arch Caves Geoparks in Ireland, and the 2011 mission to Stonehammer, North America's first Geopark, reinforced the importance of community ownership, building partnerships and the high level of preparation for the application process to the Global Geoparks Network. A five-year development and work plan has since been created.

The bedrock and landscape is a remarkable natural phenomenon, and there is enormous potential for the development of a Geopark on the Bonavista Peninsula. There are numerous sites of geological value that intertwine with the rich history and distinctive culture of the Discovery Trail. Many of these areas are economically depressed and would benefit from coordinated, regional geotourism efforts to promote, preserve and protect the geo-heritage sites and the unique cultural traditions.

PHOTOSYNTHETIC (?) MICROBIAL MATS OF THE MIDDLE ARCHEAN MOODIES GROUP, BARBERTON GREENSTONE BELT (SOUTH AFRICA)

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The composition of the Archean atmo- and biosphere, the circumstances favoring the evolution of microbial life, and the origin of (oxygenic) photosynthesis are vigorously disputed.

Probably one of the best places to address some of these issues is the Moodies Group (3.2 Ga) of the Barberton Greenstone Belt (South Africa), which exposes one of Earth's oldest siliciclastic sequences with common macroscopic microbial mats. In order to constrain their setting, facies, and habitat we measured ten detailed stratigraphic sections spread ~11 km apart along strike in the interior of the greenstone belt where Moodies strata are relatively unmetamorphosed, preserving the remains of microbial mats and associated sedimentary structures in outstanding quality. Our results indicate a tidally influenced coastal depositional system in which microbial mats occur within an interval of ~1000 m thickness. They form green anastomosing or flat laminations < 1mm thick, interbedded with medium- to coarse-grained and gravelly sandstones. Microbial mats colonized coastal (and fluvial?) habitats of varying energy and occasionally experienced subaerial exposure.

Based on the microbially induced sedimentary structures, we distinguished four facies along a land-to-sea transect: 1) wavy laminae interbedded with nodular Fe-oxide concretions indicative of a restricted shallow-water setting; 2) nearly flat laminae associated with high shear stress suggestive of an intertidal setting; 3) wavy laminae associated with herringbone cross-bedding, underlain by bedding-parallel chert bands ~0.2 cm thick, indicating a subtidal setting and 4) crinkly laminae associated with petees (~0.7 cm height) and gas or fluid escape structures of up to 6 m height, of a yet unknown setting.

We tentatively conclude, based on exclusion arguments, the phototactic micromorphology and consistent shallow-water facies that the Moodies microbial mats, were at least in part photosynthetic communities.

DECIPHERING THE MONIAN SUPERGROUP: EVIDENCE OF ?CAMBRIAN AVALONIAN NEOPROTEROZOIC ARC EXHUMATION FROM THE NEW HARBOUR GROUP, NORTH WALES, U.K.

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The Monian Supergroup (MSG) is a low grade, variably deformed, metasedimentary sequence exposed in northernmost Wales. It has been interpreted as a Peri-Gondwanan, fore-arc accretionary complex although the age of depositional remains contentious - proposals range from Neoproterozic to Early Ordovician. U-Pb detrital zircon data from the basal unit (South Stack Group) indicate a Cambrian (Series 3, Guzhangian) maximum depositional age. However in resolving one problem, this age questions the relationship between the South Stack Group and the overlying New Harbour and Gwna groups. Although the New Harbour Group shows a coherent structural history with the South Stack Group, some workers suggest that the Gwna Group metabasites are correlatives of 550-560 Ma blueschist metabasites. If such an interpretation is correct this implies that the MSG is not a contiguous stratigraphy.

New U-Pb detrital zircon data from the upper part of the New Harbour Group (Skerries Formation) in northern Anglesey have been obtained to provide an additional age constraint on MSG deposition. The Skerries type locality succession includes boulder beds of granite and granophyre. These igneous clasts have a calc-alkaline arc affinity and an igneous U-Pb zircon age of 649.1 ± 5.0 Ma, with an inherited component of c. 1500 Ma. Detrital zircons from the sandstones interbedded with the boulder beds show the main population at 560 – 760 Ma with other significant populations at 1500 Ma and 1100 Ma. The zircon inheritance age suggests an almost exclusively arc-dominated source of East Avalonian affinity for these sediments, although the granites cannot be matched directly to any exposed complexes in Southern Britain. This is consistent with Sm-Nd data for the New Harbour Group which suggest an immature source. A northerly or north-easterly-derived source has been established for the New Harbour Group (on the basis of sedimentary structures) suggesting an outboard provenance for the boulders and cobbles. This contrasts with the southerly derived underlying South Stack Group which has a more mature Sm-Nd signature and Palaeoproterozoic and Archean inherited zircon components, not seen in the New Harbour Group. This therefore suggests a significant change in depositional architecture and exhumation of an arc block in the latest Cambrian or early Ordovician which has implications for the existing tectonic interpretation. The only alternative to this model is a major structural discontinuity between the South Stack Group and New Harbour Group that has not as yet been identified.

RECENT DEVELOPMENTS UNDERSTANDING THE VOLCANIC, MAGMATIC, TECTONIC, AND METALLOGENIC EVOLUTION OF THE ELY GREENSTONE FORMATION, VERMILION DISTRICT, NE MINNESOTA

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The Ely Greenstone Formation comprises a well-preserved stratigraphic sequence of Neoarchean supracrustal and associated intrusive rocks in the southwestern part of the Wawa-Abitibi Terrane in the Vermilion District of northeastern Minnesota. The Lower Member of the Ely Greenstone (LMEG) comprises calc-alkalic and tholeiitic basalt and basalt- andesite lava flows and tuffs with subordinate felsic lava flows, tuffs, epiclastic rocks and iron formations. The Soudan Iron Formation Member (SMEG) comprises Algoma-type interlayered cherty iron formation, basalt lava flows, epiclastic rocks and felsic tuffs. The Upper Member of the Ely Greenstone Formation (UMEG) is composed of a monotonous sequence of poorly-vesiculated tholeiitic basalt lava flows and localized Algoma-type iron formation lenses. The UMEG is commonly interstratified with the Lake Vermilion Formation (LVF), which is composed of greywacke, slate, conglomerate, and dacite tuff, as well as subaerial to submarine dacite to trachyandesite lava flows, tuffs, and associated intrusions (the informally named Gafvert Lake Sequence (GLS). Locally, it is believed that the LVF unconformably overlies the LMEG and SMEG strata. Previous studies (Schulz, 1980) interpreted volcanological and sedimentary textures to indicate a change from a subaerial / shallow subaqueous setting to a deeper subaqueous environment during the temporal genesis of the Ely Greenstone Formation. This interpretation is supported by our more recent and detailed field studies. Previous lithogeochemical studies by Southwick *et al.* (1998) indicate that a sharp transition from arc-like volcanism (LMEG) to MORB-like volcanism (UMEG) occurs abruptly at the top of the SMEG. However, new major- and trace element data indicate the lithogeochemistry of volcanic rocks in the LMEG is more complicated than previously recognized. Arc-like basalts and basaltic andesites and FI- and FII-type rhyodacites and rhyolites characterize the FLS. In the CBS, arc-like basalts and basaltic andesites transition up-section into E-MORB, OIB and back-arc basin-like basalts. These basalts are temporaly associated with FIII-type felsic volcanic rocks. The UMEG is characterized by MORB-like basalt compositions that may also be the product of back-arc spreading (Southwick *et al.*, 1998). A model encompassing initial arc development followed by back-arc development and rifting during the final stages of the LMEG immediately prior to SMEG deposition appears to be most consistent with the observed volcanological and lithogeochemical characteristics in this part of the Vermilion District. Iron formations within the SMEG occur immediately up-section from the proposed arc – back-arc transition, a stratigraphic position shown in many studies to have high prospectivity for hosting volcanogenic massive sulfide orebodies.

INTERACTIONS OF SINISTRAL FAULTS AND CAMP DIABASE DIKES DURING THE FINAL STAGES OF PANGEA BREAKUP IN THE SOUTHERN APPALACHIANS

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Evidence recording the breakup of Pangea spans the mid-Triassic through the earliest Jurassic in the southern and central Appalachians. Emplacement of numerous CAMP diabase dikes post-dates Triassic rifting, deposition, and subsequent inversion of Mesozoic rift basins. Diabase dike orientations mostly trend NW (290-345) in the southern Appalachians, and rotate to a more N and NE trend in the central Appalachians and New England. A narrow N-S-trending fanned swarm also occurs in the Carolinas, although the age of these dikes is indistinguishable from the more abundant NW-trending set. Collective dike emplacement likely occurred over a few m.y. or even less, although dike characteristics suggest individual emplacement was nearly instantaneous. The lack of country rock contamination, uniform texture, and extreme surface area to width (mostly <25 m) require very rapid propagation to prevent heat transfer and crystallization prior to dikes reaching the upper crust. Assuming moderate estimates of Young's modulus and crustal density, we estimate individual dikes penetrated the thickness of the crust (35 km) in 3 minutes.

Emplacement of CAMP diabase dikes was coeval with movement along numerous small-displacement faults filled with silicified cataclasite throughout the southern Appalachian orogen, indicated by faults crosscutting dikes, and vice versa. Siliceous cataclasite faults generally trend NE, NNE, and E-W, although geographic control of orientation similar to CAMP dikes is not apparent. A single strain ellipse does not resolve all orientations of diabase dikes (YZ plane, mode I fractures) and siliceous cataclasite faults (shear planes).

Many siliceous cataclasite faults reactivate older (mostly Alleghanian) faults that formed at a much deeper crustal level. The Towaliga fault (AL-GA) is a major Alleghanian garnet-grade dextral strike-slip fault that trends ~070° in its SW segment, changes to ~035° at the NE end of the Pine Mountain window (central GA), and continues NE through the Inner Piedmont. Isolated, km-scale rhomboidal to elongate pods of intensely deformed silicified cataclasite occur along both segments of the fault. These likely represent mineralized fault-fracture meshes that formed in dilational step-overs along discrete sinistral strike-slip faults, and crosscutting relationships confirm deformation temporally overlaps CAMP dike emplacement. Other nearby faults with isolated cataclasite pods exhibit similar trends, kinematics, and temporal characteristics, but do not reactivate preexisting faults. Siliceous cataclasite faults also share some spatial relationship with low-temperature (400°C) ribbon quartz mylonite that likely formed during the late Alleghanian or early stages of Mesozoic rifting, although timing of this mylonite is poorly delimited.

THE QAVVIK-TATIGGAQ TREND: AN EVOLVING UNCONFORMITY-RELATED URANIUM CORRIDOR OF THE NORTHEAST THELON BASIN, NUNAVUT

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The Qavvik-Tatiggaq Trend (QTT) is a 25 km E-W-trending corridor within the northeast part of the Thelon Basin. It hosts two newly-discovered, basement-hosted, uranium deposits named the Qavvik and Tatiggaq deposits, as well as a zone with anomalous uranium values in the overlying sandstone sequence. The mineralization is structurally-controlled and situated within the Neoarchean Woodburn Lake Group and Paleoproterozoic Hudson Suite rocks. These rocks underwent multiple ductile and brittle deformation events during the Taltson-Thelon and Trans-Hudson orogenies. The mineralization is located proximal to ENE-trending dextral fault zones, as well as NE-, E-, and NW-trending faults; all of which are interpreted to have been initiated and reactivated during these two orogenic events, as well as after the deposition of the Thelon Formation. Uranium mineralization is associated with distinct alteration assemblages consisting of hematite, clay, bleaching, and sulphide. The protracted deformation history is important as it has led to the creation of crustal-scale fault zones, formation of long-lived sedimentary basins, subsequent structural reworking and fault reactivation, and eventually generation and migration of hydrothermal fluids and deposition of uranium.

PLIO-PLEISTOCENE MASS WASTING AND CONTOURITIC ARCHITECTURE ON THE CONTINENTAL SLOPE IN SALAR BASIN, SOUTHEAST GRAND BANKS OF NEWFOUNDLAND

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Multibeam bathymetric renderings coupled with a seismostratigraphic framework have demonstrated the diversity and ubiquity of Cenozoic mass wasting along the southeastern Canadian continental slope. Increased environmental and energy interest on the slope dictates a temporal and process understanding of slope sediment instability. The Salar Basin, on the SE Grand Banks slope, presents a mixed setting of canyons, translational slides and along-slope sediment supply that enables a contrast of these processes through the onset and domination of glacial sediment supply. A rudimentary seismostratigraphic framework supported by exploration well stratigraphy (base Pliocene) focuses on the Plio-Pleistocene interval which comprises nearly half the sediment succession above the break-up (Avalon) unconformity. Mid-slope contouritic deposition dominated over mass wasting deposition through and into the Pliocene, creating a terrace. This is followed by a change to shelf and slope-based sedimentation style, presumed to reflect the onset of shelf-crossing glaciations. The Salar Basin upper to mid slope area presents three dominating architectural regimes driving seabed morphology: a failure dominated steep upper Zone 1 (shelf break to 1200 m water depth), a terrace hosting a greater proportion of un-failed strata, Zone 2 (1200-1500 m), and a lower, hummocky and intensely mass wasted Zone 3. The zones are bounded by canyon systems to the north and south. Slope angles on the upper zone are 3 to 5°, where sharp failure scarps of translational slides have dominated, maintaining long-term bypass, locally exposing Pliocene strata and even bedrock. Upslope failure limits are generally determined by the outer shelf till boundary, however, some till failure occurred. The terrace (< 3° slope) developed as a Pliocene/early Pleistocene contouritic drift. Coincident with the change in shelf sedimentation style linked to mid Pleistocene glaciations, there was an increased mass wasting frequency, derived from zone 1 failures. These terminated on the terrace and interbedded with a dominant hemipelagic sedimentation creating a thick sediment package onlapping zone 1 which inherited and further enhanced terrace building. Zone 3 slope angles are comparable to the steep upper slope. Pervasive retrogressive slides have removed more than half of the glacially-dominated section leaving almost none of the seabed undisturbed. High resolution seismic coupled with sparse cores may allow a rough chronology of the latest slide events. The slope sedimentation architecture demonstrates that the persistent late Tertiary contouritic style in the stratified sediments was maintained despite the change in sedimentation style with glacial onset, yet increased mass wasting also marked this change.

THE SECOND ANNUAL TEACHERS' MINING TOUR - AN INSTRUCTIONAL DEVELOPMENT PROGRAM FOR EDUCATORS

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Members of the Canadian Earth Science Education and Outreach Community share a collective concern about the limited number of students choosing to pursue a post-secondary education in Earth Science. This is a problem for post-secondary institutions and Earth Science departments and ultimately leads to a paucity of youth entering Earth Science careers, including mining. The Canadian Earth Science Education

and Outreach Community has been working individually and collectively toward addressing this concern. One approach that is used is to provide instructional development opportunities to educators that teach Earth Science courses. The Ontario Teacher's Mining Tour, an educator professional development program, is an example.

The goal of the Tour is to provide teachers with the information and resources they need to be proficient Earth science teachers and to encourage their students to pursue post-secondary education and careers in Earth sciences. The objectives of the tour are to expose educators to all phases of the mining cycle through engagement with industry, Earth science and mineral education professionals, and through participation in Earth science and mineral industry themed presentations, educational resource workshops and field trips. Additional objectives are to create and cultivate a network of teachers using mining as a theme in their classrooms, and to facilitate informed decisions among participants with regard to the economic, social and environmental aspects of the mining industry. The Tour curriculum includes modern mining techniques and technologies, environmental responsibility and workplace safety, mining careers, and activities, applications, and resources for teachers and students in the classroom.

2011 marked the second annual Teachers' Mining Tour, held at the Canadian Ecology Centre (CEC) located in the Samuel De Champlain Provincial Park, near Mattawa Ontario. Twenty seven Ontario teachers participated in the program that included presentations by experts, industry professionals, and consultants, and site visits to mines and mining manufacturing operations in Sudbury and North Bay. Feedback from the teachers who participated in the inaugural 2010 program informed the 2011 Tour program, including content and presenters.

The 2011 program received favourable reviews from participating teachers, industry participants and sponsoring organizations. During the current academic year additional feedback was gathered both from the teachers who participated in the inaugural Tour and those who participated in year two. Formal surveys were circulated onto them to gauge how their tour experiences informed their teaching. The results of these surveys will be discussed.

1.2 Ga CRUSTAL EXTENSION IN THE CENTRAL GRENVILLE PROVINCE

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In addition to unravelling mountain building processes, understanding orogenic belts also involves recognition of the origin and pre-orogenic history of their constituent lithotectonic elements. In deeply exhumed orogens original rock units are largely transformed into gneisses by means of high-grade metamorphism, anatexis and deformation, making investigations of the protoliths particularly challenging. However even in such cases, detailed field studies, together with geochemical and age data, have the potential to provide insight on complex pre-orogenic tectonic settings. An example is the recent recognition of a 1.2-1.3 Ga intracontinental rift system in the hinterland of the central Grenville province, south of the Manicouagan reservoir. Rock units of that age range previously known in this area include: ~1.3 Ga granitoid plutons intrusive into the SE margin of Labradorian-age crust and ~1.2 Ga bimodal (felsic-mafic) to intermediate composition supracrustal sequences (Banded Complex) adjacent to ~1.4 Ga units farther to the SE. Based on its lithological makeup and geochemical signature the formation of this complex was attributed to crustal extension. However the original setting and relations with adjoining units were poorly constrained.

Recent detailed fieldwork revealed that SE of the Banded Complex, along strike, a ~1.4 Ga layered mafic complex (LMC) is variably impregnated by felsic material, grading into a mafic migmatite which in turn gives place to a layered quartzofeldspathic sequence (LQFS). LQFS generally consists of massive quartzofeldspathic layers with varied proportions of quartz and feldspars, but also contains heterogeneous mafic layers, 'bleached' felsic layers, garnetites, felsic gneisses with garnet and sillimanite-rich nodules, and calcsilicate rocks. This association is inferred to represent a hydrothermally altered volcanic belt. The LQFS is interpreted as a dominantly volcaniclastic sequence deposited in a crustal extension setting after cutting through the LMC, the injected parts of which represent the walls of an intracontinental rift. These field relations are locally well preserved despite Grenvillian age deformation and granulite facies metamorphism. A crustal extension origin is also consistent with geochemistry of mafic layers of the LQFS which indicates an asthenospheric mantle origin with little or no lithospheric contamination. A 1238 ± 13 Ma emplacement age is constrained by U/Pb igneous zircon data from a nodular felsic gneiss of the LQFS. This age, together with the regional distribution of units suggest that LQFS and the Banded Complex were formed during broadly the same extensional event affecting the Laurentian margin several 10s of My prior to the Grenvillian orogeny.

EFFECT OF DEPLETED CONTINENTAL LITHOSPHERE COUNTERFLOW AND INHERITED CRUSTAL WEAKNESS ON THE FORMATION OF THE NEWFOUNDLAND-IBERIA AND NOVA SCOTIA-MOROCCO CONTINENTAL MARGINS

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In the past two decades, significant advances have been made in understanding the present-day structure of rifted continental margins using reflection and refraction seismic techniques. Despite these advances, we have only a rudimentary understanding of the processes involved in the development of non-volcanic rifted margins, particularly the role of depth-dependant crustal extension, inherited crustal weaknesses, flow of lower continental mantle lithosphere, and syn-rift sedimentation.

In this study we use 2D thermo-mechanical finite element modeling to investigate the evolution of upper-mantle scale systems (1200 km wide, 600 km deep). The results are compared with the Newfoundland – Iberia and Nova Scotia – Morocco conjugate margin pairs. The models include thick (200 km) chemically depleted mantle lithosphere, inherited crustal weaknesses, and syn-rift sedimentation. When the lithosphere is thick and chemically depleted, the hotter buoyant lower mantle lithosphere flows toward to rift axis during rifting allowing the formation of exhumed continental mantle lithosphere. The result is the formation of wide tracts of exhumed mantle lithosphere, subsequently serpentinized owing to hydration, which forms transitional crust between extended continental crust and oceanic crust, consistent with observations of serpentinized continent-derived mantle rocks in the transitional crust region of the Newfoundland – Iberia conjugates, and similar interpretations from the northern Nova Scotia margin.

Inherited crustal weak zones that are offset from the main central rift axis can be reactivated as offset rift basins. Extension in these basins depends on their proximity to the central rift and the ease with which crust decouples from mantle: narrow (<50 km) basins when crust does not decouple, and longer-lived wider basins for moderate decoupling. For weak crust that readily decouples during depth-dependent extension, the offset rift basins can remain active throughout rifting, giving rise to highly allochthonous crustal terranes that are translated toward and over the central rift axis. Syn-rift sedimentation can enhance extension in offset rift basins; significant and widespread syn-rift sedimentation can result in the development of wider continental margins in general, especially when the crust is weak. Model results illustrate how offset weak zones and thick depleted mantle lithosphere flow can result in complex multi-stage rifting that has implications for the timing and structural evolution of syn-rift sediment depocenters.

OVERPRINTING MAGMATIC AND TECTONIC EVENTS IN ACCRETIONARY OROGENS AND THEIR INFLUENCE ON MINERALIZING SYSTEMS: EXAMPLE FROM THE NORTHERN CORDILLERA

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The northern Cordillera of British Columbia, Yukon and Alaska comprises several tectonic terranes that were accreted to the Laurentian margin over

approximately 150 My. The Yukon-Tanana and Stikine terranes are characterized by a Paleozoic to late Mesozoic volcanic arc and associated siliciclastic rocks that were amalgamated to form the Intermontane terranes prior to accretion to the margin. Outboard of the Intermontane terranes, the Insular terranes, mainly comprised of the Alexander terrane and Wrangellia, are characterized by Proterozoic through late Mesozoic rift and arc-related volcanic rocks and thick platformal sequences. Wrangellia was likely built on the flanks of the Alexander terrane, itself a composite terrane, and the whole mass was then accreted to the western margin of the Intermontane terranes by the Middle Jurassic.

The Coast belt is a complex of Middle Jurassic to Tertiary arc magmatic rocks that developed along the western margin of the Intermontane terranes as a result of subduction of Farallon and Pacific ocean crust and the convergence of the Insular terranes. Accretion of the Insular terranes was a prolonged, episodic event that included transpressive, transtensive and orthogonal subduction, as well as periods of transcurrent faulting. The prolonged nature of subduction led to multiple overprinting magmatic, tectonic and metallogenic events affecting the suture zone between these two superterranes. These generated several mineralizing systems, including porphyry copper-gold, epithermal gold and orogenic gold deposits. Mid-Cretaceous epithermal gold deposits are found at the flanks of a large batholithic core of the same age. Slightly younger and cross-cutting intrusion-related and orogenic gold systems occur in the core of the batholith, where they were exposed and re-mobilized during renewed magmatism and inflation of the main magmatic axis in the Late Cretaceous. Late Cretaceous porphyry copper-gold deposits and associated epithermal gold mineralization cross-cut and remobilize earlier mineralization. Continued magmatism into the latest Cretaceous and Paleocene occurred at the outboard margin (SW) of the mid-Cretaceous magmatic axis and is associated with porphyry copper-gold-molybdenum and epithermal gold deposits. In the forearc of the latest Cretaceous to Paleocene subduction zone, compressional faults were conduits for fluid flow and the formation of orogenic gold systems.

New mapping and geochronological analyses of igneous rocks from southwest Yukon illustrates the close relationships between subduction and mineralizing events and the resulting concentration of magmatic and metallogenic belts in the northern Cordillera.

FOSSILIZATION OF MICROBIAL ETCHINGS FROM THE STONYFORD VOLCANIC COMPLEX: A LINK BETWEEN MODERN SEAFLOOR BIOALTERATION AND PUTATIVE ICHNOFOSSILS IN OPHIOLITES AND GREENSTONE BELTS

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Microscopic hollow tubular and granular structures in relatively young, sub-aqueous basaltic glass have been reported from numerous submarine localities worldwide. Several independent lines of evidence, including morphology, presence of biologically-important elements (e.g., C, N, S, P), associations with organic matter, carbon isotope compositions, and geological context point to a microbial origin. Titanite-rich tubular features of similar morphology in metabasalts from ancient ophiolites and greenstone belts have similarly been interpreted as ichnofossils in rocks of up to ~3.5 Ga age. Nevertheless, a convincing mechanism for preservation of originally hollow microbial alteration textures in basaltic glass has remained illusive. In the present study, we document tubules in basaltic glasses from the Jurassic Stonyford Volcanic Complex (SVC) that are intermediate between hollow tubules commonly found in modern oceanic crust and ancient titanite-mineralized tubules. Tubules hosted in glassy material are mostly hollow, with sparse occurrences of infilling materials, likely including Fe-oxyhydroxides, phyllosilicates, and traces of titanite. Tubules are rooted on fracture surfaces and glass shard boundaries that would have been exposed to circulating fluids on the seafloor. Hollow tubules are indistinguishable from similar features hosted in basaltic glasses from in situ ocean crust. Throughout the sample, there are domains where basaltic glass has been replaced by an assemblage of zeolites with minor quartz and calcite along cracks and fractures. At glass-alteration interfaces, all hollow tubules observed abruptly change to mineralized tubular features containing fine-grained titanite and other minerals. The tubular features are continuous across the sharp transition from glassy to zeolitized domains. The mineralized zones of SVC tubules are remarkably similar to titanite-mineralized tubules documented in ancient metabasaltic rocks. In particular, they share a common occurrence along shard boundaries and fractures in basaltic glass, are filled with fine-grained titanite, commonly trending approximately perpendicular to shard edges or fractures, do not cross one another, and are of similar but somewhat larger diameter to hollow tubules. The observations reported here demonstrate a convincing mechanism for the formation of titanite-mineralized tubules along pre-existing microbially-etched tubules, and reinforces the interpretation of titanite tubules in ancient metabasalts as microbial ichnofossils.

Keynote THE ORIGIN OF THE ALPHA RIDGE AND ITS LINKS TO THE HIGH ARCTIC LARGE IGNEOUS PROVINCE

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The formation of the Alpha Ridge and the significance of the widely distributed High Arctic Large Igneous Province (HALIP) have been an enigma due to lack of direct evidence to constrain the geodynamic evolution of the region. A new 350 km long seismic refraction line was collected from the coast of northern Canada to the southern Alpha Ridge with a recorder spacing of 1.5 km and a shot spacing of 22 km to define the sedimentary to Moho structure. Near the coast the crustal velocities are 5.6 - 6.5 km/s and the depth to Moho is 30 km, compatible with the adjacent continental crust. On the Alpha Ridge there is a near-seabed velocity of 4.7-5.4 km/s interpreted as extrusive volcanics on the basis of seismic reflection and magnetic character. This layer is underlain by velocities of 6.1-6.6 km/s and 6.8-7.3 km/s, with Moho at depths of 26-32 km. The velocity structure of the Alpha Ridge is similar to that observed on other large plateaus in the oceans. In addition, a 550,000 sq km aeromagnetic survey was flown over the section of the Alpha and Lomonosov ridges adjacent to North America and Greenland. The survey comprises of a set of 800 km long flight lines, spaced 12–15 km apart, subparallel to the Lomonosov Ridge. We present the results of aeromagnetic data compiled from the new LOMGRAV survey and reprocessed NRL-98/-99 data. The combined magnetic and seismic refraction data provide hitherto undetected tectonic links between the HALIP and the Alpha Ridge that serve as important constraints on the plate tectonic setting and history.

IMPLICATIONS OF NEW U-Pb ZIRCON AGES FROM THE CORONATION MARGIN REGION OF THE SOUTH-CENTRAL PALEOPROTEROZOIC WOPMAY OROGEN, NORTHWEST TERRITORIES, CANADA

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In the northwestern Canadian Shield, the superbly exposed Paleoproterozoic Wopmay orogenic belt is a widely quoted example of Precambrian plate tectonics and terrane accretion. Results from an 8-year, 100 km by 100 km bedrock mapping transect with associated geochronological studies in south-central Wopmay orogen are presented.

In south-central Wopmay orogen, the Coronation margin is a complex region encompassing sialic basement, sedimentary and volcanic rocks of low- to high-metamorphic grade, and granitic to gabbroic

intrusions. The widespread and variably deformed tonalitic, granodioritic, and granitic basement rocks yield Archean U-Pb zircon ages ranging from >3000 Ma to ca. 2575 Ma. Exposures of thickly bedded and upright-folded, low-grade sandstone and stromatolitic carbonate of the passive margin sequence are minimal and restricted to near the craton edge. An extensive polydeformed and metamorphosed pelitic sequence with minor carbonate, sandstone, and mafic volcanic rocks, rests unconformably on the Archean basement. As such this sequence is part of an autochthonous (not exotic) succession within the Coronation margin. Paleoproterozoic intrusions were emplaced at ca. 1877, 1867, and 1858 to 1850 Ma. At ca. 1877 Ma and 1850 Ma there was coincident resetting of Archean U-Pb systematics and regional metamorphism. The ca. 1877 Ma syn-deformational intrusions are possible correlatives with the Hepburn intrusive suite, but historical models indicate this suite was emplaced about 10 m.y. earlier during the ca. 1885 Ma Calderian orogeny. Plutonic phases of ca. 1885 Ma are not identified within south-central Wopmay orogen. The pattern of metamorphic isograds that developed around the ca. 1850 Ma Rodrigues granite, suggests the thermal aureole is related to emplacement of this large pluton, potentially within a metamorphic core-complex type environment. These younger intrusions are coeval with the latest magmatism in the Great Bear magmatic zone to the west, and intruded in a post-orogenic, potentially transtensional setting. Finally, a Morel sill in the study area has yielded an 1868 Ma U-Pb zircon crystallization age, 15 m.y. younger than its previously speculated age. The new mapping and U-Pb zircon results, in conjunction with lithospheric geophysical experiments, allow us to test previously proposed and new hypotheses on the evolution of Wopmay orogen.

CONGLOMERATES AND CONGLOMERATES IN THE URANI-FEROUS NORTHEAST THELON BASIN REGION, NUNAVUT: GUIDES FOR UNRAVELLING >800 Ma OF SEQUENCE STRATIGRAPHY AND METALLOGENY

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Some twenty conglomeratic markers in the northeastern Thelon Basin region are distinguished by context, composition, texture and fabric. Many overlie local to profound unconformities. They record pre- syn- and post-depositional deformation, sequence boundaries, and mineralization. Stratigraphy helps the GSC's Geomapping for Energy and Minerals (GEM) Program provide a framework for exploration. Of seven Neoarchean assemblages, the first six constitute the Woodburn Lake group and the seventh is a Rae craton scale 2.6Ga mafic to felsic intrusive/extrusive suite. The Neoarchean is structurally intercalated (D_1) with early Paleoproterozoic platformal Ps1-3 (lower Amer and Ketyet River groups). Ps4 is molasse, overlies D_1 nappes with profound unconformity, and contains 1.9Ga detrital zircons and D_1-style deformed clasts. The 1.83 to <1.54Ga Dubawnt Supergroup comprises three rift-fill groups: Baker Lake (5 subaerial volcanic and siliciclastic sequences), Wharton (conglomerate, aeolian quartzarenite, bimodal volcanics and coarse feldspathic alluvial sequences), and Barrensland (alluvial conglomerate to sandstone sequences, topped by mafic potassic lavas and marine dolostone). Some conglomerate highlights follow.

Polymict, quartz dominated conglomerate previously interpreted as Neoarchean is intercalated in outcrop and drill core with the 2.7Ga Woodburn Lake group around Meadowbank gold mine. We suggest it is structurally intercalated basal Ps1, based on similarities with better constrained <2.6Ga Ps1 to the northwest. This raises the questions of whether pre-deformed cobbles of sulphidized BIF constrain the primary age of gold mineralization and whether other conglomerates in the Woodburn Lake group are truly Archean.

Conglomerate units help define the Ps1-Ps2 facing direction. Ps1 comprises basal schist ± basal conglomerate, quartzarenite, ± upper conglomerate. Ps2 is characterized by graphitic schist, intercalated with three discontinuous components that, where present, are always in order: impure sandstone - dolostone - basalt. Highly attenuated isoclinal D_1 folds defined by such facing directions and the flat synforms of cuspate-lobate D_2 explain the 400-1000m widths of Ps1 map units, whose pre-D_1 thicknesses were only 100-200m.

Conglomerate characteristics and angular unconformities around the margins of northeastern Thelon Basin have allowed us to recognize aeolian sandstone as Wharton, not Barrensland group. Wharton conglomerate is highly feldspathic with dominantly quartz pebble framework, whereas overlying Wharton is aeolian quartzarenite. Conversely, basal Barrensland conglomerate is highly polymict (including Wharton clasts) in a quartzose matrix whereas overlying Barrensland is clay-altered fluvial arkose. Unconformity-associated uranium deposits may be discovered below the Barrensland, and within or below the Wharton groups.

CAN TARGETING CRITERIA FROM ATHABASCA BASIN BE ADAPTED TO URANIUM EXPLORATION IN THELON AND OTHER NORTHERN PALEOPROTEROZOIC BASINS? A PROGRESS REPORT

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This question has driven investigations of northern Canadian basins since Rabbit Lake was discovered in 1968, and is the guiding hypothesis for GEM's Northern Uranium for Canada Project. Discovery of Kiggavik in 1977 and Cameco's recent exploration success just west of there demonstrate that the answer is YES for the Thelon Basin region, yet this and the other northern basins remain under-explored. We contribute improved geoscience knowledge of areas around Thelon, Angikuni and Hornby Bay basins to further evaluate this hypothesis. Speculative interpretations below do not necessarily represent the views of co-authors or corporations who contributed knowledge.

Known uranium resources near Thelon Basin are basement-hosted and occur beyond present sandstone cover. Our studies focus on integrating regional compilations with detailed mapping, and geological, geophysical and drift prospecting models, while refining Thelon Basin stratigraphy. Basement to Thelon basin differs from the Paleoproterozoic fold-thrust belts beneath Athabasca Basin: six Neoarchean sequences of ultramafic to felsic volcanic and sedimentary rocks are structurally intercalated with thin sequences of Paleoproterozoic platformal siliciclastics, minor dolostone and continental tholeiitic basalt. Graphitic metapelite is fertile beneath Athabasca Basin but barren in the few drill intersections below Thelon Basin. Disseminated cigar-shaped sandstone uranium deposits in Thelon's basement differ contextually from uranium and copper occurrences in the rift component of Athabasca's basement. In Thelon's Kiggavik area, Neoarchean metagreywacke is the preferred uranium host, especially where intruded by high-level 1.75 Ga granite. Intersecting reactivated faults localizing illite, chlorite and hematite alteration around uranium deposits are key in both basins, although details of mineralogy and zoning differ. Both basins developed intracontinentally by reactivated faulting and were filled by big rivers, but have different sequence stratigraphy, sandstone composition, diagenetic and hydrothermal alteration events. Exploration success depends on understanding each basin's parameters and adapting to the similarities and differences.

We assess other "types" of uranium deposits with the unconformity paradigm and reinterpret Lac Cinquante and Port Radium veins in circum-Angikuni (southern Baker Lake Basin) and Hornby Bay Basin areas respectively as exhumed unconformity deposits with greater vistas for exploration. We consolidate discovery of Dessert Lake Basin as correlative

with Athabasca and Thelon basins, and establish its dimensions under which favourable basement domains project. We establish that stratigraphy and structural evolution of Hornby Bay Basin are more similar to Athabasca than Thelon basins, yet with greater fault throws. Hornby Basin's thermal and uranium pulses at ~1270 Ma may be measureable in Athabasca Basin.

INVESTIGATION OF SAMPLE RESOLUTION REQUIRED FOR X-RAY FLUORESCENCE ANALYSIS TO IDENTIFY HETEROGENEITY IN FINE-GRAINED SUCCESSIONS

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This study aims to determine the sampling resolution necessary to accurately identify elemental trends through fine-grained successions. To do this two types of X-ray fluorescence (XRF) analysis were conducted on outcrop samples collected from the fine-grained Carboniferous aged (Brigantian) Benbulben Shale exposed at Streedagh Point in Sligo County, Ireland. A total of 19 samples were collected along with a detailed log, over a 5.4 m interval. The samples were analyzed with both conventional XRF techniques and an ITRAX XRF core scanner. The mineralogy (determined with X-Ray Diffraction) and microlithofacies variability (determined by optical and SEM techniques) were also investigated to provide context and identify the character of the fine-grained succession. The ITRAX scanner uses an XRF to record elemental responses at 2 mm intervals across each sample. After the scan, samples were crushed, converted into pressed pellets and analyzed using conventional XRF techniques. The scan is particularly useful, as the sedimentological controls on mineralogical distributions (e.g. quartz, calcite) can be determined. Combined with textural analyses this technique enables spatial elemental distributions to be recorded and interpreted in terms of different depositional processes responsible for rock formation. The ITRAX scan identified significant variations in elemental composition across mudstone samples due to a variety of factors including, mineralogy, bedding, amount and type of cement, bioturbation and shifts in facies. To compare between techniques the average response for each element was calculated from the scan using all data points across individual samples. Comparison between conventional XRF techniques (pressed pellet) and the ITRAX scanning technique yielded remarkably consistent results. While the conventional XRF technique provides very accurate results, the sampling resolution is often much to coarse to identify significant elemental excursions and trends within the measured unit. In very fine-grained rocks (i.e. mudstones/shale), where processes and events are preserved in the rock record at a very small scale, conducting such a bulk analysis can result in not identifying key information. Scanning techniques providing high-resolution data are very useful in these fine-grained rocks as they can elucidate a higher degree of heterogeneity, helping to identify important rock properties.

SULFUR ISOTOPE INVESTIGATION OF IRON-DISULFIDE MINERALS IN THE FINE-GRAINED EXSHAW FORMATION

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A 5 m section of the Exshaw Formation was measured and logged in Jura Creek, Alberta, Canada to investigate (using SIMS, XRD & XRF) the depositional and early diagenetic processes controlling the precipitation of varying iron-disulfide mineral assemblages (including pyrite, marcasite, sphalerite, and millerite) present in a basal arkosic arenite and in the associated overlying mudstones. This formation, along with its lateral equivalent the Bakken Shale is significant because it is a regional tight gas reservoir target. Proportions of marcasite to pyrite are particularly significant because they can provide insight into the geochemical conditions (oxygen concentrations, pH and redox) at the time of deposition. Recent research has suggested that the most likely cause for the formation of early marcasite in marine shales is the oxidation of pyrite and reprecipitation of marcasite under the acidic conditions that ensue. Microlithofacies variability (determined by optical and SEM techniques) was also investigated to provide context and identify the character of the fine-grained succession, which hosts the sulfide minerals. Apart from a basal arkose arenite the lithofacies include both laminated and thin-bedded mudstones, which are variably bioturbated and contain agglutinated benthic foraminifera. Mineralogically the mudstones are predominantly composed of quartz (62 to 79 %), feldspar (10 to 20 %), clay minerals (10 to 18 %) and variable proportions of pyrite. The arkosic arenite is a phosphate-bearing lag deposit containing sand-sized (100 to 250 μm) detrital quartz, and a significant early diagenetic component, including the iron-disulfide minerals. Sulfur isotope analysis of pyrite and marcasite identified three populations of $\delta^{34}S$ with pyrite displaying ranges from -8.1 ‰ to -14.9 ‰ and -30.7 ‰ to -38.6 ‰; and marcasite displaying a range from 6.3 ‰ to 14.5 ‰. These results suggest multiple sources of sulfur entering the system during the deposition of the unit. The pyrite oxidation and re-precipitation theory fails to explain either i) the significant difference in $\delta^{34}S$ between marcasite and earlier deposited (based on textural analysis) pyrite or ii) the co-occurrence of other metal sulfides (e.g. sphalerite and millerite). One potentially more plausible formation pathway of marcasite in this case appears to be a process similar to basinal brine deposited Pb-Zn type ore deposits, which often contain associated sulfides such as sphalerite and millerite.

PALINSPASTIC RESTORATION OF APPALACHIAN – VARISCAN CONTINUITY

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The Appalachians of North America and the Variscan of Europe are commonly interpreted as components a single orogen that developed in response to the continental collisions that heralded the formation of Pangea. Post-Pangean deformation in the Appalachian - Variscan realm is restricted to Triassic to Cretaceous rift-phase extension and subsequent drift-phase solid body translations related to Atlantic and related basin opening. Locally significant Alpine overprints are restricted to the Mediterranean and Pyrenean domains. Palinspastic closure of the Atlantic ocean should, therefore, restore continuity of the Appalachian and Variscan orogens. It does not, which begs the question why? Palinspastic closure of the Atlantic restores the Variscan orogen of Iberia against the Grand Banks - Flemish Cap continental margin offshore of Newfoundland, hence part of the problem is the inaccessibility of the offshore continuation of the Appalachians. However, a larger problem is that the Variscan orogen of westernmost Europe has been depicted as a convex to the west arcuate feature referred to as the Ibero-Armorican Arc. The Ibero-Armorican arc geometry, which requires closure of the orogen to the west leaving no easy way to establish continuity with the Appalachians, is based on assumed continuity of geological belts of southern Great Britain and northern France, including the Rheic suture, around the Cantabrian orocline, a 180 degree bend that characterizes Variscan orogen of northern Iberia, into western and southern Ibera. It is now recognized that two coupled oroclines characterize the Variscan orogen in Iberia, the convex to the west Cantabrian and a more southerly, convex to the east Central Iberian Orocline. Together these coupled oroclines (1) define a continental scale S-shaped fold of the Variscan orogen; (2) call into question the assumed continuity and westward closure of geological belts implied in the Ibero-Armorican arc interpretation; and (3) re-open the question of how the Variscan and Appalachians relate to one another. We show that the Ibero-Armorican arc interpretation can be modified to accommodate the second Iberian orocline, but suggest that the predictions of such a model are difficult to reconcile with our current understanding of Variscan geology. Alternatively, the southern limb of the Central Iberian orocline, which is truncated against the Atlantic Iberian margin, may have originally been continuous into the Appalachians. However, this geometry has its own difficulties: it results in two separate Rheic sutures, a northern suture represented by the Lizard complex of Cornwall, and a southern represented by the Beja-Acebuches of Iberia.

LITHOGEOCHEMISTRY OF THE 130-80 Ma HIGH ARCTIC LIP (HALIP) EVENT AND IMPLICATIONS FOR Ni-Cu-PGE PROSPECTIVITY

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The lithogeochemistry of a suite of samples from Axel Heiberg and Ellesmere Islands has been examined to determine the Ni-Cu-Platinum Group Element (PGE) sulphide prospectivity of the High Arctic Large Igneous Province (HALIP) event; this research represents the first systematic analysis and interpretation of the magmatic sulphide potential of this event. The HALIP consists of volcanic rocks, dyke swarms and sills of Cretaceous age that are scattered widely across the high Arctic. They occur prominently in the Sverdrup Basin Magmatic Province of the northern Arctic islands of Canada, and also in northern Greenland, Svalbard and Franz Josef Land. In the Arctic islands of Canada, the event spans some 70 Ma, with an early, tholeiitic phase of igneous activity from 130-90 Ma followed by alkaline magmatism between 85-60 Ma. The two types of magma present in the HALIP differ in their Ni-Cu-PGE magmatic sulphide prospectivity; the geochemistry of the alkaline magmas is suggestive of unfertile or poorly fertile magmas which were S-saturated when they left the mantle. As such, these magmas did not sequester significant amounts of chalcophile elements during partial melting and are probably unfertile and unprospective. In comparison, the presence of chalcophile element-undepleted samples within the tholeiitic HALIP suite indicates that the magmas that formed these rocks were S-undersaturated when they left the mantle and sequestered significant amounts of Cu and PGEs from the mantle during partial melting. In addition to chalcophile-undepleted samples, the presence of crustally contaminated chalcophile element-depleted samples within the tholeiitic suite suggests that at least some of these fertile magmas assimilated crustal material and became sulphur saturated prior to emplacement. This S-saturation event segregated immiscible magmatic sulphides from the silicate magma which may have been deposited within ultramafic or mafic intrusives associated with the older tholeiitic segments of the HALIP. This suggests that the tholeiitic portion of the HALIP should be considered prospective for Ni-Cu-PGE sulphide mineralisation, and any mafic-ultramafic sequences associated with this portion of the HALIP should be considered targets for Ni-CU-PGE mineral exploration. In addition, if further sampling indicates that the alkaline magmatic suite was fertile in part, then the evidence of crustal contamination within this suite suggests that it may also be prospective; however, the older, higher degree partial melt-related tholeiitic suite most likely represents a better target for Ni-Cu-PGE exploration.

NEW INSIGHTS INTO THE FORMATION PROCESSES OF SUPERIOR-TYPE BANDED IRON FORMATIONS: CARBONATES, AN ADDITIONAL SOURCE FOR KENO-MAGNETITE FROM THE LUCE IRON ORE DEPOSIT, LABRADOR CITY, NEWFOUNDLAND AND LABRADOR

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Banded Iron Formations (BIFs) are the main sources of iron ore today with the Paleoproterozoic Labrador Trough being host to one of the largest reserves in the world. With a significant reserve and resource base, the Iron Ore Company of Canada (IOC located in Labrador City, Labrador) is the largest iron producer in Canada. The Luce Iron Ore Deposit is one of IOC's main assets. This deposit is subdivided into three open pits: Luce South, Main and Basin.

The main stratigraphic unit mined by IOC within the Luce Deposit is the Wabush Iron Formation. It is subdivided into three members: The Lower, Middle and Upper Iron Formation, with the middle unit being the main source of iron ore. This formation has been extensively folded and metamorphosed to upper amphibolite facies during the Trans-Hudsonian and Grenvillian orogenies. The main minerals in the Wabush Iron Formation are specular hematite/martite, kenomagnetite (iron-deficient magnetite), carbonate (dolomite, ankerite and siderite) and quartz. Carbonate increases with magnetite/hematite and is most abundant in the Lower and Upper Iron Formation. Carbonate beds are present in the Middle Iron Formation on the scale of several meters in thickness.

Based on optical microscopy and Scanning Electron Microscopy-Mineral Liberation Analysis, kenomagnetite, specular hematite/martite, goethite, limonite and Fe-dolomite are identified as the main iron-bearing minerals. Textural relationships reflect both martitization (specular hematite/martite replacing kenomagnetite, reflecting oxidation) and mushketovitization (kenomagnetite replacing specular hematite/martite, reflecting reduction). Thus the ores consist of several different generations of kenomagnetite and specular hematite/martite that likely formed during regional metamorphism, contact metamorphism (associated with intrusion of the Mesoproterozoic Shabogamo Gabbro) and perhaps recent, groundwater alteration. Furthermore, BSE imaging revealed iron zoning in Fe-dolomite partially replaced by kenomagnetite. Coarse kenomagnetite is found in association with carbonate beds, which indicates that a portion of Fe-oxide minerals in the Wabush Iron Formation is derived from replacement of carbonates rather than entirely from recrystallization of original sedimentary Fe-oxides. Trace elements do not distinguish kenomagnetite formed from carbonate replacement vs. recrystallization of primary sedimentary Fe-oxide.

Total rare earth element concentrations of the BIFs are typically less than 10 ppm, but increase in some samples to approximately 50 ppm. Chondrite-normalized REE patterns are light REE enriched ($[La/Sm]_n$ typically 2 to 5), with small positive europium anamolies (Eu/Eu* commonly 1.1 to 1.4) and small negative cerium anomalies (Ce/Ce* commonly 0.7 to 0.9), indicating that Wabush iron formation was deposited in a near shore environment with both terrestrial and deep ocean REE signatures.

AQUEOUS GEOCHEMISTRY AND SUBSTRATE UTILIZATION BY MICROORGANISMS AT AN ACTIVE SITE OF SERPENTINIZATION, TABLELANDS OPHIOLITE, NEWFOUNDLAND

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The Tablelands in Gros Morne National Park Newfoundland, is an ophiolite thought to have been obducted during the closing of the Iapetus Ocean, several hundred million years ago. The Tablelands host ultra-basic, reducing springs containing dissolved H_2 and CH_4, which suggest that there is active serpentinization occurring in the subsurface. Serpentinization provides an environment that can support abiogenic and/or biogenic production of methane. Serpentinization is suspected to have occurred on Mars and may be occurring in the subsurface today.

The geochemistry of the water has been analysed at various sites within the Tablelands. Nutrient concentrations such as sulfate (0.12-1.01 ppm), phosphate (0-1.05 ppm) and nitrate (0.01-0.86 ppm) have been determined, to see what nutrients are available for microorganisms and to examine how life is surviving in this extreme environment. Concentrations of dissolved organic carbon and dissolved inorganic carbon have also been determined. These carbon pools will help determine possible substrate sources for microbes at these sites.

^{13}C-labeled carbon substrate experiments were performed to determine if methanogens are present and what carbon source(s) they may be using. ^{13}C-labeled organic acids (acetate, propionate and formate) and bicarbonate were added to water and sediment collected from the most basic and reducing spring. The ^{13}C-labeled acetate experiment was the only experiment to show a ^{13}C enrichment in CH_4. This suggests that methanogens may be active in the spring and may use an acetotrophic metabolic pathway.

Examining possible life in Tablelands ultra-basic reducing springs will help better understand carbon cycling in serpentinization environments at the surface, and possibly in the subsurface.

THREE-DIMENSIONAL GEOLOGICAL MAPPING IN MANITOBA, AN OVERVIEW

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Increasing demand for groundwater and hydrocarbons have been the two main drivers for three-dimensional (3D) mapping in Manitoba. To assist in meeting these demands and to broaden knowledge of the subsurface, the Manitoba Geological Survey (MGS) is developing a 3D geological model of the Phanerozoic succession in southern Manitoba, south of latitude 55°N. The MGS spent a great deal of time designing a workable infrastructure for data collection, integration and output as it relates to 3D modelling. A cross-section methodology was used to create the National Geoscience Mapping Program (NATMAP) southeast Manitoba model, as well as the Lake Winnipeg model. The Targeted Geoscience Initiative (TGI) Williston Basin model on the other hand, was modelled directly from high-quality drillhole data. A modified version of the cross-section methodology was used to model all of Manitoba's Phanerozoic terrane south of 55°N.

Several datasets directly and indirectly related to the geological interpretation are used during the modelling process. Geological maps and reports from various geologists including published and unpublished subsurface and surficial information are considered. Data representing various aspects of paleogeography for the area are also included. This allows a greater understanding of both glacial retreat and glacial Lake Agassiz which factor strongly in the interpretation. Overall, the goal is to integrate every piece of available information from every available source into the cross-sections.

In order to interpret the southern portion of Manitoba, south of 55°N, data from all previous geological models in the province were combined. This methodology was selected in order to resolve two issues: 1) subtle nomenclature differences from area to area, and 2) modelling issues resulting from rock formation edges along escarpments plotting in 3D at elevations other than the projected trend. To accomplish this, geological transects representing a 5 km wide east-west swath containing all available geological data, along with hand-drawn rock and Quaternary (sediment) units from previously completed regions, have been combined into 134 province-wide georeferenced vertical maps. Hand-drawn transects from Phase 1 (southeast Manitoba NATMAP), Phase 2 (Lake Winnipeg), and Phase 3 (southwest Manitoba) were scanned, georeferenced and combined in ArcGIS with computer-generated transects containing predicted stratigraphy points from the TGI Williston Basin project. All 134 province-wide transects, depicting up to 41 rock formations and 35 Quaternary units, have been digitized and imported into the 3D modelling software.

CATHODOLUMINESCENT IMAGES AND CHEMICAL COMPOSITION OF QUARTZ FROM AURIFEROUS VEINS IN THE MUSSELWHITE MINE, NORTHERN ONTARIO

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Cathodoluminescent SEM (CL-SEM) images of quartz have been used to show the evolution of mineralized hydrothermal systems. The technique was particularly effective in displaying the timing of metal introduction in porphyry copper deposits, but it has not been applied to orogenic gold deposit. This study is the first documentation of CL-SEM images of quartz from the banded iron formation-hosted gold deposit at Musselwhite mine in the North Caribou terrane of the western Superior province of Canada. Gold in the deposit is accompanied by sulphides (pyrrhotite and chalcopyrite), grunerite and garnet.

Two samples are used for this study. One represents a high-grade quartz vein associated with abundant sulphides, which is hosted by alternating bands of garnet-bearing green amphibole and grunerite. The second sample is a lean ore in alternating bands of garnet-bearing green amphibole and grunerite. Sulphide content is low in the second sample. Quartz in the high grade sample are less than 0.4 mm in size, have well defined crystal faces and show minor undulose extinction and no evidence of grain-boundary migration. Quartz in the lean ore sample is generally small ranging from 0.15 to 0.5mm in size, showing evidence of grain boundary migration and weakly developed undulose extinction.

The observed samples are essentially free of inclusions of other minerals and fluid inclusions. Transmitted and reflected-light microscopy show transparent, well-crystalline quartz in both samples. Back-scattered electron images show homogeneous compositions of quartz, yet Cl-SEM images show several fragments within individual grains. Variation in the CL response of quartz is most likely caused by defects within quartz structure and minor elements of Ti, Al and Na. The fragmentation is apparent in the high-grade samples. This evidence suggests that the auriferous hydrothermal activity at the Musselwhite mine is accompanied by complex deformation causing fragmentation and recrystallization of quartz.

STRATA AND STRUCTURE OF DISMEMBERED HUMBER ARM ALLOCHTHON BETWEEN BONNE BAY AND BAY OF ISLANDS: IMPLICATIONS FOR REGIONAL PETROLEUM EXPLORATION

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Regional mapping of the allochthonous sedimentary and igneous rocks of the Humber Arm Allochthon show these strata as key fragments in the assembly Taconic Orogen in western Newfoundland. So too, these beds also hold some of the critical elements for a petroleum system, and namely source and seal. However, by their very nature, regional maps are unable to clearly identify features that may be important for resource exploration. To help address this matter a detailed 1:50000 map of sedimentary strata and structure from Bay of Islands to Bonne Bay is being completed.

Much of the area is traditionally divided into three tectonic slices of sedimentary and igneous rocks separated by broad zones of mélange. In our work, rocks of the Blow Me Down Brook formation form the most expansive sedimentary unit in the map area and contain many of the same strata identified south of the Bay of Islands. Surprisingly large areas are nearly flat-lying; elsewhere, the formation contains large antiforms that may be analogues for subsurface hydrocarbon reservoirs or seals.

Many of the muddier and calcareous sedimentary rocks, historically interpreted as mélange are becoming reclassified as tightly folded beds and broken formation belonging to Irishtown, Cooks Brook and Middle Arm point formations. Oil stains on fractures in some of these muddy beds indicate some live oil remains underground.

In our assessment, mélange south of Trout River Pond is determined to be a much narrower zone lying on or about a major thrust. At North Arm, a relatively narrow belt of mélange is reassigned to the Middle Arm Point and Eagle Island Formations. The sedimentary characteristics of much of the mélange in the map area suggest that it was formed from the fragmentation and mixing of predominantly the Middle Arm Point and Eagle Island formations with other igneous rock lithologies from higher slices in the allochthon.

By carefully assessing rock loosely identified as mélange larger structures are being identified. These should become useful analogues for ongoing seismic assessments being conducted offshore in the Gulf of St Lawrence.

THE ROLE OF CRUSTAL CONTAMINATION IN THE ORIGIN OF RARE OCCURRENCES OF PRECIOUS METAL MINERALIZATION IN THE VOISEY'S BAY Ni-Cu-Co DEPOSIT, LABRADOR

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Rare occurrences of precious metal (PM), including platinum-group element (PGE), minerals offer a unique perspective on the development of the Voisey's Bay Ni-Cu-Co magmatic sulfide body. This deposit has low abundances of precious metals compared to other magmatic sulfide deposits. However, rare occurrences of elevated concentrations (>0.5 ppm, Pt+Pd+Au) have been identified and show some variability amongst their distribution within areas of the deposit and in their relationship to Ni and Cu concentrations (Naldrett *et al.* 2000; Lightfoot *et al.* 2011). This cannot be explained by a traditional model for the partitioning of PGE and PM into the fractionating sulfide magma alone. Partially digested xenocrysts

and isotopic compositions of the troctolitic and gabbroic host rocks suggested that early contamination of the Voisey's Bay parental magma by crustal country rocks (Tasiuyak paragneiss and Nain gneisses) triggered sulfide saturation to form the massive ore bodies (Li and Naldrett, 2000, Amelin *et al.* 2000, Lambert *et al.* 1999). This contamination may also be an important contributor to the PGE and PM mineralization process.

This project presents new PGE/PM mineralogy and geochemistry from six samples from the Discovery Hill, Ovoid and Southeast Extension zones of the Voisey's Bay deposit and compares this data to previously reported data of the Ovoid and a hornblende-gabbro dyke intersecting the Southeast Extension zones with the objective of determining a genetic model for precious metal mineralization. The PGE and PM mineral phases show differences and similarities in each zone with respect to abundance, grain-size and their relationships to associated minerals. These minerals include sperrylite ($PtAs_2$), froodite ($PdBi_2$), michenerite (PdBiTe), volynskite (AgBiTe), stutzite ($Ag_{5-x}Te_3$), electrum (Au-Ag alloy), a Re-Cu-S(?) phase, an Ir-As phase and native-Ag. Other important trace mineral phases identified are altaite (PbTe), native-Bi, breithauptite (NiSb), tsumoite (BiTe) and Pb-Te melt inclusions. Most often, the PGE and PM minerals are associated with pentlandite, galena and chalcopyrite. Our results are consistent with crystallization of precious metal minerals from a highly differentiated Cu-rich sulfide magma coexisting with an immiscible melt containing As, Bi, Te, Sb, Sn and Pb, which were inherited from a crustal source. Enrichments of As, Bi, Te, Sb, Sn and Pb in localized areas of the magmatic system provided complexing agents to form the PGE/PM minerals, which may be responsible for the differences observed in the precious metal mineralogy between the Discovery Hill, Ovoid and Southeast Extension zones.

TUFFS AND TURBIDITES: A DEEPER INSIGHT INTO THE DEPOSITIONAL ENVIRONMENT OF CHARNWOOD FOREST, UK

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The Avalon Assemblage represents the oldest known occurrence of Ediacaran macrofossils. Associated with sedimentary rocks indicative of deep-marine environments, these fossils have long proved enigmatic. Although fossils of the assemblage were first found in Charnwood Forest (UK), this region has long been considered the poor cousin of the extensive and better-known exposures in Newfoundland. Recent cleaning, silicone rubber moulding and casting of a total of c.150m^2 of the currently-known fossiliferous surfaces in Charnwood Forest have, however, revealed this region to be surprisingly rich, in terms of both abundance and diversity. Several new bedding planes at two localities have thus far been discovered. With the re-examination of beds already known, over a thousand new specimens have been recognised. We have identified at least nineteen taxa, including seven that have never been reported and a further nine that have not been reported from Charnwood Forest. The outcrop exposures are supplemented by >530m of drillcore, including 10m of core intersecting the principal fossiliferous horizons at a key locality. Approximately 300m of this core is from a series of seven closely-spaced short holes drilled over c.0.5km^2.

The Avalon region at this time formed part of a peri-Gondwanan volcanic arc, yielding a thick volcaniclastic, largely turbiditic succession. The Charnwood succession is dominated by turbiditic facies but includes a number of tuffs, some of which are welded; however, the crystal-rich tuffs below which the Newfoundland fossils are preserved have not been observed in Charnwood Forest. Bedding plane features such as low-relief pustules and irregular wrinkles have been taken to suggest the presence of microbial mats, which are frequently implicated in the preservation of Ediacaran macrofossils; however, preliminary examination of the drillcore has yet to provide confirmatory evidence. As such, they may not be as prevalent in Charnwood Forest as previously believed. Detailed sedimentological analysis of all available material currently underway will doubtless reveal further important sedimentary structures not observable in the field. These will provide additional insight into aspects of the depositional environment (substrate consistency, frequency of inundation, etc.) which would have influenced both the ecology and preservation of the organisms. Greater understanding of the subtle differences in the taphonomy of the Newfoundland and Charnwood Forest biotas, together with the detailed view we are gaining of the depositional environment will provide a clearer picture of where and how these organisms lived, as well as the conditions required for their preservation and the biases that these induce.

PLATE TECTONIC IMPLICATIONS OF THE GEOMETRY AND KINEMATICS OF THE BAY OF FUNDY TRIPLE JUNCTION

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Rifting across the Bay of Fundy and emplacement of the Central Atlantic Magmatic Province (CAMP) at ca. 200 Ma represents an early stage in the Mesozoic breakup of Pangea. Determining the pre-rift geometry of Pangea and the volume of space occupied by rift magmatism requires reconstructing the geometry and kinematics of terrane breakup. Critically, between Nova Scotia and New Brunswick, the Bay of Fundy opened as a rift-rift-rift triple junction involving the main arm of the Bay of Fundy to the west, and the Chignecto Bay and Minas Basin arms to the east. Given that the Chignecto Bay and Minas Basin arms appear to taper and terminate at their eastern ends, application of the principles of plate tectonics suggests that the Meguma Terrane rotated in a counter-clockwise fashion relative to North America as it rifted away. This constraint appears to contradict the common hypothesis that the Meguma Terrane rotated in a clockwise fashion relative to North America along the Minas Fault System and Collector Anomaly and this needs to be addressed in plate tectonic models.

STRUCTURAL INTERPRETATION OF TECTONIC CONSTRAINTS IN THE KENNETCOOK BASIN: INSIGHTS FROM NEW MAPPING

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Tectonic constraints, inferred from new bedrock mapping in the eastern part of the Kennetcook Basin, Meguma Terrane, Nova Scotia, have implications for the formation and evolution of hydrocarbon and mineral systems in the Devono-Carboniferous strata of Nova Scotia. Broadly, doubly-plunging upright fold systems, about hinge traces trending ENE across the Kennetcook Basin, appears to explain much of the geometry and distribution of both the basement (Goldenville, Halifax, and Rockville Notch Groups) and basin (Horton, Windsor, Mabou, and Cumberland Groups) strata. Basement fold systems appear to be out-of-phase with basin folding, however; synclinoriums in basement strata are draped by anticlinoriums in the basin strata, and vice versa, to a first approximation. This geometry is consistent with the following tectonic history: (1) Neoacadian shortening of the Meguma Terrane, prior to formation of the Kennetcook Basin in the late Devonian (ca. 406-388 Ma); (2) formation of a regional erosion surface and the Kennetcook Basin's initial topography, in the late Devonian/early Carboniferous (ca. 370-350? Ma); (3) deposition of Kennetcook Basin strata, between ca. 360-280 Ma; and, (4) Alleghenian upright folding of both basement and basin strata in the late Carboniferous/early Permian (ca. 325-275 Ma). Where applicable, evolutionary models for basin formation and growth can be improved by recognizing the early stage role of topographic inversion.

AN INVESTIGATION OF PREDICTIVE METHODS FOR ESTIMATING RARE-EARTH ELEMENT (REE) RESOURCES IN THE STRANGE LAKE MAIN ZONE DEPOSIT, LABRADOR-QUÉBEC

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The current interest in exploration for Rare-Earth Elements (REE) has led to the reassessment of many deposits that were previously explored for Y, Nb, Zr and Be. The Main Zone deposit at Strange Lake was defined for these commodities in the 1980s, but was not assessed in detail for REE. It

is currently an exempt mineral land, for which mineral rights rest with the province of Newfoundland and Labrador. Subsequent exploration in nearby Québec has outlined a discrete deposit (the B-Zone) that contains a potentially important REE resource. Reassessment of the original Main Zone deposit by the Department of Natural Resources focused initially on the reanalysis of archived reject samples from 1980s drilling programs, with a view to evaluating methods for prediction of REE contents and resources from existing data, notably for Y and Be.

Historical Y data and new Y analyses correlate well (although the latter are generally some 20% lower), but the two datasets for Be compare better. The REE show strong correlations with Y, and moderate correlations with Be, but are poorly correlated with Zr and Nb. In the case of the heavy REE (Gd to Lu), the correlations with Y are very strong and nearly linear, but the light REE (La to Eu) show much weaker correlations with Y. There are strong correlations amongst individual REE within both the heavy and light REE groups, but correlations between the light and heavy REE are less marked. Simple linear regression methods were used to derive equations for prediction of REE abundances from historical Y data, and two such methods were tested, using results from a second batch of reanalyzed samples. The method seems to work in practice, and could be of value in resource estimation, even if it cannot always reproduce observed REE profiles at a sample level. The new REE analyses are also of geological interest, and suggest that there are subtle differences between the REE profiles of low-grade mineralized granites, and those of high-grade pegmatite and aplite zones. A preliminary comparison between data from the Main Zone and the B-Zone suggests that the B-Zone contains a higher proportion of light REE, and a lower proportion of heavy REE.

BEYOND STRANGE: AN OVERVIEW OF GEOLOGICALLY DIVERSE RARE-EARTH ELEMENT (REE) DEPOSITS IN THE PRECAMBRIAN OF LABRADOR

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The Labrador Peninsula is best known for Strange Lake, where possible world-class deposits of REE, Zr and Nb are located on a remote segment of the Labrador-Québec border, but it also contains other diverse styles of REE mineralization.

North of the Grenville Front, the ~ 1290 Ma Flowers River Igneous Suite hosts disseminated magmatic-hydrothermal REE mineralization in permeable ash-flow tuff units within a central caldera sequence. Enriched zones contain moderate heavy REE proportions (LREE:Y:HREE = 67:21:12), and range from stratiform to dyke-like, but their character and mineralogy remain poorly known. New discoveries of disseminated to podiform oxide-rich REE mineralization have awakened interest in the large and poorly-mapped Mistastin Batholith. These locally have very high grades, and are strongly enriched in the light REE (LREE:Y:HREE = 96:2:2). The host rocks are thought to be small late-stage evolved plutons, and the oxide-rich mineralization is likely orthomagmatic, related to cumulate processes and/or development of Fe-oxide-rich residual magmas.

The Grenville Province contains the most diverse mineralization. Undersaturated alkaline metaplutonic rocks of the ~ 1330 Ma Red Wine Intrusive Suite host REE-Zr mineralization as concordant bands and layers enriched in eudialyte, and also in pyroxenites containing eudialyte and mosandrite. The original relationships are obscured by strong ductile deformation, but mineralization is suspected to have originally been orthomagmatic. Eudialyte-rich zones are enriched in the heavy REE (LREE:Y:HREE = 53:28:19) and also lack radioactivity. A completely different style of REE mineralization occurs in Grenvillian-age mylonitic zones in central Labrador, and also in southeastern Labrador. The former is strongly enriched in light REE (LREE:Y:HREE = 95:3:2), whereas the latter contains significant heavy REE (LREE:Y:HREE = 74:16:10), but there are many similarities between them. Outside the strongly mylonitic zones in both areas, there exist discordant vein-like or pegmatite networks that have variable REE enrichment and LREE:Y:HREE balance, and these may represent precursor mineralization. It is suggested that these REE-rich rock types were physically concentrated through intense deformation and transposition in shear zones, and perhaps geochemically homogenized by related fluid flow. However, other models can certainly be entertained! A third style of light-REE-enriched mineralization in the Grenville Province consists of concordant oxide-rich zones in granitoid orthogneisses. This mineralization is tentatively suggested to be the deformed and metamorphosed equivalent of orthomagmatic zones now recognized in the Mistastin Batholith. In summary, much of the REE mineralization in the Grenville province is likely pretectonic and related to older (Mesoproterozoic?) magmatic events.

DIFFERENT APPROACH FOR CLASSIFICATION OF AWIFS SATELLITE DATA AND THEIR COMPARISION WITH UNSUPERVISED CLASSIFICATION

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The variations in the local climate, environment and altitude as well as fast snow cover building up and rapid changes in snow characteristics on Himalayan region. This change can be monitor one bases of Image classification. We have proposed a novel technique for classification of AWiFS satellite image using signature file which is made on basis of threshold value. This threshold value is calculated by different algorithm (NSDI, S3, NDCI) for categorizing images into different classes. We have made 5 classes dry snow, moist snow, wet snow, rocks and vegetation. But some problem is with shadow (topographic effects). So we have applied topographic technique for removing shadows from images. The experiment results show classification accuracy of 7th Jan 2010 is 95% as compare to unsupervised classification is 89%.

PROVENANCE AND PALEOGEOGRAPHY OF THE CARBONIFEROUS SUCCESSION, NORTHEASTERN SIBERIA

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The study area is located in the Arctic portion of the Siberian Craton on its northeastern margin, where the Early Carboniferous was marked by an extensive marine transgression. Carbonate sedimentation was widely distributed in Tournaisian but, starting from Visean, clastic sedimentation predominated.

In clastic Carboniferous succession we studied 4 samples for U-Pb detrital zircon ages distribution, 8 samples for Sm-Nd isotopic system, and 22 samples for chemical composition. Detrital zircons from all samples have similar age populations, although there are some variations. Zircons of Paleoproterozic-Archean, Neoproterozoic and Devonian-Early Carboniferous ages are most widespread, whilst Cambrian and Ordovician ages constitute an insignificant portion. The analyzed samples are dominated by Proterozoic-Archean zircons. These zircon populations could have been derived from weathering of nearby basement rocks of the Siberian Craton and/or reworking of Meso-Neoproterozoic clastics, widely distributed in the northern Siberian Craton. The abundance of Neoproterozoic zircons in the studied samples suggests additional provenance areas, as the basement of the Siberian Craton does not contain correlative magmatic rocks. For similar reason the Siberian Craton provenance must be rejected as a possible source area for Paleozoic zircons. The only known potential provenance areas with magmatic rocks comparable in age with the Palaeozoic zircon populations are the Altay-Sayan and/or Taimyr orogenic belts. Chemical studies of the clastic rocks point to erosion of both felsic and mafic rocks, whereas variation of $\varepsilon_{Nd(t)}$ value from -9.2 to -0.2 show variable amount of juvenile rocks that basically is in agreement with the Taimyr and/or Altay-Sayan orogenic belts provenance and transportation of clastic material by continental-scale river systems from southwestern (Altay-Sayan) and northern (Taimyr) Siberian provenance.

NEW, PRECISE, PALEOPROTEROZOIC AGES AND PALEOMAGNETISM FROM THE WYOMING CRATON

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We present six new precise U-Pb baddeleyite ages for two different Paleoproterozoic dyke swarms in the Wyoming craton. Four NNE- to NE-trending dykes from the Bighorn Mountains are dated at ca. 2155-2160 Ma (U-Pb), and even though they are represented by quite different trends (010-015° vs. 048°) they are all likely part of a single LIP, which we name the Powder River swarm, with an emplacement age range distinct from two events in the Superior craton: Biscotasing at 2170 Ma and Riviere du Gué at 2149 Ma (see Ernst and Bleeker, 2010, CJES). We also dated the large, differentiated, Wind River dyke located more than 200 km to the southwest, as 2157 ± 5 Ma (U-Pb); this intrusion was previously dated by Harlan *et al.* (2003, Tectonophysics) as 2170 ± 8 Ma with high degree of discordance. The Wind River dyke shares a distinctive chemical zonation with that of the Powder River pass dyke in the southern Bighorns; and, after about 30° clockwise restoration of the former region, the two dyke segments can be projected along strike between the two uplifts, suggesting they could be the same intrusion. Our paleomagnetic data from the Powder River dyke swarm in the Bighorns, integrated with clockwise-corrected data of Harlan *et al.* (2003), support a viable reconstruction at ca. 2160 Ma of southeastern Wyoming directly adjacent to southern Superior. Our paleomagnetic reconstruction closely resembles that proposed by Roscoe and Card (1993, CJES), which aligned the Snowy Pass Supergroup of Wyoming against the Huronian Supergroup of southern Superior.

Additionally, we dated a NW-trending mafic dyke in the same region of the southern Bighorn Mountains to 1899 ± 5 Ma, which along with parallel dykes in the same region define what we name the Sourdough swarm. Paleomagnetic data from these dykes define a pole that is distinct from that of the nearly coeval (*ca.* 1880 Ma) Molson dykes from Superior craton, both in present North American coordinates and in the Wyoming+Superior fit described above. These discrepancies suggest that the Sourdough swarm was emplaced after Wyoming rifted away from supercraton Superia, but before it arrived in its present location within the Laurentian assembly of cratons. Ongoing studies of the Kennedy dyke swarm and other magmatic events from 2200-1900 Ma will most likely narrow down the time of rifting within the Superia and also spur novel comparisons with other cratons that may have been part of that landmass.

#2 MINE TOUR HAS HELPED PRESERVE NEWFOUNDLAND'S MINING HISTORY, AND HAS PUT BELL ISLAND ON THE MAP AS A TOURIST DESTINATION

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After 71 years of iron-ore mining, Bell Island was left with much more than a hole in the ground when mining ceased in 1966. It was left a history of toil, tragedy and people struggling to survive in difficult times. This history must be preserved and told to the families of the miners and the people of the world.

In 1994, 28 years after the mines closed, a committee was formed to preserve and share this history before all the artefacts and stories were lost. Artefacts were collected and hastily arranged in a made-over building so that a museum could open in the summer of 1995 to coincide with the 100th anniversary of the start of mining at Bell Island. Within 2 years the committee was incorporated as the Bell Island Heritage Society, a new building was completed and the abandoned #2 iron-ore mine was opened to tourists.

Before a backdrop of an actual underground mine, where tunnels fade off into the darkness in all directions, enthusiastic guides easily capture the attention and imagination of visitors, young and old. Visitors are awed as they learn how ore was mined in the early 1900's when men, boys and horses worked together, with little help from machinery, to extract the ore from under the ocean.

Since opening, the mine tour has welcomed well over 125,000 visitors from around the world. Because the mine is so accessible, we proudly tell our story to elementary and high school students who are learning about mining in Newfoundland and Labrador; to geology and mining engineering students from universities; to people who are aware of our contribution towards the war efforts in both world wars and to visitors who are just seeking something different and exciting to experience.

The Museum and Mine Tour now hire a total of 9 workers during the tourist season. The increase in the number of visitors has also increased the volume of sales in local gift shops, local restaurants and Bed and Breakfast establishments. It is clear that we have not yet reached our limit. With the proposed improvements to our facility and exhibits, we can greatly increase our numbers and extend our season.

SHELF-BASED EARLY AND MID PLEISTOCENE GLACIAL RECORDS ON THE GRAND BANKS OF NEWFOUNDLAND

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Till sheets or their remnants and sub-glacial fluvial channels provide direct evidence that Pleistocene glaciers covered the Grand Banks, but limited accommodation space resulted in removal by subsequent sea-level low-stands and glacial erosion such that timing, extent and ice regimes have yet to be clarified. However, several shelf basins have afforded preserved remnants of glacial deposits predating the last glacial maximum (LGM). A late Tertiary age canyon at the mouth of Laurentian Channel allowed a glacial depocenter nearly 800 m thick and directed ice sheets to a proto Laurentian Channel. Over 14 stacked tills are preserved, together with thick glacimarine stratified muds beveled between glacial sheet erosion surfaces, making it the most complete shelf record along the Atlantic Provinces margin. Stratigraphic position of the lowermost till with respect to tentatively dated mid Pleistocene till tongues on the adjacent St Pierre Bank slope suggests that it has an early Pleistocene age. The Channel evolved to a straighter, narrower, more flat-bottomed form, supporting multiple mid-Pleistocene ice streams. This Laurentian Channel sequence must represent full glaciation cycles, stadials and possibly auto-cyclic ice stream regime behavior.

Elsewhere on Grand Banks, overdeepened basins down-ice of basement rocks have preserved mid Pleistocene till remnants off Bonavista Bay and Halibut Channel. The overdeepening apparently results from enhanced erosion on steeper slopes and harder basal ice tools. Stacked till remnants and glacimarine muds are represented, cut by the latest (LGM) glacial erosion. The mid-shelf bank-top glacial record is limited to LGM and deglaciation tills and muds except for buried tunnel valleys which can survive multiple glaciations. A multi-generational tunnel valley fill includes possible till, colluvium and waterlain facies. Nowhere do the up to 400 m deep tunnel valleys communicate with slope situated canyons or their paleo-equivalents. They rarely extended beyond mid shelf, suggesting that only the largest of glaciations reached the shelf-break on the outer bank. However, this may have more to do with glacial meltwater regime and ice cap profile than ice terminus position. Generally the easternmost outer bank shelf-break has only one till preserved, probably from the penultimate glaciation. A variation on this is a landward prograding body with stacked channels at the shelf break adjacent Lilly Canyon, interpreted as ice marginal. In Trinity Trough, Northeast Newfoundland shelf, a buried tunnel valley complex attests to an early meltwater-dominated regime and contrasts with the ice stream generated till blankets and slope-based glacigenic debris flows of later glaciations.

Keynote HEAVY MINERAL CHEMISTRY AS A KEY TO UNDERSTAND SANDSTONE PROVENANCE IN THE DAVIS STRAIT AND THE LABRADOR SEA REGION

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Heavy mineral chemistry in 105 samples was determined using CCSEM analysis (Computer Controlled Scanning Electron Microscopy), which is a fully automated particle analysis technique developed at GEUS for the determination of chemical and physical properties of a large number of mineral grains. CCSEM enables determination of the modal abundances of

individual mineral fractions (e.g. ilmenite, rutile, zircon, or garnet) as well as their compositional variation together with grain-size and –shapes parameters of c. 1200 grains per sample. 21 of the samples represent sandstone from the Disko Nuussuaq Basin, 14 samples of sandstone from wells in the Labrador Sea and 70 representing stream sediments in West Greenland representing part of the potential sediment source area.

The composition and relative abundance of heavy minerals is a result of the sand provenance as well as of different types of events such as weathering, transportation and diagenesis. The garnet composition is a result of both the composition of the rock in which the garnet was formed originally and the metamorphic history. There is a systematic compositional variation in garnet composition in Western Greenland as a function of these factors. Ilmenite is sensitive to chemical alteration and as the content of iron decreases during alteration, the composition yield information about the maturity of the sediment. Mafic silicates are not very robust in the sedimentary cycle and where present the sediment is rather immature and locally minerals like olivine is preserved indicating that the route from source to sandstone was extremely short.

Plenary Address MICROBES AND THEIR IMPACT ON THE EVOLUTION OF THE EARTH SURFACE SYSTEM

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From their origins, perhaps some 4 billion years ago, microorganisms have had a profound influence on shaping our planet. From localised niches, that occur on the order of micrometers, to ecosystems as immense as the oceans, microbial populations are intimately involved in transforming inorganic and organic compounds to meet their nutritional and metabolic needs. Given sufficient time, the collective metabolic activities of countless microniches can even modify the dynamics of the entire Earth, controlling the composition of the oceans and atmosphere. One method for tracking biological innovation through time is through the chemical analyses of ancient marine chemical sediment, such as banded iron formations (BIF). Because these rocks precipitated directly from seawater, their trace element compositions can be used as proxies for paleo-marine chemistry, and by extension, the nutrient availability for the ancient marine biosphere. Two examples are provided here. First, it has been shown that the nickel content in BIF has changed dramatically over time, and that a drop in Ni availability in the oceans around 2.7 billion years ago would have had profound consequences for microorganisms that depended on it, that being methane-producing bacteria called methanogens. These bacteria have a unique Ni requirement for their methane-producing enzymes, and crucially, these bacteria have been implicated in controlling oxygen levels on the ancient Earth as the methane they produced was reactive with oxygen and kept atmospheric oxygen levels low. It is possible that a Ni famine eventually led to a cascade of events that began with reduced methane production, the expansion of cyanobacteria into shallow-water settings previously occupied by methanogens, and ultimately increased oxygenic photosynthesis that tipped the atmospheric balance in favour of oxygen, the so-called Great Oxidation Event (GOE) at 2.5 Gyr. Second, a recent compilation of Cr enrichment in IF shows a profound enrichment coincident with the GOE. Given the insolubility of Cr minerals, its mobilization and incorporation into IF indicates enhanced chemical weathering at that time, most likely associated with the evolution of aerobic continental pyrite oxidation.

PRINCIPAL TERRANE BOUNDARY IN THE KAOKO BELT OF NW NAMIBIA REVEALED BY DETRITAL ZIRCON DATING

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The Kaoko Belt (NW Namibia) is built of two terranes with contrasting pre-collisional tectonic setting and different tectono-thermal evolution during the Neoproterozoic Damara orogeny. Central and eastern part of the belt is built by Archaean–Mesoproterozoic basement with its Neoproterozoic (meta-)volcanosedimentary cover. The western part of the belt – the Coastal Terrane – has no pre-Neoproterozoic basement exposed. It consists of volcanosedimentary rocks intruded by plutons related to the activity of a Neoproterozoic magmatic arc to the west of the Kaoko Belt. We have dated detrital zircons in several metaquartzite samples located in the hangingwall and footwall of the c. 580-550 Ma igneous complex that has been previously interpreted as intruding the terrane boundary during the peak of Damara orogeny. The main goal of this study was to determine potential differences in detrital zircon records that would allow to recognize contrasting sedimentary sources, maximum sedimentation ages, and to clarify the position of the boundary between the two terranes.

Samples collected east of the presumed terrane boundary show solely Archaean–Mesoproterozoic ages and the observed age populations mostly match the protolith ages of c. 2.6, 2.0, 1.76, 1.67 and 1.5 Ga recognized in the basement of the Kaoko Belt. Age populations of c. 1.2 and 1.0 were also detected east of the presumed terrane boundary. Metaquartzites collected west of the terrane boundary show similar age groups of c. 2.5, 2.0, 1.7 and 1.5 Ga. In addition, all samples of this group contain significant amounts of c. 1.0 Ga old zircons and some zircons with ages of c. 1.3, 1.2 and 1.1 Ga. All samples collected west of the presumed terrane boundary contain Neoproterozoic detrital zircons showing ages of c. 800, 750, 700 or 650 Ma so far only reported from igneous rocks of the Coastal Terrane. Presence of similar zircon age populations in the studied rocks suggests possible recycling of the same pre-Neoproterozoic basement. However, samples collected west of the presumed boundary contain zircons coming probably from the evolving Neoproterozoic magmatic arc. Our study confirms that the boundary between the two principal tectonic blocks of the Kaoko Belt is sealed by the Neoproterozoic igneous complex. A large-scale shear zone that was previously proposed as an eastern limit of the Coastal Terrane is regarded as a late structure that has developed inside this unit during the late stages of the Kaoko Belt evolution.

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WHAT ABOUT THE FLUIDS? RE-EXAMINATION OF THE PETROLOGY OF PROTEROZOIC A-TYPE GRANITES FROM THE NORTH KHETRI COPPER BELT, RAJASTHAN, INDIA

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This work addresses the nature and origin of a group of Proterozoic (1660-1690 Ma) granites intruding intercalated metasedimentary (siliciclastics and carbonates) and metavolcanic rocks of the Proterozoic Delhi Supergroup in the northeast end of the Aravalli Mountains of Rajasthan Province, India. These granites have attracted attention because of their spatial association with the Khetri Cu deposits of suggested IOCG affinity. The granites (Gorwala, Gothara, Biharipur, Dabla) are 2-5 km^2 size, fine- to medium-grained with <3-5% mafics (amphibole, biotite), and characterized by zones of miarolitic cavities and pegmatites. An A-type affinity and correlation with plagiogranties has previously been proposed based on elevated Na_2O (to 11 wt. %) and depleted K_2O, Rb, Sr and Ba contents. In addition, evidence for commingling of mafic and felsic magma has been suggested (e.g., Biharipur granite). Recent field work and supporting mineralogical studies indicate that some of the earlier conclusions are suspect, as follows: (1) exo- and endoskarns are well developed in the wall rock and marginal phases of the granites, the latter equating to the field evidence for commingling, which is therefore discounted. However, lamprophyre dykes do cut several granite bodies which may be interpreted to suggest contemporaneous mafic and felsic magmatism; (2) albitite rocks peripheral to the main Biharipur intrusion are reinterpreted as massive, fine-grained marble with minor (<0.5%) diopside and garnet; and (3) the granites record pervasive alteration and development of albitite from initial amphibole (Fe/(Fe+Mg) = 0.5) and biotite (Fe/(Fe+Mg) = 0.75) - bearing leucogranites (<3-5% mafics) due to interaction with orthomagmatic fluids. Furthermore, detailed petrography and supporting SEM-EDS analysis of two of the granites (Gorwala, Gothara) indicate metasomatic transformation was accompanied by the development of pit-textured albite (An_5) and alkali feldspar (Or_{95}), formation of secondary amphibole, biotite and titanite, and development of dissolution cavities lined with allanite, epidote, apatite, fluorite, calcite, hematite, zircon, bastnaesite, thorite and uraninite. The presence of both high-density, highly saline (L-V-Halite-Multi-solids) and low-density fluid

inclusions in most of these neomorphic phases indicates metasomatism was mediated by a saline fluid, likely generated from a magmatic fluid which unmixed in the high level setting. The above observations indicate that much of the mineralogy and, hence, chemistry of these granites is not primary, which must be considered when classifying such rocks, especially as albitites and drawing analogies with plagiogranites.

MEGUMA GOLD DEPOSITS, NOVA SCOTIA: OVERVIEW OF PAST AND CURRENT RESEARCH WITH IMPLICATIONS FOR CURRENT MODELS

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Meguma gold deposits conform to slate belt hosted quartz vein deposits formed during orogene contraction with vein formation and mineralization related to fluid focusing into regional antiforms. Veins are quartz dominant with sulphide (Aspy-Po-Py) – carbonate and accessory Zn-Pb-Cu-Sb sulphides, and gold occurs in all vein types and fine-grained wall rock lithologies. Decades of study have established the following: (1) vein formation occurred in the later stages of flexural-slip folding during tightening of fold limbs; (2) relative timing of veins post-dates regional cleavage formation and in some cases is related to syn- to post intrusion of 380 Ma granites, which is consistent with absolute dating of vein-hosted silicates and sulphide phases at 408 and 380 Ma (Re-Os, Ar-Ar); (3) vein fluids are dominated by a H_2O-CO_2 ± CH_4 type fluid (X_{CO2} = 0.15) with 5 to 10 wt. % equiv. NaCl; and (4) stable isotopic data (O, S, C, D) indicate, in general, a metamorphic signature, but other isotopic (Pb, Sr, Os) and geochemical (REE) data suggest multiple fluid sources involving crustal and sub-crustal reservoirs. More recent research complements the above, further supporting a model of multiple fluid reservoirs, based on the following: (1) a regional variation of $\delta^{18}O_{H2O}$ (calculated for 400°C) from 11.5 to 9.5‰, the latter coinciding with proximity to granites; (2) fluid inclusion evaporite mound analysis (N=850, 15 deposits) indicates distinct fluid types (Na, Ca-Ca, K-Na) with variable enrichment in F, Cu, Sn, Hg, Mo, and U; (3) LA ICP-MS analysis of fluid inclusions indicates inter-deposit variation (values in ppm) for Li (<250), B, (<3000), As, (<1000), W (150), Sb (250) and Sn (200); (4) carbon "leads" in ribbon-textured quartz veins reveal high levels (wt. %) of As, S, Cu, Pb and Zn; and (5) XRF analysis (7,000 samples, > 20 elements) of pulps from exploration drilling confirms widespread enrichment of As, Ca, and S, but very little for Cu, Zn, Pb, Sb, Bi, and none for K, Rb or Ba, which is consistent with very low concentrations of these elements in fluid inclusions. These data support two stages for quartz veins and associated gold formation at 408 and 380 Ma that involved generation of H_2O-CO_2 fluids that interacted with variable host rock lithologies at different scales and also other fluids, one of which had a magmatic parentage. Current models for similar metallogenic settings (e.g., Australia) which suggest derivation of metals from a proto-ore source in the host rocks would not be inconsistent with our findings.

Keynote CANADA GOT THE MOUNTAINS, SCOTLAND GOT THE DEBRIS: EARLY NEOPROTEROZOIC TORRIDONIAN AND MOINE SUCCESSIONS RECORD PROXIMAL GRENVILLE FORELAND BASIN SEDIMENTATION IN NORTHERN SCOTLAND

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The Grenville Orogen was pivotal in the construction of the Rodinia Supercontinent and represents one of the largest orogenic systems on Earth. Detrital zircon geochronology has shown that the erosional debris from the orogen was widely dispersed into 1200 – 950 Ma sedimentary successions located across Laurentia and Baltica, some close to the Grenville Orogen, others 1000's of miles distant.

A well-exposed, 8-15 km thick, proximal succession is represented by the siliclastic Torridonian and (metamorphosed) Moine sequences of Northern Scotland. These successions are here interpreted to record three pulses of foreland-basin (*sensu-stricto*) deposition, linked with orogenic phases identified within the Grenville Orogen. Foreland-basin deposition was preceded by rifting recorded in the c. 1180 Ma Stoer group.

The earliest foreland-basin deposition (Pulse 1) may be represented by the shallow marine-fluvial Sleat group (c. 3.5 km thick), containing rare Elzevirian (c. 1250-1200 Ma) zircons, but no Ottawan phase (1080-1020 Ma) zircons. The Sleat group may record uplift at the start of the Ottawan phase.

The main pulse of foreland-basin deposition (Pulse 2) is represented by the Torridon and metamorphosed Morar (lower Moine) groups. The Torridon Group comprises a c. 7 km thick, fining-upward sequence of high-energy fluvial to ?lacustrine deposits (Pulse 2a). In the Morar Group this is a more distal transgressive cycle of moderate to low-energy fluvial-marine siliclastics capped via a flooding surface by below-wave-base marine deposition, followed by a further regressive-transgressive marine-deltaic cycle (c. 3 km thick, Pulse 2b). The succession contains numerous Ottawan zircons (1080-1020 Ma), but no zircons from late-Grenville granites (990-950 Ma). Deposition between c. 1020-980 Ma is likely, coincident with the Rigolet phase, exhumation of Grenvillian eclogite in Scotland (c. 995 Ma) and general cooling and unroofing of much of the Grenville Orogen. Sedimentation patterns and similarities in detrital zircon ages during Pulse 2 suggest basin overfilling and large-scale sediment by-passing into more distant basins, now located in East Greenland, Svalbard and Scandinavia.

The later Glenfinnan/Loch Eil (upper Moine) ?shallow marine succession (?3-5 km thick, Pulse 3) contains 980-950 Ma zircons, presumably from late-to post-Grenville granites and probably record relatively slow post-orogenic denudation.

Deposition in northern Scotland appears to be primarily controlled by varying sediment flux from the Grenville Orogen and subsidence caused by orogenic loading. Similar pulses of deposition may also be recorded by the proximal Oronto and Bayfield groups in the upper Keweenawan Supergroup of the Lake Superior region of North America.

EVIDENCE FOR A LATEST ARCHEAN CONTINENTAL FRAGMENT IN THE MIDDLE OF THE MANIKEWAN OCEAN

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The Southern Indian Domain of northern Manitoba lies in the internides of the Trans- Hudson Orogen, and consists largely of metasedimentary gneisses and migmatites with lesser amounts of volcanic rocks, all of which were metamorphosed to mid to upper amphibolite facies. It is flanked to the north by the ca. 1.865-1.850 Ga Chipewyan Batholith, a voluminous continental magmatic arc, which separates it from the southeastern Hearne craton margin and overlying Wollaston Supergroup, and is bounded to the south by the Lynn Lake – Leaf Rapids Domain.

At Southern Indian Lake, two areas dominated by volcanic rocks are preserved around a newly recognized fragment of latest Archean to earliest Proterozoic crust. U-Pb and Sm-Nd isotopic data from the Archean rocks at Southern Indian Lake show similarities to the Sask craton. However, broad terranes of juvenile rocks that record little to no evidence of interaction with an underlying crustal component occur between Southern Indian Lake and the known extent of the Sask craton, suggesting a cratonic fragment separated from other crustal components in the Trans-Hudson Orogen. The volcanic rocks can be broadly subdivided into a > 1.90 Ga juvenile series, which includes ocean floor and tholeiitic arc members, and ca. 1.90-1.88 Ga isotopically evolved, bimodal arc volcanic and volcaniclastic rocks. All sedimentary rocks in the area share a common dominant to subdominant detrital zircon mode between 2.3 and 2.5 Ga derived from shedding of the Sask-like continental rocks, but differ in their younger zircon populations. Where sediments associated with arc volcanic rocks show a prominent (arc-derived) peak between 1.88 and 1.90 Ga, this zircon population is absent in clastic sediments interlayered with juvenile volcanic rocks.

This talk will present the results of mapping, trace element geochemical, Sm-Nd isotopic and U-Pb geochronological analyses from

the various tectonostratigraphic assemblages in the Southern Indian Lake area. Collectively, the data provide evidence for volcanism and sedimentation at ca. 1.9 Ga in an active continental margin setting around a cryptic Archean microcratonic block. The scenario is similar to other proposed microcontinental fragments between the Hearne and Superior cratons, such as the Meta Incognita and Sugluk microcratons, which played an important role in the prolonged evolution of the Trans-Hudson Orogen prior to terminal collision.

A SYNGENETIC MODE FOR LODE GOLD VEIN FORMATION AND IMPLICATIONS

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The simple premise that quartz-gold lode veins (LV) form at the same time as the enclosing rocks underlies a "new" empirical model of their genesis, with major implications for existing models (Kretschmar, WorldGold 2011, *in press*). Detailed maps and drill core provide direct evidence of sea-floor hot spring origin in the 1) Cambro-Ordovician Meguma gold deposits of NS, 2) Archean Chester Twp, Ontario TTG (trondhjemite-tonalite-granodiorite)- hosted Côté L deposit, 3) Sage Gold- Prodigy Gold "Hercules" veins in the Elmhirst intrusion, Beardmore, ON, and 4) high grade LVs in the Maskwa batholith, MN. A proposed "Gold Cycle" (GC) systematizes LV description. Footwall pyroclastics, epiclastics or sedimentary lithologies fine upwards into chloritic tuff or pelagic/pelitic chlorite-carbonate sediments and LVs occur within or on top. The GC is terminated by the next influx of detritus. Using Bouma turbidite terminology, LVs occur within or at the top of the E (upper, silt-slate-pelagic-pelitic) division in predominantly A-E turbidites. E units may also be graded tuffs or volcanic flows and reflect alternation of oxidizing and reducing conditions. In the literature, E units are "shear zones" or "lamprophyre or mafic dikes". They are small scale correlative conformities described by Thurston *et al.* (2008, Ec Geol 103 p. 1097). GC "A" division lithologies encompass gabbro, diorite, granite, syenite, TTG suite and volcano-sediments. Textures (laminar, massive quartz or silica gel) support sea-floor deposition. Fluid PTX parameters for LVs are well studied. Independently, Strelly Pool cherts (De Gregorio *et al.*, 2006) show carbonaceous material and graphite - common in gold-bearing LVs - was abiotically generated at 2-300ºC and 550 bars pressure. A GC origin explains asymmetric alteration and stable isotope disequilibrium between LV and host rocks. Applications show: 1) the Bourlamaque batholith in Val d'Or, Quebec is an isoclinally folded sheet of quartz-feldspar-hornblende crystal tuff, and eight mines can be correlated across a syncline with an overturned south limb, 2) the Côté Lake deposit hosted by a fault-bounded block of felsic crystal tuffs on the limb of an overturned anticline, 3) the Hercules veins are in mafic crystal tuffs which correlate over 10 km. GCs represent a new facing direction indicator which survives high grade metamorphism. Vent geometry (fracture, point source or diffuse seep), bottom topography and fracture spacing, obtained from mine grade-thickness plots ranges from 250 to 600 m. LVs are commonly 1-3 km long and 1-3 m thick. A syngenetic origin simplifies and unifies genetic models. Implications include the need to re-examine TTG genesis since often "mafic enclaves, inclusions or rafts" are GC "E" lithologies.

IROQUOIS & EURO-CANADIAN IMPACT ON CRAWFORD LAKE: PALYNOLOGICAL EVIDENCE

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Crawford Lake is a unique body of water located near the edge of the Niagara Escarpment in a park run by Conservation Halton that includes an Iroquoian village learning center. The lake occupies a small (2.4 ha, ~250 × 150 m) but deep (z_{max} 24 m) dolostone bedrock basin that is thought to have been excavated by hydraulic mining during the last deglaciation (McAndrews and Boyko-Diakonow, 1989). Due to its dimensions, the lake is meromictic (does not fully turnover), resulting in anoxic bottom waters in the deepest part of the basin. This, in turn, allowed undisturbed annual laminae (varves) that have an exceptional fossil record to accumulate over much of the last millennium. Not only are cysts of dinoflagellates abundant in the sediments, but even the cellulosic theca produced by these phytoplankton are preserved in some intervals- one of a handful of reports of dinocyst thecae in the fossil record (Krueger, *in prep.*). The thecae are found in varves containing abundant non-arboreal (herb) pollen recording human activity (land clearing and agriculture) in the Crawford Lake catchment. Both Iroquois farming (~A.D. 1286-1500) and Euro-Canadian forestry and agriculture (since ~A.D. 1867) introduced large amounts of nutrients into the lake, increasing primary productivity and further depleting the bottom waters of oxygen. As suggested by the diatom (Ekdahl *et al.*, 2004) and rotifer (Turton and McAndrews, 2006) records, Crawford Lake did not return to pre-disturbance status following Iroquois farming. Surprisingly, the peak dinoflagellate cyst abundance is in sediments deposited from 64 cm from 59 cm (~A.D. 1290-1330), so more intense eutrophication appears to have been associated with Iroquois farming than with Euro-Canadian disturbance over the last 150 years.

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Zn ISOTOPE EVIDENCE FOR IMMEDIATE RESUMPTION OF PRIMARY PRODUCTIVITY AFTER SNOWBALL EARTH

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Zinc is assimilated in the surface ocean by primary producers and exported to the deep ocean where it is released by re-mineralization. Previous studies of Zn isotopes in the marine environment indicate a consistent biological control. Organisms preferentially assimilate the light isotopes, leaving behind an enriched surface ocean and generating a surface-to-deep isotope gradient akin to that of $\delta^{13}C$ of dissolved inorganic carbon. Since Zn is incorporated in carbonate in trace amounts and without significant isotopic fractionation, Zn isotope ratios in carbonate rocks deposited in the surface ocean should track fluctuations in primary productivity.

We analyzed Zn, C, and O isotope ratios in a 14 m-thick section of the Nuccaleena Formation, a ~635 Ma old cap dolostone that drapes Marinoan age glacial deposits in the Adelaide Rift Complex in South Australia. Carbon and oxygen isotope composition and sedimentological features mirror other Marinoan cap dolostones worldwide. The $\delta^{66}Zn$ ($^{66}Zn/^{64}Zn$, versus JMC-Lyon) composition begins with a decline from 0.47 ‰ at the base to a nadir of 0.07 ‰ at 5.6 m. Above this level, $\delta^{66}Zn$ increases to a maximum of 0.07 ‰ at the top of the section. In contrast, the insoluble residue fraction (silt and clay) yields values comparable to previously reported values for siliciclastic rocks, which cluster around mean continental crust (0.2-0.3 ‰).

The effect of diagenesis on the Zn isotope composition in carbonates is as yet unknown. However, is seems likely that post-depositional Zn exchange would drive the $\delta^{66}Zn$ composition towards the composition of the detrital component. Hence, it cannot account for the observed trend of decreasing, than increasing values. We assume the values are primary seawater signatures and propose a two-stage model to explain them. During the first stage, the $\delta^{66}Zn$ composition evolves toward the bulk of the continental crust as the intense weathering input during the post-glacial super-greenhouse climate dominates the ocean Zn budget. The trend of increasing $\delta^{66}Zn$ values can be interpreted by an invigorated biological pump, driven by a high-nutrient flux coupled to continental weathering, which depletes ^{64}Zn in the surface ocean and exports it to the deep ocean.

Preservation of the biological signal in the $\delta^{66}Zn$ profile is a consequence of the hydrological conditions that prevailed after snowball Earth. Partly melt-derived, brackish surface waters subject to intense heating would have capped cold, more saline deep water, suppressing upwelling and homogenization of the marine Zn isotope reservoir.

COUPLED ISOTOPIC U/Pb DATING AND LA-ICP-MS ANALYSES FOR DETERMINING GENETIC CONDITIONS OF THE END GRID URANIUM DEPOSIT (THELON BASIN, CANADA)

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The giant unconformity-related uranium deposits from the Paleo-proterozoic Athabasca Basin in Canada and Kombolgie Basin in Australia are so far the main high-grade uranium resource in the world. Consequently, they are currently heavily researched by exploration companies in the Athabasca and Kombolgie sedimentary basins but also to underexplored ones, like the Paleoproterozoic Thelon Basin in the Northwest Territories in Canada. In this basin, significant uranium mineralizations have been recently intercepted in the Kiggavik district.

The aim of the present study is to test if the End Grid deposit from this district has similar age and geochemical characteristics to the known giant unconformity-related U deposits from the Athabasca Basin, 1000 km to the south. REE pattern of uranium oxides by LA-ICP-MS and isotopic U/Pb dating by ion microprobe on the same minerals from the End Grid deposit are compared with data obtained by the same techniques on unconformity-related uranium deposits from the Athabasca, and especially to those from the Shea Creek area.

A bell-shape REE pattern, centered on gadolinium, is found for all the uranium oxides of the End Grid deposit. This pattern is strictly identical to the one of the uranium oxides of Shea Creek deposit. This bell-shape patterns are identical to the REE patterns obtained in other deposit from the Athabasca Basin, and more generally similar to all patterns obtained on uranium oxides from unconformity related deposits (Mercadier *et al.* 2011).

The currently measured U-Pb isotopic ages on uranium oxides from End Grid deposit are 1293±7 Ma and 1187±19 Ma. The oldest ages, obtained in the present study on the best preserved uranium oxides from the Shea Creek deposits, are around 1200 Ma. Although these ages are 150 Ma younger than those obtained by Kister (2003) on the Shea Creek area, these new age determinations confirm major U deposition events between 1350 and 1200 Ma for Athabasca and Thelon deposits, as already determined in most Athabasca Basin deposits (Cumming and Kristic, 1992).

In conclusion, both REE patterns and age determinations on uranium oxides demonstrate that the End Grid deposit shares similar characteristics to the unconformity related deposits. This opens new considerations for U exploration in the Thelon basin, near the unconformity, and its basement.

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GEOLOGICAL SETTING OF IRON ORE MINERALIZATION IN THE SNELGROVE LAKE AREA, LABRADOR TROUGH, LABRADOR

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The Snelgrove Lake property located in western Labrador is underlain by the Proterozoic Sokoman Formation, the same formation that hosts world-class iron ore deposits in the Wabush-Labrador City and Schefferville areas. Rocks in the area have been structurally modified, forming a series of tight folds that are tilted to an almost vertical angle. The folding has created interesting targets for exploration, as it seems to have thickened some of the iron oxide-rich beds in fold noses. Detailed mapping and sampling for petrography and lithogeochemistry was carried out in order to characterize lithological facies and assess the nature of the iron formations in this area so as to compare them with other regional iron ore deposits.

Stratigraphic units rich in iron comprise two major divisions: a lower unit consisting of thin beds of black ferruginous shale that contains iron mostly in the form of fine grained magnetite. It is overlain by the Sokoman Formation, which is generally divisible into: a) a lower unit of greenish laminated silicate chert; b) a middle unit of silicate chert rich in hard bluish grey hematite and dark grey magnetite that contains jasper and iron oxide sands, ooliths and intraclasts; and c) and an upper unit, only exposed in some parts, that is similar to the middle unit but contains leached lenses of greyish white porous chert. Iron formations are interbedded with pillow basalts and mafic volcaniclastic sequences, as well as sills consisting of fine- to medium-grained gabbro or diabase. The Sokoman Formation is overlain and underlain by fine grained sedimentary rocks that probably reflect a relatively deeper water environment in comparison with the shallow water features of the middle Sokoman Formation. The later likely represents a period of shallowing or regression within a general transgressive cycle.

In the Schefferville area, leaching of silica through meteoric processes in the Cretaceous period is interpreted to have created the iron enrichment that produced soft reddish iron oxide ores. In contrast, locally enriched iron formations of the Snelgrove Lake area are composed of hard, metallic bluish-grey iron oxides, which are distinctly different from the direct shipping ores of the Schefferville area. These locally enriched iron formations at Snelgrove Lake are likely to have been leached of their silica content, but by processes different than those that occurred in Schefferville (e.g., syndiagenetic?).

EXTINCTION OF THE EDIACARA BIOTA

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The Ediacaran-Cambrian boundary signals a drastic change in diversity and in the structure of ecosystems, which, coupled with a strong negative C isotope anomaly, has been interpreted as evidence for a mass extinction. The Ediacara biota, consisting of stem group animals in addition to extinct higher-order clades, shifts to the familiar (and not so familiar) Cambrian and Paleozoic faunas. Although metazoans are demonstrably present in the Ediacaran, their ecological contribution is dwarfed by Ediacaran-type clades such as the Rangeomorpha and Erniettomorpha, while Ediacaran-type constructions such as fronds, flat-lying-recliners, mat-stickers, and mat-scratchers are virtually non-existent in younger assemblages. To evaluate the likelihood of a terminal Proterozoic mass-extinction, we explored temporal and biogeographic distributions of Ediacaran taxa combined with evaluations of morphospace ranges throughout the Ediacaran. The paucity of temporally-resolved localities with diverse Ediacaran assemblages, combined with difficulties associated with differences in taphonomic regimes before and after the transition hinders the evaluation of a proposed Ediacaran mass-extinction. However, the demonstration of geographic and morphometric range changes offers a novel means of assessing the downfall of Ediacara-type taxa at the hands of emerging metazoans. Ultimately, the combination of studies on morphospace occupation, ecosystem construction, biostratigraphy, and biogeography showcases the severity of the end Ediacaran extinction on the early evolution of macroscopic life.

A DETAILED PETROGRAPHIC, GEOCHEMICAL AND GEOCHRONOLOGICAL STUDY OF THE HARE BAY GNEISS IN THE NORTHEAST GANDER ZONE, NEWFOUNDLAND

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Rocks classified as the Hare Bay Gneiss of the northeast Gander Zone have not been studied in detail, as previous work focuses on the granitic intrusions and structural history in the area. In an effort to better

understand the Hare Bay Gneiss and its importance to the Gander Zone as a whole, this study combines field observations with petrological, geochemical and geochronological data from well-exposed sections from Wind Mill Bight Provincial Park in the north to Hare Bay.

The mapped coastal exposure at Windmill Bight shows a strongly sheared rock assemblage including megacrystic granite, proto-mylonite, garnetiferous two-mica leucogranite, granodiorite as well as later cross-cutting garnetiferous pegmatite, intermediate dykes, mafic intrusions, and tourmaline-bearing quartz veins. Trace element geochemistry is being completed on these igneous volcanic rocks and U/Pb zircon CATIMS ages will be reported. The predominant rock types in this area appear to constitute a sheeted intrusive complex rather than a gneiss.

Three road cut cross sections to the south were also mapped. The Greenspond section includes several varieties of granitic orthogneiss in contact with an undeformed siliceous unit and cut by two-mica leucogranite and late pegmatite veins. Geochemical analyses will be compared to those from the Windmill Bight section. Both the leucogranite and the orthogneiss were collected for U/Pb zircon age determinations. The Trinity and I Love You sections also featured orthogneisses and late two-mica leucogranitic intrusions that are often garnet bearing. In the "I Love You" outcrop an orthogneiss is cut by a unique tonalitic intrusion containing titanite grains with plagioclase coronas. The Trinity section has mafic blocks within an orthogneiss.

Geochemical samples were taken from each locality and the I Love You tonalite and orthogneiss were sampled for geochronology. Additional geochemical samples as well as four samples for U/Pb zircon dating were collected north of Cape Freels and along roads in Valleyfield and Hare Bay.

Through mapping and extensive petrological, geochemical and geochronological sampling the complexity of the Hare Bay Gneiss is apparent, and lithologic and event correlations between outcrop areas is not obvious. This study will provide new documentation of the nature of key representative units of the Hare Bay Gneiss in the northeast Gander Zone.

ASSESSING ACCRETIONARY PROCESSES IN ANCIENT MUD-RICH CARBONATE MOUNDS

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Phanerozoic mud-rich carbonate mounds display three mechanisms of accretion: biomineralization, marine cement precipitation, and organomineralization. Biomineralization refers to skeletogenesis, cement precipitation refers to fluid flow-through, and organomineralization refers to mineral precipitation that involves a non-living organic substrate. Assessing the relative importance of these three accretionary modes in ancient mud-rich carbonate mounds establishes a continuum from essentially organomineralic (deeper water, suboxic) to cement-rich (marine-phreatic zone, sea-floor relief, low net-accretion). The contribution of skeletons (brachiopods, bryozoans, polychaetes, foraminifera, red algae, corals) varies greatly from insignificant to important in function of water depth and level of adaptation. This paper presents details of four examples of mud-rich carbonate mounds from the Palaeozoic of Canada and the Mesozoic of Morocco. At the Chute Montmorency locality (Middle Ordovician, Quebec), bioherms are lenticular bodies where in situ bryozoans could represent up to 70% of the bioclastic fraction. The reefal framework built by trepostome bryozoans provides large growth cavities where polymud fabric developed. Accretionary mechanisms rely mainly on biomineralization whereas organomineralization takes place within intra-reefal cryptic spaces but remains of minor importance. Cementation is absent. At the Anticosti Island locality (Lower Silurian, Quebec), mud-rich buildups display two distinct facies both characterized by the abundance of marine cement. The crinoid-fenestrate bryozoan mudstone-wackestone facies is distinguished by its volumetrically important polymud fabric and both shelter cavities and stromatactis. In this facies, biomineralization is of minor importance whereas organomineralization and, to a lesser extent, marine cementation within stromatactis are responsible for the net accretion. Regarding the fenestrate bryozoan cementstone facies, the contribution of biomineralization remains minor and organomineralization is absent. In this case, net accretion is the result of extensive marine cementation. At the Foum Zidet locality (Upper Sinemurian, Morocco), mounds contain mainly macroscopically preserved, calcified siliceous sponges locally used as substrate by encrusting bryozoans and polychaetes. Thus, mounds accretion combines organomineralization and, to a lesser degree, biomineralization whereas marine cement precipitation is lacking. At the Jebel Assameur locality (Bajocian, Morocco), mud-rich buildups display important amounts of scleractinian corals and coral debris. Accretionary processes consist on biomineralization that develop classical patch reefs. Organomineralization is restricted to cryptic spaces where it combines with biomineralization and cement precipitation is minor. Our comparative study illustrates how mud-rich carbonate mounds sharing similar geometry, macro and micro fabrics can evolved from the varying input of accretionary processes. Mud-rich carbonate mounds, commonly named mudmound, are indeed a morphological convergence.

DISTINGUISHING METAPELITES FROM HYDROTHERMALLY ALTERED METAVOLCANIC ROCKS IN GRANULITE FACIES BELTS: A ZIRCON STUDY FROM THE GRENVILLE PROVINCE

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A detailed U-Pb zircon and P-T study of two types of aluminous gneisses (metapelite and hydrothermally altered felsic volcanic rock) from the Canyon domain of the central Grenville Province provides important constraints to the geologic evolution in this area. Both types of rocks were metamorphosed under granulite facies conditions during the Grenvillian orogeny and consist of Quartz + Plagioclase + K-feldspar + Garnet + Sillimanite ± Biotite. The metapelite is foliated and contains large garnet porphyroblasts wrapped in sillimanite and biotite bearing quartzo-feldspathic matrix, while the metavolcanic rock has a nodular texture with generally elongated domains of garnet±sillimanite and large quartz domains floating in a K-feldspar rich matrix. Phase equilibria modelling constrained the metamorphic peak at about 8-11kbar and above 835°C for both rocks. Zircon in the metapelite is clear, inclusion-free, mainly sub-rounded to round, and is interpreted to be of detrital origin with relict cores, often igneous, overgrown by metamorphic rims. In rare cases, the whole zircon is inferred to be of metamorphic origin. In contrast, zircon from the altered metavolcanic rock is yellowish-brown, fractured, displays obvious cores, and contains a distinctive inclusion suite. The dominant type of internal texture in the metavolcanic zircon consists of a large bright core with fine oscillatory zoning overgrown by a darker, structure-free layer. This morphology and internal texture is consistent with igneous crystallization followed by minor metamorphic overgrowth. LA-ICPMS U-Pb spot analyses (30µm) were obtained from cores and/or rims of about 50 zircon grains in each sample. In the metavolcanic rock, the majority of the concordant data form a cluster between about 1200Ma and about 1300Ma and ages of cores and rims overlap. The weighted average $^{207}Pb/^{206}Pb$ age for 16 of the highest quality concordant analyses of igneous zircon grains is 1238±13Ma (MSWD=1.4). In the metapelite, cores are significantly older and yield a spread of ages (1500 to 1950Ma) confirming a sedimentary origin for this rock. In contrast rim ages are ca. 1050Ma, which represent the age of Grenvillian metamorphism in this area. The results of this study highlight the capability of separating gneisses from gneisses with a combination of careful petrography and accessory mineral analyses.

UPPER ORDOVICIAN SHALE GAS AND OIL IN QUEBEC

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In eastern USA, industry interest has recently focused on Upper Ordovician black shales in Ohio, which is the oil-rich Utica Shale. As in Ohio and New York, the Upper Ordovician black shales in Quebec (Utica and Macasty) form a thick marine clastic succession that overlies the predominantly shallow marine carbonate facies of the Cambrian-Ordovician St. Lawrence Platform. Over the years, the hydrocarbon exploration targets in southern Quebec consisted primarily of the dolomitized facies of the carbonate platform (e.g., Beekmantown, Trenton-

Black River), a small field (St. Flavien) was exploited and some sub-economic discoveries made.

Previous work on the source rock potential of the Utica Shale in southern Quebec has led to a regional understanding of the distribution of thermal domains at the surface of the St. Lawrence platform. A regional SW-oriented increase in thermal conditions from the condensate zone near Quebec City to the dry gas zone in the Montréal area is known, whereas a significant increase of maturation is observed at the Platform-Appalachians boundary. In the subsurface, data allows to identify general NW-SE oriented increase in thermal conditions of the Utica whereas domains with contrasting TOC and/or HI are now mapped in the Utica.

Because of limited sub-surface information for the Macasty Shale on Anticosti Island, the thermal and geochemical character of the Macasty is less complete. Current available data indicate that roughly the northeastern half of the island is in the oil window, the remaining southwestern part being in the dry gas zone. The average and maximum TOC and HI values in the Macasty are usually higher compared to those of the Utica, the data for the Macasty indicate an oil-prone Type I and II organic matter.

For the Utica Shale (50 to 300 m thick), extensive testing of their potential to release natural gas through high pressure hydraulic fracturing started a few years ago. It has been recently documented that the calcareous shales of the Utica have the capacity to release significant volume of natural gas, whereas a liquid-rich window has been identified near Quebec City; a situation in line with our current understanding of regional thermal maturation in southern Quebec. On Anticosti Island, preliminary data from the industry indicates that the Macasty shales (20 to 80 m thick) are, at least locally, oil-rich. However, the potential of these shales to release economic volume of oil is still unknown.

MASS SPECTROMETRIC MICROANALYSIS AND IMAGING: WHAT CAN THEY TELL US ABOUT MARINE BIOMINERAL-IZATION?

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Mass spectrometer based microanalysis – using LA-ICP-MS and SIMS techniques – is widely used to study marine biomineralization. Both techniques are now routinely applied to studies of reef forming tropical corals and fish otoliths. Further, these techniques can reveal useful elemental and isotopic records, on a micron scale, in a wide variety of other fauna – e.g., cold water corals, foraminifera, and algal rhodoliths.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) provides rapid trace element analyses, with a pronounced strength for quickly mapping detailed compositional profiles of marine organisms such as tropical corals. Many geoscientists and oceanographers are also familiar with the utility of Secondary Ion Mass Spectrometry (SIMS) for microanalysis of trace elements (Na, Mg, Fe, Mn, Sr, Ba) and stable isotopes (especially $\delta^{18}O$) in carbonate skeletons. Although often more time consuming than LA-ICP-MS, SIMS provides a spatial resolution fine enough to measure sub-daily variations in faster growing organisms (e.g., reef building tropical corals like Porites lutea). SIMS is also capable of 2D (and 3D) mapping of samples through scanning ion imaging (SII).

Mass spectrometric microanalyses can access a paleoceanographic archive that extends well beyond their now traditional application to the study of elemental and isotopic proxies for sea surface temperature (SST) in more equatorial regimes. For example, periodicity in the micron scale chemistry of many organisms yields information valuable in assessing growth rates, and in interpreting the meaning of growth banding features visible with light microscopy, SEM or other imaging. Intriguingly, an increasing number of deep coldwater organisms are being recognized as showing monthly growth banding – generally interpreted as a coupling to the flux of nutrients from surface waters.

High resolution mass spectrometry, with advanced large format SIMS instruments, can determine Sr isotope variations in carbonate biomineralization with sufficient accuracy to examine habitat contrasts – particularly in fish species that change residence between fresh and marine environments on a seasonal or longer term basis. Another incipient application of SIMS is the determination of $\delta^{11}B$ in carbonate skeletons as a proxy for the pH of ancient seawater.

An exciting recent development is the availability of "NanoSIMS" instruments - optimized to deliver sub-micron resolution scanning ion images. These have the potential to allow more rapid development of information on organisms that do not grow symmetrically, and to allow the location and assessment of very short term variations or disruptions consequent to disease, major storms or anthropogenic insults such as industrial pollutants.

3D MORPHOLOGY AND PERMEAMETRY OF *OPHIOMORPHA IRREGULAIRE*; IMPLICATIONS FOR RESERVOIR QUALITY

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Ophiomorpha comprises a predominant ichnofabric in many bioturbated siliciclastic petroleum reservoirs worldwide. Nevertheless its full effect on reservoir permeability, especially in three dimensions, is not yet understood. The aims of this research are (1) to amalgamate traditional two dimensional permeametry data, with contemporary three dimensional models of *Ophiomorpha irregulaire* and (2) to increase the current understanding of production properties of reservoirs containing *O. irregulaire*.

This study incorporates both core and field samples. Core samples were collected from the L-55 Ben Nevis well, Ben Nevis Formation, Jeanne d'Arc Basin, offshore Newfoundland. Three core specimens were used to obtain spot permeametry (in one cm^3 increments) conducted by a steady-state probe permeameter. Field specimens were collected from the deep marine Juncal Formation, California to create high resolution three-dimensional morphological models by utilising a serial grinding method. The volume of the trace fossil was calculated from the 3D model.

The three dimensional model revealed a meander maze, a distinguishing morphological feature of *O. irregulaire*. The volume of the meander maze is 3.5 cm^3, occupying 17.7% of the total volume. Each core segment displayed a different sedimentary facies; (1) a very fine-grained cemented sandstone; (2) a highly bioturbated fine-grained sandstone; and (3) a fine-grained sandstone with primary sedimentary features visible. Of the three fabrics the *Ophiomorpha irregulaire* burrows exhibit an average decrease in permeability of 66%, compared to the sedimentary fabric surrounding the burrow. Coupled with the volume of the burrow, one can extrapolate the decrease in permeability on a reservoir-wide scale, by taking into account the percent of bioturbation, lateral variability, and connectivity of burrows. These findings will enable a more realistic evaluation of reservoir quality and allow correct delineation of production properties before exploration is undertaken.

UNDERSTANDING MODERN COLD-WATER CORALS HABITATS IN CANADA USING MULTI-SCALE BATHYMETRIC DATA ANALYSIS

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Knowledge of modern cold-water corals in Canada has significantly improved during the last decade through studies using data from scientific trawl surveys and commercial fisheries bycatch. While such data improve our understanding of coral biogeography at a global scale, they provide almost no information on the characteristics of coral habitats at a local scale. By contrast, direct observations using Remotely Operated Vehicles (ROV) allow descriptions of coral habitat at a local scale, but can miss larger-scale habitat features. This project studies modern cold-water coral habitats using bathymetric datasets of different resolution to understand the role of scale on our understanding of corals' habitat.

High-resolution multibeam sonar, video and oceanographic data were collected in July 2010 and November 2011 using the Canadian ROV ROPOS. ROPOS operated between 1000 and 3000 m depth in the Flemish Cap and the Orphan Knoll regions, off Newfoundland and Labrador, and between 100 and 500 m depth in three sites of the Strait of Georgia (Sabine Channel, McCall Bank and Coral Knoll) in British Columbia. Multibeam data were collected from two different altitudes above the seafloor, providing centimetre- and decimetre-scale bathymetric data. In addition, ship-based multibeam data and the General Bathymetric Chart of the Oceans (GEBCO) world bathymetric dataset, covering the same regions, provided two other scales of analysis. Different terrain parameters

(e.g. slope, rugosity, complexity) were derived from those bathymetric datasets using a Geographic Information System (GIS), and statistically analyzed in relationship to corals distribution and abundance, in order to quantitatively characterize seabed morphology in coral habitats.

Corals in the deep Flemish Cap sites studied mostly occupied bedrock and ice-rafted debris. Corals on the Orphan Knoll mounds studied grew on bedrock, bedrock-derived talus, and ice-rafted debris. The dominant coral fauna observed in those areas included gorgonians, antipatharians, soft corals and localized solitary scleractinians. In the Strait of Georgia coral sites studied, the seabed is composed of glacially scoured bedrock, and the coral fauna was dominated by the gorgonians Paragorgia and Primnoa. A glass sponge reef surveyed was mostly developed on soft substrates.

The next step in this project is to quantify the relationship between the distribution and abundance of corals and the morphology of the seafloor measured at different scales. We aim to determine which scale is best to understand those relationships, which seafloor morphology terrain parameters best explain coral distribution and abundance, and the differences in habitat characteristics among different corals species or groups.

Keynote MONITORING SUBSURFACE OIL RELEASED FROM DEEPWATER HORIZON MC 252 IN THE GULF OF MEXICO AND OIL SPILL CLEAN UP ON GRAND ISLE, LOUISIANA

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The Deepwater Horizon MC252 released methane gas and oil under pressure which facilitated the formation of a plume of physically dispersed oil within the water column. Furthermore, to reduce the impact of the surface oil reaching sensitive coastal environments, the dispersant Corexit 9500 was also directly injected into the wellhead at a depth of 1500m. Very small oil droplets (<100 microns in diameter) resulting from physical dispersion and dispersant additions would rise to the surface very slowly, and ocean turbulence could keep them entrained in the water column for months.

Sea-going data was collected from the *R/V Brooks McCall* to monitor the presence of the small oil droplets and their subsurface dispersion. The vessel was also equipped with standard oceanographic equipment to measure conductivity, temperature and depth (CTD), Colored Dissolved Organic Matter (CDOM) and *in situ* dissolved oxygen (DO_2). During the study period, over 190 discrete locations were sampled from the wellhead to a distance of approximately 50 km. Based on real-time data recovered during the CTD down-cast, sample depths were selected for the recovery of water samples for analyses of oil droplet size (LISST laser particle size analysis) and hydrocarbon fluorescence.

The LISST particle size analysis correlated with CDOM results which showed an anomaly attributable to oil at 1000–1300m depth with the strongest signal near the wellhead during oil release and reduced levels with distance in the direction of ocean currents along the isobath. The DO_2 data from CTD casts showed a depression attributed to biochemical oxygen demand from the microbial degradation of subsurface oil. The data provided insights on the transport, fate and effects of oil released from the Deepwater Horizon MC252 well. Discussion is also given to the significance of the interaction of oil with fine mineral particles in the process of oil spill clean up.

ANALOGUE MODELS OF MIXING AND UNMIXING OF MAGMATIC SULPHIDE ORES IN THE VOISEY'S BAY DEPOSIT, LABRADOR

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Sulphide liquids can form a dense, fluid immiscible phase in magmatic systems. Distribution coefficients for valuable metals between sulphide and silicate are very high (a few hundred to tens of thousands) but to form an economic magmatic sulphide ore deposit it is advantageous if there is intimate contact between the phases so that the sulphides can efficiently scavenge the metals. Evidently this happened in the Voisey's Bay magmatic sulphide deposit. Analogue laboratory experiments, where magmas are represented by common liquids at room temperature and pressure, are convenient ways of investigating and illustrating the physical processes involved.

The Voisey's Bay intrusion is a 1.34 Ga intrusion of mainly troctolites and olivine gabbros within older gneisses, and is one the oldest members of the predominantly anorthositic Nain Plutonic Suite in Labrador, Canada. The intrusion consists of a sub-vertical magmatic conduit several kilometres long and ~30m wide, between two kilometre-scale magma chambers. Mineralization with sulphide ores occurs principally at the base of one magma chamber and in bends and kinks in the conduit. Sulphide mineralization occurs as lenses of massive ore, disseminated blobs within the troctolite host or 'net-textured' ore, where sulphide makes up a background matrix containing a network of silicate crystals. Field evidence suggests that emplacement of the bulk of the liquid sulphide ore occurred rapidly. Questions of interest include: where and in what form the sulphide phase first arose; and how the sulphide was transported to shallow emplacement depths.

We have carried out simple analogue experiments to model the situation where a sulphide phase forms in drops or pockets in a crystal-rich lower crustal magma chamber, and is mobilized upward by tectonic forces (e.g. caldera collapse). Water droplets (representing dense, fluid, immiscible sulphide) were introduced into a mush of plastic shavings and vegetable oil (silicate crystals and liquid) and then compressed the mush. We found that in certain circumstances, the analogue sulphide was preferentially squeezed from the crystal mush, emerging as an emulsion of sulphide droplets in silicate liquid. Such an emulsion would be easier to transport upward against gravity than larger slugs of heavy sulphide liquid.

UNSTRUCTURED GRID MODELLING TO CREATE 3D EARTH MODELS THAT UNIFY GEOLOGICAL AND GEOPHYSICAL INFORMATION

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Earth models used for mineral exploration or other subsurface investigations should be consistent with all available geological and geophysical information. Geophysical inversion provides the means to integrate geological information, geophysical survey data, and physical property measurements taken on rock samples. Inversion is a computational process that recovers models of the subsurface that could have given rise to measured geophysical data while maintaining consistency with the geological knowledge available.

Throughout the development of a mineral exploration site, geological ore deposit models are commonly developed based on available data and subsequent interpretations. Geological contacts are often known at points from delineation drilling or outcrop observations. The contacts can be interpolated or extrapolated throughout the subsurface volume of interest. The accuracy of these models is crucial when used to determine if a deposit is economic.

Such 3D geological models are typically created on unstructured wireframes, which are sufficiently flexible to allow the representation of arbitrarily complicated subsurface structures. However, geophysical modelling algorithms typically work with regular rectilinear meshes of brick-like cells when parameterizing the subsurface because this simplifies the development of numerical methods. Rectilinear meshes create pixelated models that will always be incompatible with wireframe geological models, regardless of how fine a discretization is used. To address this incompatibility, we are using unstructured tetrahedral meshes in our geophysical modelling methods.

We will present our modelling methods and apply them to examples from the Voisey's Bay massive sulphide deposit in Labrador. The processing stages involved when working on unstructured grids will be demonstrated, from building 3D reference models from point-located downhole data and vertical cross-sections, to using those models to constrain joint inversions of potential field and seismic data. We will compare that process to the equivalent steps required for rectilinear meshes.

By working directly with unstructured discretizations of the subsurface in our modelling methods, we are able to represent arbitrarily complicated features and seamlessly combine geological and geophysical

data. It is thereby possible to have geological and geophysical models that are, in essence, the same Earth model.

STRUCTURAL CHARACTERIZATION AND $^{40}Ar/^{39}Ar$ DATING OF OROGENIC GOLD DEPOSITS OF THE BOURLAMAQUE PLUTON, VAL D'OR, CANADA – TECTONIC IMPLICATIONS FOR THE ARCHEAN ABITIBI GREENSTONE BELT

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Two types of orogenic gold occurrences have been described in the Val d'Or mining camp of the Abitibi greenstone Belt: (1) «early» (>2696 Ma) quartz-carbonate-chlorite veins, and (2) «late» (<2680 Ma) quartz-tourmaline veins. These «late» veins are abundant in the 2700 ± 1 Ma (U/Pb zircon age), synvolcanic Bourlamaque pluton in the Val d'Or area, and are exposed in the Sullivan, Dumont, Lac Herbin, Ferderber, Beacon, Wrightbar and Beaufor deposits. They are typically hosted by ductile, EW-trending and south-dipping shear zones that are currently considered to be the product of faulting and hydrothermalism genetically related to the Cadillac Tectonic Zone, a 1st-order regional structure that may represents the channelway for Au-rich fluids towards 2nd- and 3rd-order structures hosting the quartz veins. The Lac Herbin deposit exposes the development of Riedel-type structures related to steeply-dipping shear zones that host the auriferous quartz veins. The Beaufor mine shows a similar network of Riedel shears but gold mineralisation is hosted there by moderately-dipping secondary structures, suggesting a more efficient hydrothermal activity as compared to Lac-Herbin. North-dipping barren structures with dextral slip component, such the Beaufor and Perron faults in the Beaufor deposit, and the «K» Zone, the Beacon and Lac Herbin-South faults of the Sullivan, Beacon and Lac Herbin deposits, respectively, currently interpreted as 2nd-order shears, more likely represent post-mineralization faults.

Fifty-seven samples have been dated by $^{40}Ar/^{39}Ar$ single-grain step-heating method. Dating on amphiboles from the undeformed Bourlamaque pluton yield ages as old as ~2690 Ma, consistent with the crystallisation ages of the intrusion. Muscovite $^{40}Ar/^{39}Ar$ dating from mylonites and related Au-rich quartz veins of the Lac Herbin, Beaufor and Beacon deposits yielded ages between 2610 and 2420 Ma, a time range that is clearly younger than the inferred timing of regional metamorphism (ca. 2660-2680 Ma). $^{40}Ar/^{39}Ar$ spectra from the Lac Herbin and Beaufor deposits show systematic and reproducible patterns: muscovites from the sheared quartz veins range from ~2610 to ~2530 Ma whereas muscovites from the hosting mylonites yield high-temperature apparent ages that are consistent with the veins but show perturbations as young as 2515-2520 Ma in the low temperature steps. This is attributed to late stages deformation following the main event of auriferous hydrothermalism. Our structural and geochronological results have major implications regarding both the typology of mineralized quartz-tourmaline vein structures of the Val d'Or mining camp and the source of mineralizing fluids which are currently considered to be of metamorphic origin.

HIGH DENSITY $^{18}O/^{16}O$ ISOTOPIC MAPPING OF HYDRO-THERMAL FLUID FLOW PATHWAYS WITHIN CARBONATE ROCK-HOSTED GOLD DEPOSITS: NE NEVADA

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The Long Canyon deposit is a sediment-hosted gold deposit located in northeastern Nevada, over 150 km east of the Carlin Trend. The deposit geology, geochemistry and mineralogy suggest that it is a Carlin-type deposit, although the host rocks are slightly older, Cambro-Ordovician age, and were deposited in a platform carbonate rather than a continental slope setting. This project tests the extents of auriferous hydrothermal fluid infiltration through carbonate rocks at Long Canyon using patterns of $^{18}O/^{16}O$ depletion to define the limits of fluid-rock interaction. In particular, patterns of isotope depletion are used to assess the structural and lithologic controls on fluid flow, and the lateral extent of fluid rock interaction beyond the limits of trace element halos genetically associated with gold mineralization (antimony, thallium, mercury and arsenic). Carbon and oxygen isotope ratios were measured using the Mineral Deposit Research Unit's Mineral Isotope Analyzer (MIA) at the University of British Columbia. This laser-based desktop analyser provides rapid analysis of oxygen and carbon isotope in carbonate rocks and enables the mapping of isotopic depletion at a sample density not previously attempted.

In this study several scales of sampling were tested, with increasing resolution of petrophysical and physicochemical controls on depletion patterns; from contiguous drill assay pulps over drilling cross sections, to surface sampling along traverses, to closely spaced hand sample coverage down drill holes, to micro-drilled samples. Presented here are the results of over 2,800 unique O^{18}/O^{16} carbonate sample compositions from across the deposit. Results indicate stable isotope depletion mapping around carbonate-hosted ore bodies with sufficient sample density can provide far field vectors to fluid flow paths beyond what traditional lithogeochemistry alone may show. Additionally, it is evident from the pattern of oxygen isotope depletion that hydrothermal fluid flow responsible for mineralization was largely constrained to brittle damage zones within boudin necks, or incipient boudin necks, within massive dolomite units. There was minimal lateral flow within or vertically across stratigraphic units without pre-existing structural damage.

EMERGENT MONIAN (POST-PENOBSCOTTIAN) ACCRETION-ARY THRUSTS ON THE OUTBOARD MARGIN OF EAST AVALONIA, ANGLESEY, NW WALES

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Anglesey (Ynys Môn) records a complex and protracted history of tectonic accretion along the outboard margin of East Avalonia. Late Neoproterozoic subduction and accretion included emplacement, at around 560 Ma, of the Penmynydd Zone blueschist facies assemblage. However, much of the present tectonic architecture of the island is a product of SE-vergent, and later south-vergent, accretionary tectonics that commenced in the Early Ordovician. Coaxial, to intensely non-coaxial SE-vergent, Monian/Penobscottian deformation assembled Late Neoproterozoic rocks along with the Middle Cambrian to Early Ordovician Monian Supergroup. Post-Penobscottian deposits include early to mid-Arenig tuffs and olistostromal molasse deposits of Gwna Group affinity, the latter reworking an uplifted Late Neoproterozoic shelf. Renewed late-Arenig subsidence accommodated a strongly asymmetric, overstepping and SE-migrating, marine, Middle Ordovician to early Silurian foreland basin succession. These overstepping post-Penobscottian successions are now arranged in a south- (or SSE) vergent, accretionary thrust duplex. The Mynydd-Mechel Thrust Sheet occupies the highest structural level of this (Salinic?) duplex, and the basal Mynydd-Mechel Thrust clearly oversteps and truncates earlier accretionary stacking and consequent fabrics, including the Carmel Head Thrust.

Translation on the Mynydd-Mechel and Carmel Head thrusts succeeded significant uplift and erosion of the accretionary margin of this Anglesey sector of East Avalonia. That theme, of active over-riding of tectonic molasse, is continued in Anglesey until the Early Devonian at least. The axially sourced fluvial Old Red Sandstone of central eastern Anglesey was over-ridden by the Mynydd-Mechel Thrust Sheet, survives as outlying erosional klippe.

New field observations have identified several locations where emergent thrusts must have cropped out at surface, at the foot of an active fault scarp shedding detritus in front of the advancing thrust sheet hanging wall. Basal thrusts override undeformed but silicified breccio-conglomerate molasse resting unconformably on crystalline footwall rocks. The footwall rocks host a locally very dense, and largely disor-ganised, network of quartz veins. Most of these veins, and rare occurrences of injected tuffisite, are inferred to be a product of thrusting-induced fluid

overpressuring. The breccio-conglomerate molasse includes fragments of vein quartz and quartz-veined rock, and is itself cut by quartz veins. Different generations of quartz veining may correspond to discrete thrusting events.

The poster illustrates these new observations, which are unique in the UK.

A MONIAN (PENOBSCOTTIAN-SALINIC) ACCRETION HISTORY ON THE OUTBOARD MARGIN OF EAST AVALONIA, ANGLESEY, NW WALES

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Anglesey (Ynys Môn) records a complex and protracted history of tectonic accretion along the outboard margin of East Avalonia. The evidence for Late Neoproterozoic subduction and accretion is provided by ca. 650 Ma metamorphism in the Coedana Complex, ca. 615 Ma intrusion of the supra-subduction zone Coedana Granite, and emplacement, at around 560 Ma, of the Penmynydd Zone blueschist facies assemblage. However, much of the present tectonic architecture of the island is a product of SE-vergent, and later south-vergent, accretionary tectonics that commenced in the Early Ordovician, consistent with Penobscottian accretion in the northern Appalachians. Coaxial to intensely non-coaxial SE-vergent Monian/Penobscottian deformation assembled the Late Neoproterozoic rocks along with the Middle Cambrian to Early Ordovician Monian Supergroup.

That accretionary assembly is overstepped on successive unconformities by early to mid-Arenig, tuffs, and then by olistrostomal molasse deposits of Gwna Group affinities that rework an uplifted Late Neoproterozoic shelf. Renewed late-Arenig subsidence accommodated deposition of a strongly asymmetric, overstepping and SE-migrating, marine, Middle Ordovician to early Silurian foreland basin succession. Deposition possibly occurred in a strongly (sinistral) transtensional régime but these post-Penobscottian successions are now arranged in a south- (or SSE) vergent, accretionary thrust duplex. Mylonitic rocks of the Mynydd-Mechel Thrust Sheet occur at the highest structural level in this (Salinic?) duplex, the basal Mynydd-Mechel Thrust clearly oversteps and truncates the earlier accretionary stacking and consequent fabrics, including the Carmel Head Thrust.

Translation on the Mynydd-Mechel and Carmel Head thrusts must have succeeded significant uplift and erosion of the accretionary margin. At several locations, these thrusts override molasse deposits derived from the advancing thrust sheet and the basal thrust must have been emergent at the foot of an active fault scarp shedding detritus. This theme of active over-riding of tectonic mollase is continued in Anglesey until the Early Devonian at least. The axially sourced fluvial Old Red Sandstone of central eastern Anglesey is over-ridden (in the Acadian?) by what is now, an outlying klippe of the Mynydd-Mechel Thrust Sheet.

PROCESSES AND SEABED IMPACT OF MAJOR STORMS ON GRAND BANKS

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Storms can generate significant surface waves and strong wind-driven currents on the Grand Banks, Newfoundland. The strong waves and wind-driven currents induced by the major storms can cause seabed scouring and bedform mobility, and hence impact the engineering design and safety of offshore seabed installations. The wind-driven current pattern and sediment transport processes during storms are also important to predicting the dispersion of material from oil spill incidents. Wind, wave hindcast data, and ocean and wind-driven currents predicted from a 3D ocean model for 22 selected major storms for the past 50 years were used to investigate the pattern, processes, and impact on the seabed by major storms on the Grand Banks. These wave and ocean current data, together with model-predicted tidal current and observed grain size data, were coupled in a sediment transport model to predict seabed shear stresses, magnitude and frequency of sediment mobility, and sediment transport flux for the selected major storms.

Wind and waves are to the NE during most of the major storms on Grand Banks, and the associated storm-induced currents are predominantly to the SE. Although stronger wind tends to generate stronger currents, significant variance exists and suggests that other factors, e.g. storm track and storm center translation speed, also affect the storm impact. Storms significantly alter current patterns on Grand Banks. At the peaks of major storms, surface wind-driven currents are dominantly to the SE and can reach as high as 140 cm/s, more than 4 times stronger than that under non-storm conditions. In the near-bottom layer, strongest currents up to 50-70 cm/s occur on the western Grand Banks and are dominantly to the southeast and east. Near-bottom currents reach about 30 cm/s and are to the north and northwest on the NE Grand Bank. Under non-storm conditions, seabed shear velocity is < 2 cm/s and low sediment transport occurs only in isolated spots. During major storms, bottom shear velocity is increased to >10 cm/s due to strong waves and wind-driven currents and significant sediment transport is widely predicted on the Grand Banks. Maximum sediment transport rate reaches about 2-3 kg/m/s and occurs on the SE Grand Bank. Maximum seabed forcing during major storms can transport up to small pebbles, and intermittent transport of sediment should occur on most bedforms during these storms.

Keynote MAGMA CHAMBER GEOMETRY AND THE LOCALIZATION OF Ni-Cu±(PGE) SULPHIDE MINERALIZATION: GLOBAL EXAMPLES AND THEIR RELEVANCE TO VOISEY'S BAY

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The distribution of magmatic Ni-Cu-platinum group element (PGE) deposits and mineralization in mafic intrusions is controlled by the geometry of the magma chamber which is often recorded in the form and shape of the intrusions (Lightfoot, 2007). The recognition that the Ovoid Deposit and the Eastern Deeps Deposit at Voisey's Bay are localized where a dyke enters a larger intrusive body has been a key observation that has underpinned much of the exploration activity. These relationships are not unique. Some of the best examples of mineralisation within intrusions adjacent to feeder conduits are found in China; the Hong Qi Ling Number 1 Intrusion in Jilin Province shows the juxtaposition of a small mineralised mafic intrusion adjacent to a mafic dyke. These relationships are repeated at Huangshandong and Jingbulake in Xinjiang Province, where disseminated sulphides are localized at the base of differentiated intrusions above comagmatic dykes, and at Jinchuan in Gansu Province, where the configuration of the intrusion is controlled by regional structures that create space for the emplacement of a small intrusion. Many other small differentiated intrusions have dyke-like keels, including the weakly mineralized Qingquanshan Intrusion in Sichuan Province. A few examples of mineralization occur in chonoliths like the Kalatungke Intrusion in Xinjiang province, which broadly resembles the morphology of the Babel-Nebo Intrusion in Western Australia. This presentation emphasizes the significance of these empirical relationships and shows how the geology of deposits like Eagle in Michigan and Double Eagle in Ontario are explained by this model. The ongoing exploration focus at Voisey's Bay respects these relationships, and continues to provide a new level of understanding of the controls of magma chamber development and intrusion geometry on the localization of mineralization (Lightfoot *et al.*, 2011).

NEOARCHEAN IS A PERIOD OF TRANSITION FROM VERTICAL TO HORIZONTAL TECTONISM: STRUCTURAL AND GEOCHRONOLOGICAL EVIDENCE FROM THE SUPERIOR PROVINCE, CANADA

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"Vertical tectonism" and "horizontal tectonism" are two contrasting processes that have been proposed for Archean tectonics. Vertical tectonism is due to density inversion and is characterized by buoyant rising of granitoids (diapirism) and sinking of greenstones (sagduction). Horizontal tectonism is similar (but probably not identical) to the present-day plate tectonics and is characterized by regional scale horizontal motion (drift) of "plates" or "microplates" and the resulting interactions (e.g. collision) among them. The two processes need not be mutually exclusive, and it is not necessary to downplay the significance of one to validate the other. Recent results show that both processes played an important role in Archean tectonic evolution. Furthermore, in the Superior Province, there is convincing evidence that the two processes occurred synchronously (and poten-tially interactively) at the late stages of Archean cratonization, and horizontal shearing (a result of horizontal tectonism) is concentrated in synclinal keels (a result of vertical tectonism).

"Timiskaming-type" groups are the stratigraphically youngest supracrustal rocks in many Archean greenstone belts. Traditionally these groups are interpreted to have been deposited in strike-slip basins opened by horizontal plate tectonic processes. More recent studies have suggested that they were deposited in inter-diapiric basins formed by vertical tectonic processes during synchronous vertical and horizontal tectonism.

The Island Lake Group is such a group in the northwestern Superior province. Ages of detrital zircons in the group match the known ages of volcanism and plutonism in the surrounding area. They change from the bottom to the top of the group and indicate a scenario that involves erosion down through a supracrustal pile in the early stage of basin formation and sedimentation, and unroofing of plutons in the latter stages. This supports the interpretation that the sediments were deposited in synclinal keels between granitoid domes during diapirism and sagduction as a result of vertical tectonism.

It is suggested that synchronous vertical and horizontal tectonism was a common process in the Neoarchean and represents a transition from dominant vertical tectonism in the Mesoarchean (and Paleoarchean?) to dominant horizontal tectonism in the Proterozoic and Phanerozoic.

REMARKABLE INSIGHTS INTO THE PALEOECOLOGY OF THE AVALONIAN EDIACARAN BIOTA

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Ediacaran macrofossils from the Avalon region (Newfoundland and the U.K.) document the emergence of some of the earliest large and complex organisms on the planet. While the Ediacaran taxa preserved in these areas have variously been interpreted as extinct phyla, fungi, bacterial colonies and metazoans, in recent years a raft of new data and discoveries has revealed remarkable insights into Ediacaran biology, ecology, and taphonomy.

In the absence of abundant morphological characters, one way to explore the biological affinities of the Ediacaran biota is to study their paleoecological attributes, in order to gain evidence about behaviour and community interactions. Recent finds include simple horizontal surface locomotion traces, ~565 Ma, at Mistaken Point, Newfoundland. These specimens can be taken to suggest that at least some Avalonian organisms were capable of active movement. This finding sits at odds with previously accepted views, and reasons for their rarity will be discussed.

The discovery of a diverse assemblage of juvenile Charnia masoni, Trepassia wardae, and other rangeomorph forms (all <30 mm in length), as well as wavy filamentous fossils from the Drook Formation of Pigeon Cove, Newfoundland, provides new insights into the early ontogenetic growth stages of those organisms. These fossils allow for discussion of reproductive strategies within the rangeomorphs. The juveniles also reveal the potential for preservation of minute forms in the Avalonian successions, opening a previously unrecognised taphonomic window into their biology.

Finally, comprehensive reassessments of the taphonomy of some Ediacaran macro-organisms, and recognition of time averaging within the preserved fossil communities, require a re-evaluation of previous measurements of ecosystem attributes. Such an undertaking suggests that the use of modern ecosystem parameters to interpret the paleoecology of extinct communities must be carefully applied, and conclusions drawn from them need to be considered in the context of significant methodological limitations.

These studies combine to improve our knowledge of the features, behaviours and interactions that can be extracted from Ediacaran deep-marine paleocommunities. When taken together with new discoveries of diverse and spectacularly preserved Ediacaran fossil assemblages from across the Avalon zone, it becomes apparent that there is currently much potential for further breakthroughs in Late Ediacaran paleoecology, making this a fascinating time to be working in this field.

SETTING AND STYLES OF HYDROTHERMAL MUDSTONES NEAR THE LEMARCHANT VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, CENTRAL MOBILE BELT, NEWFOUNDLAND

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In some volcanogenic massive sulfide (VMS) s there is a close association of black shales and hydrothermal mudstones and massive sulfide mineralization, yet our understanding of the relationship of these muds to VMS genesis and exploration is incomplete. The Lemarchant VMS deposit is an excellent location to study the relationship of black shales/hydrothermal muds to VMS mineralization because there is an intimate relationship between precious-metal bearing Zn-Pb-Cu sulfides and hydrothermal sedimentary rocks. The Lemarchant VMS deposit is hosted by the late Cambrian Tally Pond volcanic belt, Central Mobile Belt, Newfoundland and represents a bimodal felsic VMS deposit with a typical stratigraphic sequence consisting of rhyolite domes and/or breccias with a stockwork stringer zone, overlain by the massive sulfides, one or more barite bed(s), and are capped by hydrothermal sediments/mudstones. Mafic volcanic flows, predominantly pillowed basalts, are deposited on top of this sequence and represent a new cycle of volcanic activity. Metalliferous mudstones represent a hiatus in this volcanic activity, where the deposition of hydrothermal matter dominates over the abiogenic pelagic background sedimentation. In the drilled cores these mudstones/shales occur either stratigraphically on top of the massive sulfide deposits or as interflow muds in basaltic units. The sulfide-rich hydrothermal sediments comprise brown to black graphite-rich mudstones and finely laminated shales, which can be intercalated by siliciclastic and/or kidney-shaped chert layers as well as by fine layers of organic matter. The sulfides occur parallel to the bedding in the organic-rich layers indicating biological activity, but also in later-stage veins, which are cross-cutting the original bedding. The main sulfide phases are pyrite and pyrrhotite plus minor amounts of chalcopyrite, sphalerite, arsenopyrite and galena. Pyrite mostly occurs as euhedral grains or as framboids (diagenetic?), whereas pyrrhotite forms fine granules or irregular shaped grains to massive grains filling veins. Ongoing research includes detailed mineralogical-petrographical studies of the sulfides, whole-rock lithogeochemical analyses, and sulfur isotope geochemistry. The research is aimed at understanding both the role that basin redox conditions has on the genesis of the Lemarchant deposit, discriminating the relative contributions of hydrothermal, detrital or hydrogenous (seawater-derived) materials in the genesis of the shales,

distinguishing between hydrothermal, diagenetic and biological sulfur sources in the sediments, and utilizing the latter to create potential exploration vectors at Lemarchant and for other shale-associated VMS systems.

TRACE ELEMENT GEOCHEMISTRY AND PHYSICAL VOLCANOLOGY OF THE SHEBANDOWAN GREENSTONE BELT, SUPERIOR CRATON, CANADA; IMPLICATIONS FOR VMS MINERALIZATION AND TECTONIC PROCESSES IN THE NEOARCHEAN

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To better understand the volcanotectonic setting and volcanogenic massive sulphide (VMS) metallogeny of the Shebandowan Greenstone Belt (SGB), northwestern Ontario, the spatial distribution of trace element data, epsilon-Nd values, and the volcanic lithofacies and architecture were examined across eleven regional-scale transects. The SGB has been subject to a century of near continuous base metal exploration, but these efforts have yet to yield an economic VMS deposit. The SGB were previously interpreted to be deposited in a submarine arc- to rifted arc-like setting, which is an ideal setting to form VMS mineralization. This disparity in VMS-potential versus favourable VMS-setting is magnified when compared to other time-equivalent and VMS-endowed 2720 Ma greenstone belts in the Wawa Subprovince.

Element mobility resulting from complex and often superimposed alteration requires the use of immobile trace elements to discriminate between different geodynamic settings in ancient volcanic successions. Primitive mantle-normalized trace element concentrations of basalts have distinctive geochemical signatures depending on the geodynamic setting. For example, arc basalts have negative Nb, Ta, and Ti anomalies and LREE enrichment, whereas MORB have depleted to flat LREE patterns. Felsic to intermediate rocks that are most commonly associated with VMS mineralization have flat REE patterns or have slight LREE enrichment (FII to FIV rhyolites). When the spatial distribution of signature geochemical trace element patterns is analyzed across the SGB, discrete and homogeneous geochemical domains are apparent. Although isoclinaly folded, volcanic successions with arc-like and MORB-BABB geochemistry are separate, which suggests that these distinct, geochemical successions are not stratigraphic. The fold-thrust belt geometry of the SGB, and the presence of "geochemically" separate geodynamic domains suggests that their contacts are faults, and that they were justaposed through horizontal tectonic - accretionary - processes.

The lithofacies of arc-like and rift-type basalts are very similar but do vary across the SGB. They range from massive and pillowed flows associated with ultramafic flows and sills, to highly amygdaloidal mafic flows and breccias. Felsic to intermediate lithofacies vary in abundance across the SGB and range from massive flows, breccias, to volcaniclastic deposits with accretionary lapilli. The spatial distribution of rift environments, FII-type felsic and intermediate volcanics, and VMS-alteration has highlighted two successions in the SGB that have the highest VMS-potential. These areas are associated with highly amygdaloidal mafic flows, and basalt breccias with mature arc-like felsic volcaniclastics. A shallower-water, mature arc setting may account for the lack of economic VMS deposits.

PERCHED BOULDER BERMS AS AN INDICATOR OF FLASHY DISCHARGE IN EPHEMERAL RIVER DEPOSITS IN THE PRECAMBRIAN AND PLEISTOCENE

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Clusters of boulders and cobbles on the upper part of lateral accretion surfaces in mixed sandy-gravelly fluvial deposits are a potential indicator of highly variable to catastrophic discharge characteristics in ephemeral and highly seasonal fluvial systems. An example of cobble berms, developed on the part of lateral accretion surfaces in the Neoproterozoic Whyte Inlet Formation, Bylot Supergroup, north of Fury and Hecla Straights, Canada, is suggestive of irregular peak discharge, with velocities in the order of 2.4 m/sec. Boulder and cobble grade examples in Middle Pleistocene cliff exposures near Monteceto California show similar evidence of similar upper-flow regime conditions, with maximum flow, based on boulder size, in the order of 3.5 m/sec. The major difference in the two examples is that the Pleistocene examples have higher mud content, presumably due to a combination of provenance and enhanced weathering by organic acids.

CARBON, GOLD AND URANIUM ON INTERFLUVIAL DEGRADATION SURFACES IN THE PALEOPROTEROZOIC HURONIAN SUPERGROUP, CANADA

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Laterally extensive auriferous pyritic conglomerates framework-supported, cobble and boulder conglomerates of shallow braided river origin in the basal 30 m of the Huronian Supergroup in the southern part of the Cobalt Plain have been interpreted as pre-oxygenic modified placer deposits. Recent drilling by Ginguro Exploration (Sudbury) has confirmed significant gold values in the conglomerates over an area of at least 3 × 10 km. Gold values are not restricted to the basal pyritic conglomerates, but also occurred well up in the upper part of the predominantly sandy Mississagi Formation within thin beds of small to medium pebble conglomerate, with only trace amounts of pyrite. In all cases high gold values are associated with enhanced uranium concentrations. SEM scans revealed scattered black-material of fine sand grade that is analogous to fly-spec carbon the Witwatersrand. Comparison of the carbon and oxygen maps support this interpretation, as does Raman Spectral analysis, which indicates that it a kerogen. Pores in the carbon grains are filled with uraninite, with enhanced values of gold and yttrium. The presence of carbon in these small pebble conglomerates suggests that they may represent erosional channels developed on the alluvial braidplain (fan). They are not continuous across the basin, as inter-fluvial areas would have developed as flat-topped barriers to lateral channel migration. Clay deposition, combined with concentration of organic material may have occurred in low flow stages within channel thalweg ponds, with the organic material being remobilized during metamorphism. Given the link between fly spec carbon and the high uranium content in Witwaterand placers it is suggested that comparable high U_3O_8/Au ratios in the Huronian deposits might be used as a vector to predict the location for settings with optimal gold potential.

THE POTSDAM GROUP IN NEW YORK STATE, ONTARIO AND QUEBEC: STRATIGRAPHIC RELATIONSHIPS AND CHARACTER OF CONTINENTAL AND SHALLOW MARINE SEDIMENTATION IN A TECTONICALLY ACTIVE CONTINENTAL BASIN

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The Cambrian to Early Ordovician Potsdam Group in the St. Lawrence Lowlands (Ontario, Quebec and New York State) preserves a record of early Paleozoic sedimentation in a continental basin that was coeval with sedimentation on the passive-margin Laurentian Platform. Previous work suggests that the Potsdam Group consists of an assemblage of eolian to shallow marine sedimentary rocks with a distinctive geographical and stratal zonation. These past observations also suggest that the Potsdam Group records a protracted transgression that eventually covered continental facies with shallow marine deposits. This simple depositional history, however, is complicated by outliers in the lowest part of the succession consisting of siliciclastic and carbonate rocks, the latter of marine affinity, as well as by a number of significant internal stratal discontinuities.

In the western part of the St. Lawrence Lowlands a number of discrete stratal units have been recognized and stratigraphically upward include: (a) undifferentiated basal outliers, (b) eolian strata, (c) mostly fluvial strata, and (d) shallow marine strata. Discontinuities separate these units, and nowhere is the succession fully preserved. Unit (a) overlies Grenville basement rocks and in many places is tectonically deformed, and in some places marine in origin. Above Unit (a) structural deformation is

less common and less intense, and all units, except for Unit (d), are non-marine. Field evidence suggests that unconformities occur above units (a) and (b). Following deposition of each unit, sediment was lithified, locally structurally deformed and eroded. In addition, a major change in climate, specifically from dry to wet, is indicated across the top of Unit (b). The contact between units (c) and (d) is also a sharp, locally erosional discontinuity marked by a change from mainly terrestrial to fully marine conditions. Below the contact, poorly-sorted to boulder conglomerate, overlain by a silcrete horizon, indicates a period of uplift, rapid erosion and deposition followed by non-depositon and paleosol development. This was followed by marine inundation, Unit (d), which then grades conformably upward into carbonate rocks of the overlying Beekmantown Group.

In summary, the Potsdam Group in the western St. Lawrence Lowlands records a long history of mostly continental clastic deposition interrupted by periods of tectonic uplift and erosion, with transgression near its top. Tectonism along the western basin margin was the dominant factor that controlled accommodation, erosion, and sedimentation, and ultimately distribution of stratal units throughout the area.

THE TIMING AND DURATION OF GRANITE-RELATED MAGMATIC-HYDROTHERMAL EVENTS IN SOUTHEASTERN NEWFOUNDLAND: RESULTS OF Re-Os MOLYBDENITE GEOCHRONOLOGY

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The geology of southeastern Newfoundland includes an arcuate belt of late-orogenic leucogranites associated with variable intrusion- and vein-hosted mineralization (e.g. Mo, Cu, W, Sn, F). Granite magmatism and related hydrothermal activity developed during the latter stages of the Acadian Orogeny and was spatially focused along the Gander-Avalon suture zone. We present the results of Re-Os molybdenite geochronology from mineralized localities in southeastern Newfoundland that constrains the timing and duration of this regional-scale, magmatic-hydrothermal event.

From east to west the results are: (1) At Granite Lake in south-central Newfoundland (Gander Zone), quartz vein-hosted Mo-Cu-W mineralization in the Wolf Mountain Granite has a mean age of 386.8 ± 1.6 Ma (n = 3). This date is inferred to constrain the age of the granite which also hosts disseminated molybdenite. (2) On the south coast, molybdenite from the Moly Brook Mo-Cu deposit and adjacent Grey River W deposit define mean ages of 380.8 ± 1.6 Ma (n = 4) and 381.3 ± 1.8 Ma (n = 2), respectively. Here, mineralization is spatially associated with minor granite intrusions. (3) Further east (Avalon Zone), disseminated and vein-hosted molybdenite in the Harbour Breton Granite is dated at 381.2 ± 1.9 Ma and 382.5 ± 1.7 Ma, respectively. These model ages are identical within uncertainty and constrain the age of the pluton and mineralization. (4) In the southern Ackley Granite, disseminated molybdenite from four localities has the following ages: Ackley City, 379.4 ± 1.7 Ma (n = 5); Motu, 378.1 ± 1.7 Ma (n = 1); Wylie Hill, 380.2 ± 1.6 Ma (n = 2); Anesty Hill South, 379.2 ± 4.6 Ma (n = 1). (5) At Belle Island, located between the Harbour Breton and Ackley granites, vein-hosted molybdenite associated with a granite stock is dated at 382.3 ± 1.5 Ma. (6) On the Burin Peninsula, molybdenite from a quartz-fluorite veinlet within the St Lawrence Granite yielded a model age of 365.8 ± 2.8 Ma. This date is younger than the accepted age of the granite (374 ± 2 Ma) and likely reflects prolonged hydrothermal activity during granite cooling and/or unroofing.

These data indicate that a spatially focused episode of granophile mineralization evolved in this region between ~ 387 – 366 Ma, with a principal magmatic-hydrothermal event occurring at ca. 380 Ma. The Re-Os ages correlate late-orogenic granite magmatism across the Gander-Avalon zones and establish a geochronological framework for granophile mineralization in this sector of the Newfoundland Appalachians.

THE KAMISTIATUSSET (KAMI) IRON DEPOSIT, WABUSH, LABRADOR – A DEPOSIT ON THE EDGE

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The Kamistiatusset ("Kami") iron oxide deposits lie on the southeastern flank of the metamorphosed Labrador Trough iron formation and associated stratigraphy between Wabush, Labrador and Fermont, Quebec. The Rose and the Mills Lake deposits have an indicated resource of 490 million tonnes at 30.0% iron with an additional inferred resource of 598 million tonnes at 30.3% iron. Between 2008 and 2012, 226 drillholes totalling 68,130 m have been drilled to delineate the deposits. The project is operated by Alderon Iron Ore Corp. of Montreal, QC.

The Kami deposits are atypical of the past and currently producing iron mines in the Labrador-Quebec metataconite belt in that the iron oxides are 65% magnetite: 35% hematite. These will be the first high-magnetite iron oxide deposits brought into production in the region. Each deposit formed in separate iron formation basins, juxtaposed together by two main phases of deformation and thrust faults; each has distinctive characteristics. The Rose deposit was deposited on the margins of the informally named Wabush Basin while the Mills Lake deposit may be related to more distal parts of the Mont-Wright basin.

The deposits show the cumulative effects of geological events from Paleoproterozoic deposition through the Grenville orogeny and later deformations culminating in deep weathering attributed to the Cretaceous weathering. Certain structural features are poorly documented in the literature yet significantly impact the deposit geometry. The prevalence of deep weathering in the district also has received little regional study. The economic impacts of each of these elements will be discussed.

Geometallurgical methods were used from initial stages of exploration to help guide metallurgy and future mining development. These include tracking trace element and mineralogical deportment spatially throughout the deposits in fine detail in order to assess the relationship between observed stratigraphy and potential economic consequences. These studies assist in the rapid understanding of deposit details that reduces economic risk in fast-paced development projects. The complex magnetite-hematite deposits respond well to integrated approaches that assess the mineralogical and structural components.

GEOCHEMISTRY AND REFINED CORRELATIONS OF EDIACARAN STRATA IN NORTHWESTERN CANADA: IMPLICATIONS FOR THE AGE OF EDIACARAN FAUNA AND THEIR RELATIONSHIP TO THE PUTATIVE SECOND RISE OF OXYGEN

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Ediacaran strata are present in the Ogilvie, Wernecke, and Mackenzie Mountains of NW Canada. These successions contain Ediacaran fauna, abundant trace fossils, large carbon isotope anomalies, and significant shifts in Fe speciation data that have been previously attributed to a rise in oxygen coincident with the first appearance of Ediacara fauna. Here we report new geological mapping, stratigraphic sections, detrital zircon geochronology, Fe speciation, trace element, and C_{carb}, C_{org} and S isotope data from Ediacaran exposures across northwestern Canada. These data demonstrate that the Ediacaran fauna from the relatively distal Sekwi Brook sections occur above an unconformity and are not correlative with the Sheepbed Formation at more proximal sections near Shale Lake. The Ediacara-bearing unit at Sekwi Brook that has previously been correlated with the Sheepbed Formation due to its stratigraphic position beneath the Gametrail and Blueflower Formations; however, the fossiliferous strata are not associated with the Hayhook cap carbonate, are bound by a basal unconformity recorded by a significant incised channel that contains abundant resedimented carbonate, ooid, and coarse quartz grains, all of which are absent in the Sheepbed Formation near Shale Lake and elsewhere in NW Canada. The lower Ediacaran bearing unit at Sekwi Brook is also isotopically distinct from both the Sheepbed Formation and

the type Gametrail Formation. A new stratigraphic name is probably appropriate for these sub-Gametrail strata at Sekwi Brook. These data imply that the reported link between Fe speciation data and the first appearance of Ediacaran fauna in the Mackenzie Mountains reflects a miscorrelation. These data imply there is no relationship between the reported Fe speciation data and the first appearance of Ediacaran fauna. Instead, a large negative carbon isotope anomaly, potentially correlative with the Shuram anomaly, occurs in the overlying Blueflower Formation directly above the first well developed trace fossil assemblages.

THE FIFTEENMILE GROUP: A SEDIMENTARY RESPONSE TO EARLY NEOPROTEROZOIC RIFTING ON THE NORTH-WESTERN MARGIN OF LAURENTIA

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Geological mapping of the early Neoproterozoic Fifteenmile Group in the western Ogilvie Mountains of Yukon, Canada, has revealed large lateral facies changes in both carbonate and siliciclastic sedimentary rocks. These lithological differences are the product of topographic relief that was created by syn-sedimentary north by northwest (NNW) side down normal faulting during deposition of the lower formations of the Fifteenmile Group. A NNW-facing reef complex developed above sealed normal faults with distinct reef-core, fore-reef and slope facies. Up-section, carbonate facies prograde northwest in multiple highstand tracts with the Bitter Springs isotopic stage and an 811 Ma ash in the penultimate transgressive sequence. Hf isotope data suggest that the 811 Ma ash was sourced from a LIP in South China. With these data, we propose a new tectonic model for the Neoproterozoic evolution of NW Canada, beginning at ca. 1.1 Ga with the accretion of the Yangtze and Cathaysia Blocks, and the formation of the Pinguicula Group in a foredeep basin that outlined the Mackenzie Arc. The ca. 1.1 Ga Sibao orogeny in China provided a local source of Grenville-age zircons to the Fifteenmile Group as well as zircons that fill the 1.4-1.6 Ga 'North American magmatic gap', which otherwise lack an obvious source. This collision marked the final amalgamation of Rodinia in a modified SWEAT-Missing Link reconstruction. The Pinguicula Group is unconformably overlain by the Fifteenmile Group, which formed in an extensional basin adjacent to the coeval Tsezotene, Katherine, and Little Dal groups. Correlations between specific formations within these groups are tested with carbon isotope chemostratigraphy. Importantly, new age constraints on successions in the western US indicate that there are no known basins that formed between 1.0 and 0.8 Ga between the Laird line and Mexico, such that the basin forming event which accommodated the Fifteenmile Group and equivalents in the Shaler and Mackenzie Mountains supergroups is strictly a phenomenon of the NW margin of Laurentia and not the whole of the western margin. The uniqueness of early Neoproterozoic rifting in NW Laurentia is likely related to its proximity to the plume that Australia-South China-Laurentia passed over, which manifested itself sequentially in the Gaidner, Gubei, Gunbarrel, and Franklin LIPs. Paleomagnetic and geochronological studies will provide further tests for the proposed tectonic model.

AMS MAGNETOFABRICS AND EMPLACEMENT OF FRANKLIN DIKES, VICTORIA ISLAND, ARCTIC CANADA

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The extensive Franklin platform of Neo-Proterozoic mafic sills and flows covers a large area of NW-central Victoria Island in the Canadian Arctic Islands. Magnetofabric studies have been carried out on sills and dikes of this Large Igneous Province. In this report, magnetofabric results are presented from two dikes which fed sill complexes in the vicinity of Minto Inlet. These dikes were sampled at 21 sites: 4 sites in a smaller feeder dike north of Minto Inlet, and 17 sites in a much larger feeder dike system south of Minto Inlet. Approximately 104 oriented cores were drilled from oriented blocks from those Minto feeder dikes. Generally speaking, magmatic flow axes can be inferred from crystal alignments in igneous rocks, although factors other than flow gradients may influence crystal lineations. Also, the orientation of the axis of maximum susceptibility, K_{max}, is generally reliable as a proxy for crystal lineations in igneous rocks. The orientation of the K_{max} axes in these two dikes is predominantly steep to the south. Subordinate near-horizontal orientations of K_{max} were also found. The observed Kmax patterns suggest a southern magmatic source region for the dikes that were sampled. Suggested explanations for the shallow-plunging K_{max} axes, consistent with near-horizontal flow or other interpretations, are also discussed.

LATE DEVONIAN-EARLY CARBONIFEROUS RIFT-RELATED BI-MODAL MAGMATISM WITHIN THE EASTERN COBEQUID HIGHLANDS AND ASSOCIATED REE AND EPITHERMAL-AU STYLE MINERALIZATION, NOVA SCOTIA, CANADA

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Bimodal Late Devonian to Early Carboniferous mafic and felsic plutonic and volcanic rocks dominate the geology of the central and northeastern Cobequid Highlands of mainland Nova Scotia. From southwest to northeast the main lithotectonic units include: the Folly Lake Pluton (mafic intrusives), Hart Lake-Byers Lake Pluton (felsic intrusives), Byers Brook Formation (felsic volcanics), and Diamond Brook Formation (mafic volcanics).

Significant rare earth element (REE) and associated Y, Zr, Nb mineralization has recently been discovered along the contact zone between granitic rocks of the Hart Lake-Byers Lake Pluton and overlying cogenetic felsic volcanic and volcaniclastic rocks of the Byers Brook Formation. REE mineralization is represented by fine- to coarse-grained magmatic/hydrothermal granitic dykes that range in thickness from < 1 to > 50 cm. Chemically, the mineralized dykes are characterized by elevated SiO_2 (up to 75 wt.%), Fe_2O_3T (~7-13 wt.%), F (0.06-1.4 wt.%), exceptional heavy rare earth (HREE) and high-field-strength (HFSE) element enrichments (e.g. Y > 6000 ppm, Yb > 1000 ppm, Zr > 10000, Nb > 1000 ppm), and anomalous Sn (200-800 ppm), W (20-200 ppm), Sb (2-8 ppm) and Zn (200-800 ppm). The origin of the dykes is interpreted, in part, to be related to differentiation of a high-level, unusually HFSE-rich, (Na-Fe)-amphibole-bearing alkali-feldspar granite phase of the Hart Lake pluton. A prominent role for REE-partitioning into Na-Fe-F-rich hydrothermal fluids of magmatic origin is suspected.

New detailed mapping within the Byers Brook and Diamond Brook Formations has provided several new and important discoveries: (1) epithermal-style Au mineralization has been confirmed via visible Au found within silicified/sulfidized basalt; (2) associated with the new Au discovery are anomalous concentrations of As, Cd, Sb, and Pb; (3) numerous locations within the Byers Brook and Diamond Brook Formations are host to silicified and sufidized volcanic rocks containing anomalous concentrations of one or more of the following elements (As, Ag, Cd, Sb, Pb, Zn, Se, Cd), and thus may also contain Au; (4) The main centre for rhyolite magma and subsequently basaltic magma production and eruption was within the most easterly portions of the Byers and Diamond Brook Formations; (5) the subdivision of the Diamond Brook Formation needs revision to reflect the east to west transition from exclusively compound vesicular basalt flows to stratigraphically equivalent intercalations of basalt, felsic volcanic/volcaniclasic rocks and notably significant occurrences of epiclasitic and silicicalstic rocks.

TECTONOMAGMATIC HISTORY OF THE EASTERN COBEQUID HIGHLANDS OF NOVA SCOTIA: IMPLICATIONS FOR AVALONIAN LITHOSPHERIC EVOLUTION AND COR-RELATIONS WITHIN THE APPALACHIAN OROGEN

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New mapping, geochronology, and geochemical studies in the eastern Cobequid Highlands of Nova Scotia have revealed previously unrecog-nized Neoproterozoic, Early Ordovician, and Late Devonian to Early

Carboniferous tectonomagmatic events that have important implications for lithospheric evolution and lithotectonic correlations within Avalonia. North of the Rockland Brook fault in the southeasternmost part of the Cobequid Highlands a newly recognized ca. 740-750 Ma calc-alkaline gabbro/diorite, granodiorite, and granite magmatic suite intrududes polydeformed ortho- and paragneissic units of the Mount Thom complex. Together these units represent some of the oldest and volumetrically most significant portions of Avalonian crust yet recognized in the Appalachian orogen. Geochemistry and Nd isotopic compositions for the suite suggest formation in a continental margin volcanic arc setting, and evolved isotopic compositions of gabbroic rocks in particular implicate the involvement of previously enriched lithospheic mantle during this stage of Avalonian crustal formation. Currently U-Pb age investigations are underway to ascertain the age of orthogneissic units of the Mount Thom Complex to test the possibility that they are portions of the postulated Meso- to Paleoproterozoic Avalonian basement based on Nd model ages. Immediately south of the Mount Thom complex a newly recognized ca. 485 Ma bi-modal gabbro/diorite, syenite/granite intrusive suite has been documented. This suite is similar in age and composition to the recently discovered Ordovician West Barneys River plutonic suite in the southern Antigonish Highlands of Nova Scotia. Geochemical and Nd isotopic signatures suggest an extensional, within-plate continental setting, and the isotopic composition of mafic end-members of this suite require input from depleted asthenospheric mantle sources. South of the Rockland Brook Fault, and the newly recognized ca. 750-740 and 485 Ma magmatic suites, new U-Pb zircon geochronology has documented a ca. 580 Ma calc-alkaline diorite, granodiorite, and granite magmatic suite. Geochemical and Nd isotopic compositions suggest a continental margin volcanic arc setting for this suite. East of the ca. 580 Ma suite, and in faulted contact with Late Carboniferous sedimentary rocks is an undated bimodal plutonic suite comprised of granite and diorite, and less abundant hybrid rocks derived via mixing and mingling of these end-members is found. Based on mineralogical, textural, and compositional similarities with ca. 360-355 Ma intrusive rocks found north of the Rockland Brook Fault this suite is interpreted to be of similar age. Geochemical and Nd isotopic compositions of this suite suggest that Neoproterozoic Avalonian crust was reworked during this magmatic event.

THE RAGLAN HILLS GABBRO: A POTENTIAL Ni-Cu DEPOSIT

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The Central Metasedimentary Belt of the Grenville Province in Ontario is host to several mafic intrusive suites, such as the Lavant and Killer Creek gabbroic suites, within which Ni-Cu-PGE mineral exploration has so far proven to be unfruitful. Recently, First Nickel Inc. has reported the presence of Ni-Cu and PGE mineralization in different parts of the Raglan Hills gabbro, one of several mafic intrusions in the Bancroft Domain. Subsequently, this study was initiated to better understand the geology, geochemistry and metallogeny of the Raglan Hills gabbro, and to compare it to other Grenvillian gabbros in order to gain insight into the nature of Ni-Cu-PGE mineralization within the Central Metasedimentary Belt. One month of fieldwork was completed in 2011, from which the data and preliminary interpretations presented herein are based.

The Raglan Hills gabbro has been subjected to at least 2 regional metamorphic events at *circa* 1160 and 1050 Ma, respectively. Despite this history, deformation of the Raglan Hills gabbro is concentrated along the margins of the body, and local preservation of primary textures occurs in the core of the body. The Raglan Hills gabbro has been previously assigned to the Killer Creek gabbroic suite, based on limited data.

Three main rock types are present in the Raglan Hills gabbro, each with distinct major- and trace-element geochemical signatures in both major and trace elements; these are referred to as primary gabbro, deformed gabbro, and hornblendite.

The primary (pyroxene-bearing) and deformed gabbro (amphibolites) phases have been observed in diamond-drill core to grade into and out of one-another, suggesting that the deformed gabbro is the product of metamorphosing the primary gabbro, likely through the introduction of a hydrous phase. Both rock types display relatively flat REE patterns at roughly 10 to 20 times chondritic values, and negative anomalies in the high-field-strength (HFSE) elements (Th, Zr, Hf, Ti), as well as P, Nb and Ta. These anomalies suggest that the magma was crustally-contaminated during emplacement.

The hornblendites (meta-pyroxenites) have been observed to cross-cut igneous layering preserved in the gabbroic units, both in outcrop and in diamond-drill core. These rocks are enriched in REEs and phosphorous, but have less pronounced negative HFSE anomalies. These hornblendites may represent a slightly more evolved magma, albeit more mafic; and perhaps the mechanism by which magma was fed from the magma chamber (the Raglan Hills gabbro) into mafic dykes, sills, and metavolcanic rock units surrounding the intrusion.

MINERAL CHEMISTRY AND THERMOMETRY OF MAFIC AMPHIBOLITE-FACIES ROCKS IN NUVVUAGITTUUQ GREENSTONE BELT, CANADA

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The dominant lithologies of the Nuvvuagittuq Greenstone belt (Northeastern Superior Province, Canada) are composed of mafic amphibolite-facies rocks (referred as the Ujaraaluk unit). With a minimum age of 3.8 Ga and possibly as old as 4.3 Ga, these rocks are among the oldest in the world. The Nuvvuagittuq Greenstone belt occurs in the western Minto Block which was last pervasively metamorphosed at ca. 2.7 Ga.

Rocks from the Ujaraaluk unit are generally Ca-poor and subdivided into a high-Ti and a low-Ti group based on their bulk chemical composition. The low-Ti rocks are interpreted to stratigraphically overlie the high-Ti rocks. Here we present a detailed mineral chemistry and thermometry study of the Nuvvuagittuq mafic rocks to investigate if their paragenesis is controlled by a metamorphic gradient through the belt or whether it is controlled by geochemical variations.

Petrography and mineral chemistry reveal two different rock types: garnet + biotite + plagioclase + quartz schists without amphibole, occuring primarily in the central part of the area, and amphibole schists composed of biotite + amphibole + plagioclase + quartz ± garnet. Amphibole may be either cummingtonite or anthophyllite or Mg- and Fe-hornblende occuring alone or in combination. Although the mineral assemblages are different, no systematic geographical distribution is found in the field.

Garnets, primarily in the central part of the Nuvvuagittuq Greenstone Belt, are mostly unzoned with respect to major cations; most have thin rims reflecting cation exhange on cooling. Garnet-bearing samples have higher whole-rock FeO* and Al_2O_3 than garnet-poor samples. Biotite-garnet geothermometry was applied to both rock types from 18 localities, and gives temperatures clustering around 660°C. Whole-rock chemistry, garnet mineral chemistry and thermometry across the region suggest that the presence of garnets is a result of the whole-rock chemistry rather than metamorphic grade.

We suggest that the event responsible for metamorphism of the Minto Block at 2.7 Ga was also the main metamorphic event that affected the Nuvvuagittuq Greenstone Belt. This conclusion is also supported by Neoarchean Sm-Nd ages obtained in the Nuvvuagittuq garnets. Any earlier metamorphism, likely given the protracted history of these rocks, has apparently been obliterated.

MORPHOLOGY OF DETRITAL MAGNETITE IN GLACIAL TILL: CASE STUDY FOR APPLICATION TO MINERAL EXPLORATION FOR VMS DEPOSITS AT IZOK LAKE, NUNAVUT

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Surface textures and shape of detrital mineral grains document their history from hypogene formation to erosion and transport to a sedimentary

deposit. We report results from a study of the surface textures and shapes of detrital magnetite from glacial till that contains debris eroded from the amphibolite-grade Izok Lake Zn-Cu-Pb-Ag VMS deposit. The surface textures and grain shapes are integrated with distance from the deposit and ice-flow paths to outline criteria useful for application in VMS exploration. A total of 279 grains from the 0.25-2.0mm ferromagnetic fraction of host rocks, mineralized rocks, till samples up- and down-ice from the deposit were examined. Mineral grains were liberated from rocks using electric pulse disaggregation so as not to destroy or break grains. Surface texture and shape have been investigated using a Scanning Electron Microscope.

Magnetite in gabbroic rocks displays an angular shape and the predominant textures including triangular pits, and overgrowth. In iron formations, magnetite is porous and forms aggregates with silicates. Magnetite in gahnite-rich rocks has irregular to triangular dissolution pits, overgrowth, cracks, and sub-conchoidal and step-like fractures. Disseminated magnetite is abundant at the contact of gahnite-rich zones and massive sulfides. It is locally porous and fractured. In mineralized rocks, magnetite is euhedral with cracks and sub-conchoidal, step-like, and irregular fractures. Porous magnetite in all these rocks locally forms rims surrounding primary hematite. The porous nature of the magnetite is the result of hematite reduction to magnetite in presence of Al, Ca, Mg oxides or silicates. Presence of these elements in magnetite composition was verified using an Electron Probe Micro-Analysis. It shows that magnetite surface features correlate with its chemistry. Triangular pits are likely growth defects similar to those reported on diamonds.

In detrital magnetite, grain roundness and the number of cracks gradually increase as distance increases from the mineralization along ice-flow paths. Appearance of spherical fractures, widespread dissolution features, presence of pits resulted from dissolution of inclusions, and precipitation textures characterize detrital magnetite and contrast it from magnetite in host rocks. These textures are compatible with glacial transport and have been developed as the grains have experienced more erosion and transport. The final shape of detrital magnetite is a function of its primary crystallization shape and its glacial transport, and can be used to estimate relative distance of glacial transport. Accordingly, magnetite shape and surface texture information combined with mineral chemistry can be useful for VMS exploration in glaciated terrain.

NEW FISSION-TRACK DATA IN THE NORTHEASTERN GASPÉ BELT: IMPLICATIONS FOR BURIAL HISTORY OF ORDOVICIAN AND DEVONIAN SOURCE ROCKS IN THE GASPÉ PENINSULA

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The Gaspé Belt is the largest middle Paleozoic belt in the Canadian Appalachians. In the Gaspé Peninsula, it consists of Upper Ordovician to Middle Devonian sedimentary rocks, with minor volcanics, resting unconformably on Cambrian-Ordovician rocks of the Humber and Dunnage zones.

Lower Devonian siliciclastic rocks of the Indian Point, York River and Battery Point formations were collected on both sides of the Bras Nord-Ouest fault for apatite fission track (AFT) dating. These Devonian rocks, mainly deformed during the Middle Devonian Acadian orogeny, are unconformably overlain by flat-lying Carboniferous strata. Post-Devonian reactivation of a few faults is documented by the offset of a Carboniferous dyke.

Seven surface samples yielded a sufficient amount of apatite to allow AFT dating. AFT ages range between 284 ± 35 and 247 ± 27 Ma (Permian to lowermost Triassic) with mean track length from 11.7 to 12.3 ± 1.7 microns. AFT ages are younger than the sandstone ages, which indicate that the AFT clock has been reset and thus the hosting rocks experienced temperature higher than ~100°C, in agreement with organic matter maturation data. The difference in AFT ages for samples from both sides of the Bras-Nord-Ouest Fault is probably not significant, indicating that post-Carboniferous vertical motions along the fault were not enough to alter the AFT age distribution.

In the study area, previous thermal modeling studies considered that the maximum burial occurred during the sedimentation of the Middle Devonian Malbaie Formation, which was followed by Acadian deformation and erosion before deposition of a relatively thin (~ 500 m) Carboniferous cover, and low denudation rates up to the Permian. In an alternative scenario, significant burial was reached due to the sedimentation of a pluri-kilometric Carboniferous sedimentary pile as it is recognized in the Gulf of St. Lawrence. In this case, sampled rocks left the apatite partial annealing zone (~60-120°C; ~oil window) later, after the Upper Paleozoic Maritimes Basin sedimentation, in agreement with AFT ages. New thermal models indicate that a realistic solution in which calculated organic maturation values closely match observed values in wells can be generated for both scenarios with geologically acceptable parameters. However, these two scenarios may differ significantly on the timing of hydrocarbons generation and migration.

EFFECTS OF LICHEN COVER ON REMOTE SENSING BASED NORTHERN MINERAL EXPLORATION

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Optical remote sensing systems offer mineral mapping solutions for Canada's North through the measurement of a contiguous, high resolution spectral measurements of non-vegetated surfaces. Past research has shown that minerals, with distinct visible and infrared reflectance properties, can be detected with satellite based observations. Although a large portion of the Canadian North is above the tree- line and considered exposed and therefore optimal for mapping of surficial geology, lichen cover can signifcantly obscure underlying mineral signatures. This paper attempts to address lichen cover issues by comparing in situ and remotely sensed spectral measurements of surficial mineralogy from the massive sulphide deposit at Izok Lake, Nunavut. The in situ spectral measurements consist of both lichen covered sites and co-located sites with the lichen removed by pressure-washing. The remotely sensed imagery consists of hyperspectral imagery acquired ProSpecTIR-VS sensor imagery on August 17, 2010 at 1.0m resolution with 360 bands between the 390-2500 nm spectral range. The spectral properties of lichen and non-lichen minerals were compared and hyperspectral "unmixing" techniques were employed to map both percent lichen cover and mineral composition for exposed rock. Simulations of scale effects were also considered to test the suitability of current and proposed operational sensor resolutions, such as Landsat at 30m, for mineral mapping in regions of significant lichen cover.

SM-ND PROVENANCE STUDY OF THE PERMIAN TO PALEOGENE STRATA, THE NORTHEAST PART OF SIBERIAN CRATON

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The Northeast part of the Siberian Craton contains a thick Permian – Paleogene clastic succession in which Permian – Jurassic rocks were deposited on the craton's margin, Cretaceous rocks were deposited in the Priverkhoyansk foreland basin and Lena-Anabar sedimentary basin, whereas Paleogene rocks fill in rift basins. We have carried out a Sm-Nd study to identify possible provenance of clastic rocks. Forty two sandstone and shale samples of different stratigraphic levels were analyzed. For provenance analysis we used variations in $\varepsilon_{Nd(t)}$ values where ε_{Nd} value is referred to the time of sedimentation. Data on Th/Sc ratio values are incorporated as well.

Permian sediments have $\varepsilon_{Nd(t)}$ values varying from -2 to -11 that reflects mixed cratonic and juvenile sources. Significant deviations to less negative (more juvenile) values between -6 and +1 represent mixing derivation of mafic rocks and recycled Permian sediments. The Th/Sc ratio values from Triassic sediments are typical for mafic rocks, that points to their wide distribution in the provenance. Jurassic sediments show heterogeneity with $\varepsilon_{Nd(t)}$ values from -2 to -12 and can be explained by existence of two source areas with predominance of cratonic and juvenile rocks. Cretaceous and Paleogene sediments show significant decreasing in

$\varepsilon_{Nd(t)}$ values up to -20, suggested as increasing input of the cratonic source. Data on Th/Sc ratio values correspond with this conclusion.

According to the Nd isotopic and Th/Sc data we propose that studied clastic succession were derived from several types of sources such as cratonic and juvenile ones. The cratonic sources were the Precambrian basement highs including, probably, the Anabar and Aldan shields. Juvenile components are likely derived from Taimyr orogen in Permian and from Norilsk traps and their correlatives in Triassic and Jurrassic time.

TECTONIC AND DEPOSITIONAL CONTROLS AFFECTING OIL AND GAS PRODUCTION FROM THE UTICA SHALE, EASTERN NORTH AMERICA

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Experience developing shale gas plays in the past 30 years has demonstrated that every shale play is unique. Each individual play has been defined, tested and expanded based on understanding the geology, resource distribution, natural fracture patterns, and limitations of the reservoir, and each play has required solutions to problems and issues required for commercial production. The Ordovician Utica Shale and its equivalents are no different.

These shales were deposited very broadly across the foreland basin created during the Taconic orogeny and cover thousands of square miles across eastern North America. The complex relationship between the development of the orogeny and the basin are critical to understanding the development of productive black shale reservoirs.

Deposition of the Utica black shale beds occurred during an active tectonic period, cyclically depositing shale and carbonate units. Syndepositional faulting resulted in variable depositional rates and depths, causing TOC variations across the faults separating the fault blocks. During and after deposition, Taconic tectonism promoted the development of fractures, folds and faults. In eastern NYS these early fractures are now filled with vein material. These early fractures may have been migration pathways for early hydrocarbon generation, since the fracture fills (veins) commonly contain anthraxolite. Later fractures were generated during later orogenic cycles, including the Alleghanian and more recent stress fields. These fracture remain vein-free, but they probably also acted as hydrocarbon migration pathways.

Ultimately, deposition and bed heterogeneity can be traced to this complex structural history. Analysis indicates that rapid declines in thermal maturity occur over very short distances away from the overthrust zone. These factors affect the presence of organic material, catagenesis, and the development of organic porosity. Understanding how these factors affect hydrocarbon quantity and quality may help answer whether we can identify the sweet spots in the Utica Shale.

RHEOMORPHIC FENITE AND CRUSTAL CARBONATITES: NEW COMPLICATIONS IN THE GRENVILLE CRUST, OLD CHELSEA AREA, QUEBEC

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The recent (2009) opening of an extension of Autoroute 5 north of Old Chelsea, Quebec, has produced striking roadcuts over a length of 2 km, with a wide variety of rock types and a very complex and bewildering juxtaposition of igneous, metamorphic, and metasomatic assemblages of minerals. We focus here on an unexpected discovery of evidence of fenitization of the regionally developed quartzofeldspathic gray gneiss. This transformation occurs near dikes of orange calcite, which typically have a selvage of tiny euhedral diopside crystals and apatite granules. Above the dikes are diffuse zones of fracture-controlled reddening of the gray gneiss, in which the original mineralogy is replaced by a more felsic, alkali-feldspar-dominant "syenitic" material. The orange calcite in those dikes [δ^{13}C ¡Ö –1‰, δ^{18}O ¡Ö 16‰] is isotopically intermediate between the regionally developed white marble [δ^{13}C ¡Ö 3‰, δ^{18}O ¡Ö 24‰] and a typical mantle-derived carbonatite [δ^{13}C ¡Ö –5‰, δ^{18}O ¡Ö 6‰]. We contend that the regional marble was locally metasomatized by an alkaline fluid of mixed crust and mantle derivation, then melted. Upon crystallization, this carbonate melt gave off a strongly alkaline H_2O-dominant fluid that converted the gneissic host-rock into a quartz-bearing syenitic composition. Nearby, we see evidence of zoned dikes of unusual syenite that cut the orange dikes or are cut by them. The margin of the syenite dikes contain a peristeritic sodic plagioclase, whereas the core is pink and K-feldspar- dominant. There are also signs of coarse graphic granite in some dikes. The whole package is consistent with an influx of fluids and heat at the Late Ottawan stage of the Grenville event in the area, at roughly 1040 Ma. We attribute this activity to renewed delamination, rapid rise of an asthenospheric mantle in the process of degassing, aggressive metasomatism of deep crustal units, and localized production of coeval anatectic syenitic, granitic and carbonatitic magmas. Whether such fenitization reactions active on a broader scale are responsible for large plutons of syenite in the area (e.g., the Wakefield syenite) merits an in depth investigation. Models for the evolution of the Grenville crust must necessarily involve input from the mantle.

NYAINQÊNTANGLHA GLACIATION: COUPLING BETWEEN TECTONICS, LANDSCAPE MORPHOLOGY AND GLACIAL EROSION

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The Nyainqêntanglha Mountain range is located 300 km northwest of Lhasa and immediately south of Namtso Lake in central Tibet. It strikes southwest-northeast and spans a distance of over 600 km. The range is bounded to the southeast by a normal fault. 30 peaks within the range surpass 6,000 m elevation, and 4 peaks are over 7,000 m high, with the highest peak reaching 7,162 m. In this study we analyzed 590 glaciers located throughout the range to see how they interact with the morphology of the landscape and exhumation rates, and how this can be connected to the local climate. Using ArcGIS and remote sensing imagery including Landsat ETM+, and GDEM 30 m resolution digital elevation models we identified the location of glaciers across the range, and quantified several of their key characteristics such as area, length, head/toe elevations, slope, and ELA. When calculating the ELA of the glaciers, AA and AABR methods were used, using a BR ratio of 1.75. ELA is related to the relative size and altitude distribution of the accumulation and ablation zones of each glacier, and is tied to the location of maximum glacial erosion. Therefore, identifying these local and regional ELA variations is essential in order to understand the overall range morphology. As ELA is controlled by temperature and precipitation, we also relate our ELA observations to local climate. For this study PRISM data is used to estimate the amount of precipitation that falls throughout the range, but due to a lack of weather stations in the area, no temperature data are available. Preliminary results indicate that the majority of the glaciers are found on the upwind, southeastern side of the range, which is possibly due to increased orographic precipitation there. The largest glaciers are found straddling the highest peaks, but it is not yet known if they are caused by the high precipitation drawn in by the peaks, or if they themselves are promoting the formation of high peaks by eroding material and increasing local exhumation rates and relief production. It was also found that the high peaks are offset to the east from the drainage divide, which suggests that there is either aggressive headward erosion or the preservation of an older, pre-uplift drainage basin morphology.

PALEOENVIONMENTAL ANALYSIS OF EDIACARAN FOSSIL-BEARING FORMATIONS OF THE CATALINA DOME, BONAVISTA PENINSULA, NEWFOUNDLAND

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In 2008, Hofmann and colleagues described Ediacaran fossils from Newfoundland's Bonavista Peninsula, exposed in a small (about 5km diameter) dome near the town of Catalina. The strata in which these fossils are found have been correlated with the Conception and St. John's groups of the adjacent Avalon Peninsula, famous for the Mistaken Point assemblage of early complex macrofossils. Detailed sedimentological study of the Catalina Dome allows for comparison with previous

paleoenvironmental analyses of correlative Avalon Peninsula stratigraphy in order to constrain further the nature of the basin in which the Ediacaran biota evolved. The succession formed in a deep marine environment in a tectonically active possible forearc basin. It is dominated by muddy turbidites with abundant thin beds of volcanic ash; soft sediment deformation occurs throughout the succession, due to seismicity in the lower part, and due to slumping toward the top. This records a transition from a basin plane to slope environment. Thick-bedded muddy turbidites in the lower third of the succession are consistent with a previous interpretation that turbidite ponding may have occurred due to a topographic high to the east. A particularly sandy 94 m-thick interval not present in the Avalon succession may have been deposited in a turbidite channel. Compared to equivalent strata on the Avalon Peninsula, ash is more abundant in the Catalina Dome, with thicker beds and persistence of ash deposition to higher stratigraphic levels, likely due to a position closer to the volcanic arc to the west. Because the ash provides the mechanism for preservation of soft-bodied biota, and fossil assemblages are similar between the base and the top of the succession, Hofmann *et al.* observed that this succession extends the stratigraphic range of the Mistaken Point biota. The occurrence of complex frond fossils beneath ash beds at this stratigraphic level as well as surfaces with only the controversial discoid taxon Aspidella that is similar to what is observed in equivalent strata on the Avalon Peninsula supports interpretation of Aspidella as the holdfast of otherwise unpreserved frondose organisms. Previous workers studying the Conception and St. John's groups on the Avalon Peninsula recorded a shift in turbidite paleocurrent direction from roughly eastward to southward, consistent with the existing tectonic model for the basin: a transition from convergence to strike-slip. However, the paleocurrent change occurs at a different stratigraphic level in each area, which suggests significant diachroneity in this transition.

OPENING THE WINDOW ON SHALLOW MARINE TO NON MARINE PALAEOBIOLOGY IN THE EDICARAN OF AVALONIA

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Rocks of the Avalon terrane from England and Newfoundland show many remarkable similarities in their succession of environments, passing from deeper marine slope deposits on the flanks of a volcanic arc, through deltaic cycles, towards fluvial sediments and then non deposition shortly before the end of the Ediacaran Period. Shallow marine to fluvial deposits within the St John's Group, in Newfoundland, have hitherto been regarded as having a poor or even non-existent biota. This is not confirmed by our current studies, in which we are finding remarkably preserved macrofossils and microfossils in these rocks, which show exciting comparisons to those of the Longmyndian in England. Of great interest in these studies is the possibility that some of these shallow water deposits are contemporaneous with deeper water sediments containing the more familiar rangeomorph assemblages. These shallow marine to fluvial environments, and others under investigation, clearly have interesting potential for palaeontological discoveries within the Ediacaran of Avalonia.

MICROFOSSIL EVIDENCE OF AN 8000 YEAR HIATUS ON THE CRAWFORD LAKE SHORELINE

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Crawford Lake occupies a small (~2.5 ha), deep (z_{max} ~24 m) basin excavated by glacial activity from the edge of the Niagara Escarpment in Milton. Because of its morphology, the lake is meromictic, allowing varved sediments to accumulate in the deep basin over much of the last millennium (Boyko-Diakonow, 1979; Dickman, 1979). In a core recovered from the shoreline at its outflow, however, a long hiatus is recorded between marl deposited during the early Holocene pine zone (McAndrews, 1994) and ragweed pollen-rich woody organic debris deposited since Euro-Canadian settlement. The lower 17 cm of the 97 cm core consists of grey calcareous clay assigned to the late Pleistocene spruce zone and a gradual transition from buff clay to marl around 60 cm (during the early Holocene northern pine zone) records a decline in water level during this arid interval. Continued warming allowed southern pine to replace northern pine ~8.2 ka BP and led to an increase in productivity in the lake that is recorded in the planktonic and benthic microfossil record. This natural eutrophication is probably due to evaporation and concentration of nutrients, a response similar to that in Sluice Pond, MA (Hubeny *et al.*, submitted). No sediments were deposited between ~ 7.5 ka BP and the 1880s when logging (to which the woody debris is attributed) took place. The hydrology of Crawford Lake appears to have been sufficiently altered by construction of the lumber mill on the south shore of the lake to allow sediments to accumulate again at the lake's outflow following several millennia of drought-induced low lake levels, especially between ~4.8 and 2 ka (Yu *et al.*, 1997).

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METAL ZONATION AND DEVELOPMENT OF Cu-ZONES IN VOLCANOGENIC MASSIVE SULFIDE DEPOSITS OF THE BATHURST CAMP, NEW BRUNSWICK: AN OVERVIEW

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Zn-Pb-Cu-Ag-type volcanogenic massive sulfide deposits of the Bathurst Mining Camp (BMC) are for the most part syngenetic-exhalative in origin, and intimately associated with laterally extensive Algoma-type iron formations that together define the Brunswick Horizon. Based on mineralogy and stratigraphic (footwall-hanging wall) relationships, massive sulfides in the BMC can be divided into two principal hydrothermal facies; 1) An exhalative Zn- and Pb-rich bedded sulfide facies composed of pyrite, sphalerite, galena and lesser chalcopyrite; and 2) An epigenetic Cu-rich sulfide facies, commonly referred to as a basal Cu-zone or vent complex, and comprising massive to brecciated pyrite (± pyrrhotite) and chalcopyrite with lesser sphalerite.

The largest and most developed Cu resource in the BMC occurs at the 329 Mt Brunswick No.12 deposit, where a Cu-enriched basal keel underlying bedded Zn-Pb (ore) is estimated to contain 64.5 Mt grading 0.98% Cu, of which 5.4 Mt grades 1.53% Cu. Massive sulfides sampled (n=64) from the Brunswick No.12 Cu-zone average 1.28% Cu, 1.05% Zn, 0.28% Pb, 38.0 ppm Ag, and 0.35 ppm Au, and exhibit distinct enrichments in Bi (555 ppm), Co (1690 ppm), and Se (34.2 ppm), relative to the bedded sulfide facies. Pyrrhotite is a significant component of the basal Cu-zone, comprising up to 40% of the Cu zone and strongly controlling contents of Co and Se, averaging 0.09% and 0.03%, respectively. Sphalerite, which can exhibit extensive chalcopyrite disease, is markedly depleted in the Cu zone and accounts for less Co (ave., 0.08%) and Se (ave., 0.02%). Pyrrhotite barren Cu-zones in the BMC typically exhibit lower levels of Co. The 21 Mt Murray Brook deposit has one of the richest Cu-zones in the BMC with an estimated 2.1 Mt grading 2.0% Cu. Yet massive sulfides sampled (n=37) from this Cu-zone (ave., 4.72% Cu) exhibit much lower levels of Co (379 ppm). Nevertheless, these Cu-zones

display marked enrichment in Co, Se and Bi, relative to their co-genetic Zn-Pb sulfide facies.

A proximal Cu-Co-Bi-Se signature is prevalent among Cu-zones of the BMC and its distribution across hydrothermal facies is interpreted to reflect high temperature zone-refining processes. This is corroborated by the high abundance of chalcopyrite, arsenopyrite, and native bismuth all of which have higher temperature sensitive solubilities than sphalerite and galena, and strongly reflecting assemblages in adjacent (footwall) epigenetic stockwork zones. Variations in mineralogy (± pyrrhotite) result from differing fS_2, and perhaps fO_2 conditions, during development of the large replacement-style Cu-rich facies.

TRILOBITES FROM THE EARLY ORDOVICIAN (IBEX) OF NORTH-EAST GREENLAND: REVISITING OLD COLLECTIONS IN THE LIGHT OF NEW LITHO- AND BIOSTRATIGRAPHIC DATA

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A 1.5 km thick succession of Early to Middle Ordovician peritidal to subtidal carbonates is exposed in North-East Greenland, mainly on Ella Ø and Albert Heim Bjerge. A significant trilobite collection was amassed by John Cowie and Peter Adams during 1950s mapping of the area, but descriptions were never published. Ongoing studies of the macro- and microfaunas incorporate these historical collections with those made during GEUS-led mapping and logging of the Cambrian–Ordovician sequence in 2000/2001. The data from these expeditions has made it possible to place the earlier trilobite collections within updated lithostratigraphic and conodont biostratigraphic contexts.

The revised Antiklinalbugt Formation (Tremadocian) has yielded a diverse trilobite fauna, including two new species of the dimeropygid *Tulepyge*. Conodonts place the lower Antiklinalbugt Formation in the *Cordylodus intermedius* Biozone, the lower upper part in the *Cordylodus angulatus* conodont Biozone and the uppermost part in the *Rossodus manitouensis* conodont Biozone.

The Cape Weber Formation has also been revised, and a new formation, the Septembersø formation, erected at its base. A significant disconformity encompassing the upper Tremadocian Stage (= Stairsian Stage) separates the Antiklinalbugt from the overlying Septembersø formation. The trilobites of the Septembersø formation comprise members of the Family Bathyuridae, including, *Bolbocephalus*, *Peltabellia*, *Punka*, *Randaynia* and a new genus.

The diverse trilobite fauna of the (revised) Cape Weber Formation (ca. 1100 m thick) is dominated by bathyurids; at least seven other families are represented. The trilobites indicate correlation with *Strigigenalis brevicaudata*, *S. caudata* and *Benthamaspis gibberula* zones of western Newfoundland, equivalent to *Protopliomerella contracta* (G_2) to *Presbynileus ibexensis* (I) zones of Utah-Nevada. Some trilobites in the upper subunits of the Cape Weber Formation range into the *Pseudocybele nasuta* Zone (J). This age range is supported by conodonts, which represent the *Oneotodus costatus*, *Oepikodus communis* and *O. intermedius* Biozones.

The 'Black Limestones', a distinctive dark grey limestone unit developed on Albert Heim Bjerge but not Ella Ø, yielded biostratigraphically important trilobite species, indicating a range into the *Pseudocybele nasuta* Zone (J) (*Cybelopsis speciosa* Zone of western Newfoundland); based on conodont evidence, the unit correlates with the upper member of the revised Cape Weber Formation. The 'Black Limestones' provide evidence for deeper water incursion onto the carbonate platform, corresponding to the eustatic high known as the 'Evae transgression'.

A NEW U-Pb ZIRCON AGE AND GRAPTOLITE FAUNA FOR THE BELLEWSTOWN TERRANE, EASTERN IRELAND, CONSTRAIN DUNNAGE ZONE CORRELATIONS

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New exposures within the Ordovician Bellewstown Terrane sequence in the Iapetus suture zone of eastern Ireland (Hilltown Formation) reveal a graptolite fauna in shale overlying a felsic tuff. Zircons extracted from sand-grade tuff are exclusively prismatic and primary in appearance. U-Pb dating of the zircons by LA-ICP-MS (n=75) gives a 'TuffZirc' age of 474.1 +1.1-2.5 Ma (Floian: Arenig). An intra-Iapetus brachiopod fauna from a horizon just below the dated tuff was previously assigned to the D. artus Biozone (Darriwilian: Llanvirn) based on graptolites from elsewhere in the Hilltown Formation, although equivalent brachiopod faunas in the Dunnage Zone of Newfoundland are older. Characterisation of the new graptolite fauna is ongoing and will be reported at the conference. The new age for the tuff appears to reconcile the previous faunal age discrepancy and allow correlation between Bellewstown and other intra-Iapetan volcanic terranes.

NEW INSIGHTS INTO THE STRATIGRAPHIC-STRUCTURAL RELATIONSHIPS OF COMPLEXLY FOLDED ROCKS OF THE WOODBURN LAKE AND KETYET RIVER GROUPS, NUNAVUT, CANADA

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Archean to Paleoproterozoic rocks of the Rae Craton, Western Churchill Province, have been affected by polyphase deformation and metamorphism causing structural complexity and confusion regarding the age and affiliation of rock units. This study aims to improve the stratigraphic-structural understanding of Neoarchean rocks and the Paleoproterozoic Ketyet River group through detailed mapping of four areas in the region NNW of Baker Lake: "Nipterk Lake", "Ukalik Lake", "Bar Lake" and Kiggavik, north of the uranium deposits. This will provide better knowledge of the basement rocks to assist unconformity-related uranium exploration marginal to the late Paleoproterozoic Thelon Basin.

In 2010 and 2011, 1:6,000 to 1:70,000 scale mapping in the first three areas revealed that the Ketyet River group comprises thin metaconglomerate gradationally overlain by orthoquartzite and grey pelitic schist. At Bar Lake, sills of metagabbro within the latter may be equivalent to the Five Mile Lake basalts, substantiating correlation to the Amer Group. The metaconglomerate and orthoquartzite unconformably overlie 2.6 Ga quartz-K-feldspar porphyritic schist (QFP schist) and parts of the Woodburn Lake group ranging from feldspathic metagreywacke to komatiite. Where the metaconglomerate is absent, the base of the orthoquartzite contains "quartz eyes" resembling those of the QFP schist. Cross-beds at the base and top of the orthoquartzite respectively face away from the QFP schist and toward the pelitic schist, providing control on the younging direction. The quartzite-pelitic schist contact is gradational; approaching the contact, decimetre-scale pebble-metaconglomerate and centimetre-scale pelitic schist interbeds are more common, whereas above the contact, the pelitic schist contains graded granule metaconglomerate interbeds.

Four ductile deformational events (D_1 – D_4) affected all of these rocks. The first two strongly controlled the map pattern, whereas D_3 and D_4 are recorded mainly at the outcrop scale as strong domainal crenulation cleavages defined by micas in the QFP and pelitic schists. D_1 recumbent isoclinal folds and thrusts caused multiple structural repetitions of the Neoarchean and Paleoproterozoic strata. D_2 coaxially refolded D_1 structures, producing type 3 "hook" interference patterns. D_1 structures were generally transposed sub-parallel to the inclined axial planes of

second generation open to closed folds (F_2) cut by northwesterly directed thrusts. At Kiggavik, relationships are similar except that F_2 axial planes are moderately north-dipping rather than steeply south-dipping. Brittle faulting related to Thelon Basin development dextrally offset basement rocks at Bar Lake and Kiggavik, allowing definition of three structural domains at Bar Lake that are rotated relative to one another.

Keynote 3D GIS-BASED EXPERT SYSTEMS FOR EXPLORATION TARGETING

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The past several years has seen a progressive, successful development and deployment of 3D GIS-based expert systems for mineral exploration targeting. The general principle is to combine multiple 3D earth model elements to determine spatial locations with the statistical characteristics diagnostic of economic mineral occurrence. The general approach is to take as input multiple pre-computed properties and proximity relationships interpolated on a 3D grid to compute a classified and ranked list of targets. Typical input properties are lithology, formation, physical and geochemical rock properties, proximity relationships of structural and topological model objects, proximity to existing boreholes, and presence, proximity, and classification of geophysical anomalies. Workflows have been implemented to guide geoscientists through the complex sequence of steps required for input data designation, characterization, quality control, normalization, and possible re-classification. Tools from the field of 2D-GIS spatial expert systems, largely developed and proven at the Geological Survey of Canada in the 1980s and 1990s, have provided a solid foundation for extension to 3D. These include the knowledge-driven techniques of Boolean Logic, Index Overlay, Multi-Class Index Overlay, and Fuzzy Logic, as well as the data-driven techniques of Weights-of-Evidence.

Practical implementation of 3D expert-system methods has required parallel advances in earth modelling. The last several years has seen systematic progress in our ability to quantitatively interpret and integrate geoscience data for 3D exploration targeting at regional, prospect, and mine scales. Interpretational advances have occurred individually in each of the sub-disciplines of geology, geophysics, and geochemistry. Our ability to integrate these interpretations into practical targeting models, approximately consistent with both geological reasoning and data, has similarly advanced and delivered success at the drillbit.

PALEOPROTEROZOIC LATE-TECTONIC PEGMATITE-HOSTED U-Th±REE-Y-Nb MINERALIZATION IN THE WOLLASTON DOMAIN, NORTHERN SASKATCHEWAN

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In northern Saskatchewan late-tectonic granitic pegmatites intrude Early Paleoproterozoic Wollaston Group metasedimentary rocks and interfolded granitoids that unconformably overlie Late Archean gneisses, all of which have been subjected to deformation during the 1.86 to 1.78 Ga Trans-Hudson Orogeny. The high-T metamorphic events during the THO generated partial melting of recycled lower crustal materials, producing syn- to late-tectonic granitoid magmas. Variably mineralized U-Th±REE-Y-Nb–pegmatite intrusions and fracture-controlled uranium mineralization characterizes the U-Th±REE-Y-Nb mineral showings in the Kulyk and Eagle lakes region, within the Wollaston Domain.

The highly evolved (mineralized) pegmatites in the Kulyk and Eagle lakes area range from simple granitic pegmatites to partially zoned, mineralogically complex pegmatites. The complex pegmatites often have diffuse contact margins that are hybridized as a result of bimetasomatic interaction with the metasedimentary host rocks, and are mineralogically heterogeneous (biotite, actinolite, diopside, magnetite, ilmenite, titanite, pyrite, xenotime, zircon, monazite, thorite, and allanite). U-Th±REE-Y-Nb mineralization is concentrated within these "hybrid" contact zones and biotite metasomatic reaction zones along the pegmatite margins. Generally, it is the concordant hybridized pegmatites that are more mineralogically complex than the discordant pegmatites, suggesting that the concordant pegmatites have reacted more completely with the host rocks; this is similar to late-tectonic uraniferous pegmatites of the Grenville Province.

Geochemical analysis of the mineralized simple granitic to hybridized pegmatites indicate they are rare-element Nb-Y-F pegmatites, that average 33 ppm Nb, 175 ppm Y, 670 ppm U, 320 ppm Th, 400 ppm Zr, and 1300 ppm ∑REE. They are variably high Sr-Ba pegmatites interpreted as anatectic melts generated from an extremely fractionated, crustally derived A- to I-type leucogranitic magma; this setting agrees with U-Pb geochronology of these granitic pegmatites, which constrains them between peak to late metamorphic events ca. 1.81 Ga. Previous Pb isotopic data from similar concordant pegmatites, to the south of the Kulyk and Eagle lakes region, indicate they were derived from Hearne basement that is Paleoproterozoic orogenic rock metamorphosed to granulite facies.

U, Th, REE, Y, and Nb were most likely maintained at significant concentrations in these enriched crustal melts as they ascended, up to the final stages of the hybrid pegmatite evolution. These hybridized pegmatites represent a dynamic environment, in which hybridization processes evolved during active assimilation and fractional crystallization at the site of pegmatite emplacement, promoting the exchange of accessory phases between multiple pegmatite injections, and resulting in saturation of mineralizing phases, such as U, Th, and REEs, along these bimeta-somatic hybrid border zones.

VOLCANIC AND HYDROTHERMAL RE-CONSTRUCTION OF PILLEY'S ISLAND VMS DISTRICT, NOTRE DAME BAY REGION, CENTRAL NEWFOUNDLAND

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Pilley's Island in Notre Dame Bay, central Newfoundland is host to a significant cluster of bimodal felsic Zn-Pb-Cu volcanogenic massive sulfide (VMS) deposits within the Ordovician Annieopsquotch Accretionary Tract (AAT). The Pilley's Island terrane of the Roberts Arm – Buchans belt within the AAT is dominated by altered, glassy, dacitic breccia and volcaniclastic rocks intercalated with lesser flow banded dacite, and mafic pillow lava and pillow breccia. The rocks of the Pilley's Island terrane are interpreted to have originated within a peri-Laurentian volcanic arc/back-arc in the western Iapetus Ocean.

Recent exploration programs have identified several southeast dipping thrust faults that offset the stratigraphy. The identification of these faults has created a need for re-interpretation of the district's stratigraphy, structure, hydrothermal alteration and lithogeochemistry. Detailed mapping and drillcore logging have allowed a reconstruction of the volcanic stratigraphy, hydrothermal alteration and 3D visualization of the VMS district, with considerable focus on the Bumblebee Bight/3B and Mine area.

Pilley's Island hosts three VMS deposits, from west to east: Spencer's Dock, Old Mine and Bumblebee Bight/3B. The deposits vary by mineralization style including: 1) sub-seafloor massive pyrite replacement deposits (Spencer's Dock, Old Mine); 2) sea floor massive sulfide deposits (3B, Bumble Bee Bight); and 3) breccia sulfide deposits (Bull Road showing). The stratigraphy of each panel varies with each deposit style, for example: 1) Spencer's Dock Panel is dominated by contorted dacitic flows; 2) Old Mine-3B Panel consists of mostly felsic volcaniclastics; and 3) Bull Road Panel (host to Bull Road showing and Bumble Bee Bight deposit) is dominated by massive dacitic flows and lesser volcaniclastic rocks.

Mapping, petrography, lithogeochemistry, and shortwave infrared-near infrared (SWIR-NIR) spectroscopy have identified alteration haloes around the VMS deposits. Major alteration zones, from strongest to weakest alteration, include: illitic phengite and phengite, illitic muscovite and muscovite, and Fe to Fe-Mg to Mg chlorite. These haloes also correspond to increased element mobility in zones of strongest alteration, specifically Na depletion and K-Mg-Fe enrichment. Lithogeochemistry has also been very useful in identifying element mobility and primary

petrochemistry so as to compare and contrast different thrust panels as well as vectoring towards prospective zones for VMS mineralization.

TECTONIC EVOLUTION OF THE ADIRONDACK PORTION OF THE GRENVILLE PROVINCE

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The oldest rocks in the Adirondacks are ca. 1.4-1.3 Ga tonalites and quartzites of the Dysart-Mt. Holly suite rifted from the Laurentian marginal arc and exposed in the Appalachian Mesoproterozoic inliers at least as far south as the New Jersey Highlands. They are intruded by ca. 1.25 Ga. Elzevirian granites and overlain by ca. 1.3-1.22 Ga metapelites and marbles presumably deposited in backarc basins. Closure of the backarc archipelago was underway by ca. 1.2 Ga and signaled the onset of the Shawinigan orogeny whose contractional phase terminated by ca. 1.16 Ga and was followed by the emplacement of the ca. 1.16-1.14 Ga AMCG suite. Shawinigan P,T reached amphibolite grade in the Adirondack Lowlands and granulite grade in the Highlands resulting in regional anatexis. Additionally, the Lowlands were thrust over the Highlands to form a local Orogenic Lid, thus escaping granulite facies conditions of the ca. 1.09-1.04 Ga Ottawan pulse of the Grenvillian orogeny. Evidence for Shawinigan orogenesis extends southeast into the Appalachians.

Initial Ottawan orogenesis in the Adirondacks coincides with termination of Hawkeye granitic magmatism at ca. 1093 Ma and was followed by development of penetrative fabrics and nappe-like structures throughout the Highlands. There is little preserved evidence for magmatism or anatexis until ca. 1.05 Ga when the periphery of the present Highlands was intruded by the A-type Lyon Mountain Granite (LMG). Highland titanite cooling ages of ca. 1.03 Ga and monazite ages of 1.50-1.25 Ga reflect Ottawan T ≥800°C, whereas Lowlands titanite ages of ca. 1.15 Ga and hornblende Ar/Ar ages >1.06 Ga demonstrate that this region did not experience high grade Ottawan conditions. These data reflect the ca. 1.05 Ga down-to-the-west faulting of the Lowlands from its perch above the Highlands and demonstrate that it is part of the southeast Grenville Orogenic Lid. In the eastern Adirondacks, east-side-down faulting along a mylonitic shear zone at ca. 1.05 Ga (monazite) indicates that the Highlands represent a late Ottawan symmetrical core complex (gneiss dome) reflecting regional Grenville orogen collapse. Downfaulted Orogenic Lid rocks probably lie beneath Paleozoic cover to the east. The detachment fault zone coincides with the southward projection of the Canadian Tawachiche shear zone. Collapse accompanied intrusion of the 1050±10 Ma LMG that reflects deep crustal melting and weakening. LMG crosscuts early Ottawan F_1 structures but is folded by upright, open F_2 and F_3 folds which formed during terminal Ottawan extension and collapse.

METALLOGENY OF URANIUM DEPOSITS IN THE CENTRAL MINERAL BELT, LABRADOR, CANADA

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The Central Mineral Belt (CMB) extends for over 250 × 75 km through central to coastal Labrador and is underlain by a series of six Mesoproterozoic supracrustal sequences and associated intrusive suites. Uranium was first discovered in 1954 with subsequent exploration through to the late 1970s and more recently since 2003. At least 180 occurrences with a variety of forms were delineated in all units and associated basement rocks. Since 2003, defined uranium resources in the CMB have increased six-fold from 25 to 154 M pounds including: Michelin, (103M lbs.) Jacques Lake (17M lbs.), C-zone (10M lbs.) and Inda (6.6M lbs.), among others. This growth in discovery was contemporaneous with, and at least partly dependent upon, the acquisition of large, detailed geological/ geophysical/geochemical data sets. A recent compilation of these data has allowed for a much more detailed definition of the regional geological setting of uranium mineralization of the CMB. Specifically, we present the results of the compilation and review the local setting of deposits within the context of the compilation.

THE PINGUICULA GROUP, NORTHERN YUKON: PROGRESS IN THE PROTEROZOIC PUZZLE OF WESTERN NORTH AMERICA

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The late Meso- or early Neoproterozoic Pinguicula Group, Wernecke Mountains, Yukon, is a siliciclastic and carbonate succession deposited on an angular unconformity developed on the Wernecke Supergroup. Detailed stratigraphic observations indicate that the Pinguicula Group was deposited during overall deepening of the basin: fining-upward siliciclastic facies of unit A are overlain by mid-slope carbonate facies of unit B, which grade to lower slope and possibly basinal carbonate facies of unit C. Detrital zircon geochronology from the Pinguicula Group unit A sandstone provides information on provenance and age of the sediment deposited in the Pinguicula basin. Neoarchean and Paleoproterozoic populations are abundant and may be derived from the underlying Wernecke Supergroup or the Laurentian craton. A distinctive population from the Meso-proterozoic, between 1610 and 1490 Ma (North American Magmatic Gap), suggests that sediment may have been derived from Australia. The possibility of Australia as a sediment source suggests that the Pinguicula Group may have been deposited in an intracratonic basin between the Laurentian and Australian cratons. In addition, a single Grenvillian detrital zircon $^{207}Pb/^{206}Pb$ age (1144±25 Ma) from the Wernecke inlier raises the possibility that the Pinguicula Group is younger than ~1150 Ma. If additional grains of this age are found to support a statistically viable population, and the depositional age of <1150 Ma is confirmed, then correlations between the Pinguicula Group and other successions in northern Canada, such as the Dismal Lakes Group, will need to be revisited.

MODELING OF EFFECTIVE THERMAL CONDUCTIVITIES OF POROUS MEDIA AS A FUNCTION OF TEMPERATURE IN THE SOLID REGION

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The thermal conductivity, thermal diffusivity, and heat capacity per unit volume of dunite rocks taken from Chillas near Gilgit, Pakistan, have been measured simultaneously using the transient plane source technique. The temperature dependence of the thermal transport properties was studied in the temperature range from 303°K to 483°K. Based on the temperature-dependent experimental data listed above, model calculations have been performed to achieve a deeper insight into the thermodynamical behavior of these materials within the high-temperature solid regime.

Two different models are proposed for the prediction of effective thermal conductivities of alloy series taking into account the thermal conductivities of the constituents, the temperature, and a fit parameter. For such calculations, it is of special importance to choose model functions that are both physically relevant and numerically robust. It is observed that the values of the effective thermal conductivity predicted by the models are in agreement with the experimentally determined thermal conductivities by pulse heating technique within 8%.

TERRANE AFFINITIES OF CALEDONIAN ROCKS IN SOUTHEAST IRELAND

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A collage of peri-Gondwanan micro-terranes rifted from Gondwana and accreted to Laurentia during the Caledonian – Appalachian orogeny.

Southeast Ireland occupies a key position for along-strike correlation in the orogen, but data have been inadequate to assess correlation of peri-Gondwanan terranes. U-Pb detrital zircon dating and Sm-Nd whole-rock isotope analysis are useful methods for distinguishing, correlating and, ultimately, reconstructing these dispersed fragments. These methods have therefore been applied in southeast Ireland to clastic metasedimentary rocks that may have been derived from pre-Caledonian crystalline basement. Sm-Nd whole-rock isotope analysis has also been carried out on granitic intrusions that are likely to have formed mainly from melts of pre-Caledonian crystalline basement, or of its sedimentary derivatives.

Early Ordovician metasedimentary rocks in southeastern Ireland have detrital zircon age spectra with dominant late Neoproterozoic ages, typical of peri-Gondwanan sources. The Ribband Group also has a spread of Mesoproterozoic, Palaeoproterozoic and Neoarchaean ages, typical of Amazonian Gondwanan sources and similar to rocks from Avalonia and Ganderia. Although there are differences in the age spectra, it is not possible to definitively distinguish between Ribband Group samples from either side of the Wicklow Fault Zone, a putative terrane boundary. The Grahormack Fm (Tagoat Gp) has very sparse Mesoproterozoic and Neoarchaean signals and small but significant clusters of Palaeoproterozoic and Mesoarchaean ages, similar to rocks from the Meguma terrane and possibly suggesting a source in West African Gondwana.

Nd isotope ratios, expressed as the parameter ε_{Nd}, are calculated for 400 Ma to optimize comparison between rocks of different age. Neoproterozoic to early Devonian felsic igneous rocks from southeastern Ireland have ε_{Nd}(400 Ma) values of -7 to -1, whilst Neoproterozoic to Ordovician sedimentary and metasedimentary rocks have ε_{Nd}(400 Ma) values of -6 to -12. These ranges compare well with the ranges exhibited by rocks of the Gander Zone in Newfoundland and Nova Scotia. There are no positive values of ε_{Nd}(400 Ma) in the Irish rocks, in contrast to the Avalonian of the Maritime Provinces. It is unclear whether the data for Wales and England are significantly different to those from the Irish samples.

HUDSONIAN URANIUM MINERALIZATION IN THE WESTERN MARGIN OF THE TRANS-HUDSON OROGEN (SASKATCHEWAN, CANADA): A MAJOR PROTORE FOR UNCONFORMITY-RELATED URANIUM DEPOSITS?

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The genetic model of the giant unconformity-related uranium deposits of the Athabasca Basin is still debated; one of the main questions being the source of the metals concentrated by the diagenetic-hydrothermal events during the Mesoproterozoic Era (ca. 1.6-1 Ga) at the interface between the Athabasca Basin and the underlying Archean/Paleoproterozoic basement rocks. Currently, accessory minerals such as monazite, zircon or apatite from the sedimentary basin and basement rocks are proposed as the primary uranium source for these high-grade uranium deposits.

A systematic study of two areas of basement rocks located near the eastern part of the Athabasca Basin (i.e. Way Lake and Moore Lake properties) highlights the significant and widespread occurrences of Hudsonian (ca. 1.82-1.76 Ga) uranium oxide mineralization in these zones. Two types of mineralization are identified: magmatic uranium oxides related to granitic pegmatites and high-temperature uranium oxides in veins. The most common type occurs within granitic pegmatites, but the highest grade occurs as veins. The two types were formed during events related to the evolution of the Trans-Hudson Orogeny at 1820-1720 Ma. The magmatic uranium oxides were formed by partial melting of Wollaston Group metasedimentary rocks, with differential melt extraction processes, melt transfer, and fractional crystallization. The origin of the vein-type occurrences is unclear, but they seem to be related to Ca- and/or Na-metasomatism. The uranium oxides are associated with other U-, Th- and REE-bearing accessory minerals like monazite, zircon, and/or uranothorite, enriching the metal contents of these UO_2-bearing rocks, which are up to 200 times (only considering U-rich pegmatites) more enriched in U than other basement or basin lithologies. The studied rock samples, even macroscopically fresh and located far away from any known unconformity-related U deposit, present clear evidence of alteration with clay minerals, alumino-phosphate-sulfate (APS) minerals and UO_2 dissolution, indicating the percolation of brines associated with the formation of unconformity-related uranium deposits.

Due to the geological similarities between the studied zones and the basement domains from the eastern part of the Athabasca Basin, (i.e. the Hearne Province), it is proposed that these geological domains were a significant host of uranium protores of Hudsonian age, which provided uranium and other metals for the metal enrichment of basinal brines and formation of Athabasca Basin U deposits. These observations bring new insight to the source debate for the metals in unconformity-related U deposits, and reinforce the greater metal potential of the basement compared to that of the sedimentary basin.

FROM SOURCES TO DEPOSITS: RECENT ADVANCES ON THE U-MINERALIZING BRINES IN THE ATHABASCA BASIN (SASKATCHEWAN, CANADA)

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Giant unconformity-related uranium deposits were formed during the Mesoproterozoic era, 1.6-1.0 Ga ago, in both Paleo- to Meso-Proterozoic Athabasca Basin (Canada) and Proterozoic Kombolgie Basin (Australia). They are precious witnesses of protracted large-scale fluid flows at the interface between sedimentary basins and their Archean to Paleoproterozoic crystalline basement, at conditions close to peak diagenesis (130-220°C). Although the Athabasca Basin hosts the world's largest high-grade uranium deposits and consequently has been the subject of extensive research, metallogenic models still bear important uncertainties. The objective of this contribution is to present new insights about the genetic model of these exceptional deposits from the study of the U-mineralizing brines.

Origin of the mineralizing brines

The origin of the brines has been investigated based on coupled Cl/Br and δ^{37}Cl composition of fluid inclusions trapped in quartz-dolomite veins and δ^{11}B composition of Mg-tourmalines associated with U ores. These studies have shown that the brines originate from subaerial evaporation of seawater up to epsomite saturation (salt content of ca. 25-35 wt%) forming a Cl-Na-K-Mg-rich brines.

Fluid percolation in the basement rocks, metal uptake and brine modifications

The original Cl-Na-K-Mg brines have percolated through the sedimentary pile and also extensively in the underlying basement, during tectonic reactivation, thanks to major faults and dense network of microfractures, partly inherited from late-orogenic deformation related to Trans-Hudson Orogen. Intensive brine/basement interaction was responsible for major chemical and isotopic changes (O, H, C) of the initial brines to form two chemically distinct Cl-Na-Ca-Mg-K (NaCl-rich) and Cl-Ca-Mg-Na-K ($CaCl_2$-rich) brines, both being highly enriched in metals (U, Zn, Pb, Mn, Cu, Sr). Their high metal content compared to modern sedimentary brines and metal enrichment comparable with brines related to MVT Pb-Zn deposits supports the idea that the basement was the dominant source for metals, and especially for U.

Conditions for the transport and deposition of uranium

The mineralizing brines have U concentrations between 1×10^{-6} and 2.8×10^{-3} mol.l^{-1}, making them the U richest crustal fluids so far. This exceptional U content is related to the oxidizing and acidic nature of the brines (pH between 2.5 and 4.5) and to the high availability of U sources. The mixing of the NaCl-rich and $CaCl_2$-rich brines is coeval with the UO_2 deposition but the reductant necessary for UO_2 precipitation remains enigmatic.

THE GOLD CONTENT OF VMS DEPOSITS: KEY FEATURES AND CONTROLLING PARAMETERS, WITH IMPLICATIONS FOR EXPLORATION IN THE APPALACHIAN OROGEN

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VMS deposits contain variable amounts of gold, both in terms of average grade and total contents. The analysis of gold grades and tonnages of 513 VMS deposits of all ages worldwide revealed that a large proportion of deposits are characterized by a relatively low gold grade (<2 g/t). The geometric mean and geometric standard deviation appear to be the simplest metric for identifying subclasses of VMS deposits based on gold grade. The geometric mean gold grade is 0.76 g/t; the geometric standard deviation is +2.70 g/t Au. Deposits with more than 3.46 g/t Au (geometric mean plus one geometric standard deviation) are considered auriferous. The geometric mean gold content is 4.7 t Au, with a geometric standard deviation of +26.3 t Au. Deposits containing 31 t Au or more are considered to be anomalous in terms of gold content, irrespective of the gold grade. Deposits with more than 3.46 g/t Au and 31 t Au are considered gold-rich VMS. A large proportion of the total gold hosted in VMS worldwide is found in a relatively small number of such deposits. The identification of these truly anomalous systems helps shed light on the geological parameters that control unusual enrichment of gold in VMS. At the district scale, the gold-rich deposits occupy a stratigraphic position and volcanic setting that commonly differs from other deposits of the district possibly due to a step change in the geodynamic and magmatic evolution of local volcanic complexes. The gold-rich VMS are commonly associated with transitional to calc-alkaline intermediate to felsic volcanic rocks, which may reflect a particularly fertile geodynamic setting and/or timing (e.g., early arc rifting). At the deposit scale, uncommon alteration assemblages (e.g., advanced argillic) and trace element signatures are present, suggesting a direct magmatic input in some systems.

There are over 30 VMS deposits and occurrences for which tonnage is known in the Appalachian orogen of Newfoundland, including about 10 deposits that have reported gold grades. These VMS deposits are hosted in distinct arc and back-arc sequences, and those hosted in the Baie Verte oceanic tract, including Rambler-Ming, are enriched in gold relative to the deposits of the Annieopsquotch and Penobscot sequences. Similar trends are developed in the Bathurst Camp with the VMS deposits of the California Lake Group being on average slightly richer than the VMS deposits of the Tetagouche Group. This suggests that some specific rock sequences of the Appalachian orogen are more prospective than others to host gold-rich and auriferous VMS deposits.

COMPOSITION, PROBABLE ORIGIN, AND RECENT CORAL FAUNA OF ENIGMATIC MOUNDS ON ORPHAN KNOLL, NORTHWEST ATLANTIC OCEAN

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Orphan Knoll is a foundered fragment of the North American continental crust found in deep water off the continental margin of Newfoundland. Orphan Knoll contains more than 250 mounds that range from 60 to 300 m of meters tall and 1 to 3 km wide. Possible origins proposed for these mounds have included a karstified limestone plateau, block-faulted bedrock, bioherms or cold-seep carbonate mounds. The principal objective of the study was to determine the composition and probable age of the enigmatic Orphan Knoll mounds, in an effort to better understand their possible origins. They were also studied as habitats of live deep-water corals.

A geological and biological survey using the remotely-operated vehicle ROPOS in July, 2010, collected bedrock samples, 3.5 kHz sub-bottom profiles, high-definition video, CTD data, and near-bottom multibeam bathymetry of mounds from the southeastern and northeastern parts of Orphan Knoll, at approximate depth ranges of 2900-2400 m and 2000-1750 m, respectively. Video surveys of several mounds found bedrock at the centre of the mound, surrounded by mixed sediment composed of bedrock-derived talus, ice-rafted debris, and drifted hemipelagic sediment. Rock samples from the upper layer of limestone on top of one northeast Orphan Knoll mound were identified as mid-Miocene thinly bedded pelagic limestone bedrock with Miocene foraminiferans (Orbulina spp. and Globigerina spp.), interbedded with thick Mn-oxide crusts. These limestones unconformably overlie a lower thick-bedded limestone of unknown age. Strike and dip estimates from video suggested SW-NW dips of ~10-45°. Mn-oxide crusts with interbedded pelagic limestone were found at the top of several mounds. Our observations suggest block-faulted bedrock as the most likely origin of the studied mounds. Formation of these mounds may have been initiated through listric faulting during Mesozoic and Cenozoic extension, and reactivated by faulting during the Neogene and Quaternary.

Recent coral fauna of the Orphan Knoll mounds included several gorgonians, especially Isidids, Chrysogorgia spp, Acanthogorgia sp. and an unknown gorgonian, at least two species of antipatharians, several species of soft corals and the solitary scleractinians Flabellum spp., Vaughanella margaritata, and Desmophyllum dianthus, mostly on the shallower mounds. No colonial scleractinians were observed. Although live D. dianthus were not highly abundant, dead D. dianthus formed a time-averaged "coral graveyard" deposit on the eastern slope of a cliff of one of the northeast mounds. Dominant corals on soft sediment habitats surrounding the mound centres were several species of sea pens, soft corals, and reclining solitary scleractinians.

EXAMINING THE GEOCHEMICAL POTENTIAL FOR USING U-Th-Pb ISOTOPE SYSTEMS IN THE BASEMENT LITHOLOGIES OF THE ATHABASCA BASIN TO VECTOR TOWARDS MINERALIZATION

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The largest unconformity-type (U/C-type) uranium deposits in the world are found in the Proterozoic Athabasca Basin in northern Saskatchewan, Canada. The basin is comprised of a sedimentary rock sequence underlain by Archean to Paleoproterozoic metamorphosed basement rocks, which include graphitic pelitic gneisses and granitic pegmatites. Major faults cutting these rocks, initially related to the Talston Magmatic Zone and the Trans Hudson Orogen, were reactivated episodically and thus provided focal points for fluid flow and mixing.

Many researchers agree that oxidized basinal brines flowed through the basement lithologies, mixing with reducing fluids or interacting with reduced rocks to cause uranium to precipitate. Although the source of the uranium deposited at or near the unconformity is an unresolved and highly debated subject, monazite is often considered a possible source because it can contain significant amounts of U and Th within the crystal structure. If hot, saline rich fluids interact with monazite, U and Th may become fractionated as U is typically more mobile. This could generate U-Th-Pb variations between altered and unaltered basement lithologies.

This research aims to provide some insight into the U-Th-Pb isotopic system of the basement lithologies beneath the Athabasca Basin, especially since many researchers have used anomalous radiogenic lead ratios to detect proximity to uranium mineralization. A suite of fresh to strongly altered graphitic pelitic gneisses and granitic pegmatites selected from the Dawn Lake region (12.9 Mlbs @ 1.69% U_3O_8) were analyzed by HR-ICPMS and MC-ICPMS to determine U-Th-Pb bulk chemistry isotopic ratios. Preliminary geochemical analysis of graphitic pelitic gneiss and granitic pegmatitic samples exhibit elevated Th/U ratios up to 18.5 from a wide range of U (2 to 177) and Th (2 to 114) concentrations, accompanied by anomalous $^{206}Pb/^{204}Pb$ ratios as high as 200. Elevated Th/U ratios and anomalous radiogenic Pb may indicate the presence of U-depleted Th-bearing minerals and that U bearing fluids may have flowed through the basement rocks.

STONEHAMMER GEOPARK; BUILDING ON 'A BILLION YEARS OF STORIES'

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Stonehammer Geopark, established in 2010 as North America's first member of the Global Geoparks Network, tells a story of Earth history by linking together existing parks under a common brand. Stonehammer promotes itself as 'A Billion Years of Stories' linking the science of geology with the stories of people. Stonehammer is about more than rocks, it is about making a meaningful connection between people and the Earth in interesting and engaging ways.

Stonehammer has a complex geology exposed along rugged ocean and river shorelines, on sparsely vegetated landscapes, and on roadways. The scenic landscape has resulted in a rich mosaic of parks scattered through the region, depending on geology for their beauty, but with little interpretation of the rocks. The geopark incorporates more than sixty significant geological and fossil locales, including more than fifteen publicly accessible sites across 2500 square kilometers. Each place brings a unique geological story, along with its own management, scientific, tourism or recreation focus, creating a varied geopark. The public face of Stonehammer Geopark includes two provincial parks, seven municipal parks, a proposed fossil interpretation centre, and a museum. Dozens of other outcrops on public lands display many geological features, including significant fossil sites, from more than 100 formal geological formations and igneous suites.

Using existing parks allows Stonehammer Geopark to make use of built infrastructure with minimal cost required to add layers of geological interpretation. Potential visitors to a geopark are already travelling to these sites, including many of the 200,000 annual visitors from cruise ships.

From Precambrian stromatolites to Neogene brittlestars; island arc volcanics to an ancient rift valley, the geopark has a range of stories to fit almost any geologic process. The region's long history of geologic exploration, palaeontology and mining, much of it conducted by local geologists, is a key feature of our interpretive program. Studying the Earth is as much a part of the community's history as shipbuilding, fishing, lumbering and commerce.

RARE METAL EXPLORATION IN BRITISH COLUMBIA – A FOCUS ON CARBONATITES AND ASSOCIATED ALKALINE

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In British Columbia a variety of geological settings are being explored for rare metals, many of which are related to alkaline rocks. These alkaline intrusions are associated with a continental-scale valley called the Rocky Mountain Trench that follows a long-lived, transcurrent fault system. This zone is informally known as the Rocky Mountain Rare Metal Belt.

A staking rush between 2008 and 2010 resulted in dozens of rare metal projects in this belt, most of which were based on information that had been available since the late 1980's. These projects were fueled by the success of Commerce Resources' Blue River tantalum-niobium project and reports of significant rare earth element (REE) mineralization at Spectrum Mining Corp.'s Wicheeda project, amongst others. In this context some companies tried to improve their exploration strategies and deepen their understanding of the belt and its mineralization by establishing joint ventures between industry and academia. This study reports on several elements of such a joint venture and will discuss the initial goal, the applied strategy and methodology, and what has been achieved in the two years since the project was initiated.

The first step of an exploration program is often to select general target areas by evaluating easily accessible regional databases (e.g., Regional Geochemical Survey stream sediment databases). Once a number of targets have been selected, follow-up work will include field programs and/or airborne geophysics to narrow down prospective areas. These areas will then become the focus of intensified field work, which may include mineralogical investigations in order to evaluate the feasibility of processing, and drilling at a more advanced stage. However, our deeper understanding of the many possible types of deposits is founded on the combined results of field work and scientific studies, which try to unravel the processes that lead to the formation of a deposit and in doing so making it comparable to similar deposits. This research covers the various aspects of mineralization types and also links the distribution of different deposits to geological times and settings and will ultimately enhance exploration efforts on local and regional scales.

The results of our study link carbonatitic and alkaline magmatism in the Canadian Cordillera to three distinct magmatic events, but only one is of economic interest to date. These results have implications for exploration efforts on a regional scale, whereas geological field work and mineralogical studies were able to identify promising areas on a local scale.

VOLCANIC STRATIGRAPHY AND SETTING OF THE HOOD VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, NUNAVUT, CANADA

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The Slave Province, Nunavut, contains numerous undeveloped and underexplored volcanogenic massive sulfide (VMS) deposits. The Hood deposit of the Hanikahimajuk Lake area, Nunavut (total resource of all lenses - 3.8 Mt @ 2.6% Cu and 3.8% Zn), located 425 km north of Yellowknife, NWT, remains poorly understood, in spite of intermittent exploration for the past 40 years. The Hood deposit consists of a cluster of lenses over a ~10 km^2 area hosted by the late Archean Amooga Booga volcanic belt. Re-logging of drill core has resulted in new stratigraphic reconstructions for the different lenses of the deposit, including the H10, H41 and H41A lenses. Mineralization is hosted in a bimodal volcanic sequence composed of basaltic and rhyolitic tuffs and flows. Basaltic and diorite dykes cross-cut the volcanic rocks. The volcanic and intrusive rocks are regionally metamorphosed to greenschist grade. Younger (~2.58 Ga) pink granitoids have intruded all the above rocks and are associated with quartz-K-feldspar alteration. There are variations in the lithofacies, host rocks, and structural setting in each lens. The H10 lens is hosted in steeply-dipping isoclinally folded sequence dominated by felsic volcanic flows. Stratigraphy of the H41 deposits lies at a near vertical angle and mineralized horizons occur near the contact of mafic and felsic volcanic flows. The H41A deposit is dominated by steeply dipping mafic volcanic rocks including abundant mafic to intermediate tuffs. Volcanogenic massive sulfide-related alteration includes chlorite-quartz and sericite-quartz alteration that is strong in the immediate footwall of the various lenses and extends into the hanging wall. Mineralization in the lenses consists of massive and semi-massive pyrite-pyrrhotite-sphalerite-chalcopyrite and minor zones of stringer sulfides. Abundant clasts within the ore and abundant hanging wall alteration are consistent with formation via subseafloor replacement.

TRACING FLUID-FLOW THROUGH SPACE AND TIME: EPIGENETIC MINERALIZATION IN THE REDSTONE COPPERBELT

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The Redstone Copperbelt spans an arcuate zone of approximately 300 km × 15 km within the Mackenzie Mountains, NWT, Canada. Neoproterozoic strata that host copper mineralization are part of a fold and thrust belt within the easternmost limit of deformation of the northern Cordillera. The Coates Lake deposit, the largest discovered deposit of the copperbelt, contains a NI-43-101 compliant historical inferred resource of 33.6 Mt @ 3.92% Cu, 9 g/t Ag. The Redstone Copperbelt has many similarities to the sedimentary rock-hosted copper deposits of the African Copperbelt or the European Kupferschiefer "red-bed" deposits. We set out to test the hypothesis that copper mineralization is early diagenetic by studying the spatial and temporal aspects of fluid-flow.

Stratiform, disseminated chalcocite-bornite-chalcopyrite and copper-bearing vein style mineralization occur in the Transition Zone between the Redstone River Formation and the overlying Coppercap Formation.

Sulphide mineral assemblage zones are symmetric above and below mineralized beds, indicating flow along rather than across ore horizons. Fluid-flow relating to copper mineralization is controlled laterally by more permeable lithologies and vertically by structures, including syn-sedimentary faults and reverse faults. A weak foliation is developed within ore zones and within the Redstone River Formation, likely related to Cretaceous fold-thrust deformation across the Cordillera. This foliation controls the orientation of copper sulphides and the presence of sulphides in strain shadows indicates growth of some sulphides during deformation.

Element mapping of monazites in mineralized Transition Zone rocks reveals texturally and chemically distinct Th-rich, core and Th-U-poor, rim domains. Electron microprobe U-Th-(Pb) dating of monazite rims and cores show that cores are detrital (>1023 ± 15 Ma) and rims are authigenic (557-711 ± ~41 Ma). Euhedral rim-overgrowths on rounded, detrital monazites share grain boundaries with irregular, intergranular masses of copper sulphides. The growth of monazite rims records a fluid event, which may relate to copper mineralization, occurring significantly after the deposition and burial of the host rocks. Transition Zone-hosted copper mineralization is epigenetic and it originated from low-temperature hydrothermal or late-diagenetic processes. There are other styles of copper mineralization present in the Redstone Copperbelt that are hosted at younger stratigraphical intervals and encompass significant regional unconformities. It is possible that a single, epigenetic fluid event is responsible for copper mineralization across the copperbelt or mineralization may be episodic in nature. The region has a prolonged history of basin-development, fluid-flow and tectonism that has resulted in the generation of significant amounts of copper mineralization.

CHARACTERIZATION OF THE GOLD MINERALIZING FLUIDS AT THE VIKING PROPERTY, WHITE BAY, NEWFOUNDLAND

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The Viking Gold Property is a Silurian-Devonian epigenetic gold system that has many geologic features in common with mesothermal gold deposits. Located approximately 10 km southeast of Pollards Point, White Bay, it is the most recently discovered gold prospect in the region and has been intensely explored over the past four years. Mineralization consists of coarse (up to 50 µm) blebby gold and argentiferous electrum grains within quartz veinlets and as inclusions in associated sulphide minerals (pyrite, galena, sphalerite, and chalcopyrite). Arsenic concentrations are low (< 100 ppm) and arsenopyrite is absent.

There are a number of gold prospects in the White Bay area of western Newfoundland proximal to the Doucer's Valley Fault System (DVFS). The DVFS is a prominent north-east trending structural lineament which juxtaposes Cambrian to Ordovician clastic and carbonate rocks of the Labrador Group unconformably upon Neoproterozoic granitoid rocks. The Viking vein systems appear to fill secondary splays and dilational zones associated with movement along the DVFS. These secondary structures likely acted as favourable environments for the passage of Au-enriched fluids in a series of hydrothermal pulses over a ca. 150 Ma interval of protracted sinistral strike-slip movement.

This study aims to document the nature and composition of the fluids responsible for precipitating the structurally controlled gold mineralization within the ca. 1030 Ma Main River Pluton. Fluid inclusion data indicate that the ore-forming fluids were aqueous-carbonic H_2O-CO_2 with low to medium salinities (< 10 wt% NaCl equivalent). T_{Homo} indicate that the gold and sulphide-bearing quartz±calcite veinlets precipitated at 240-350°C under pressures of 1200 to 3300 bars; such pressures correspond to depths between 4.3 and 11.1 km under lithostatic load. Sulphur isotope ratios for pyrite chalcopyrite fall within the 0 to +9‰ range characteristic of mesothermal deposits; however, $\delta^{34}S$ for galena were typically higher than this range. Characterization of the orogenic fluids responsible for the precipitation of gold mineralization at the Viking Property will enable local and regional correlation of similar deposits within the Appalachians.

SPATIAL ANALYSIS OF SPECIES DISTRIBUTIONS FROM MISTAKEN POINT, NEWFOUNDLAND

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Bedding-plane assemblages of Ediacaran fossils at Mistaken Point, Newfoundland (565 Ma), are the oldest known examples of *in-situ* macroscopic communities. The constituent organisms have few similarities with living forms, making their ecology difficult to assess. To investigate the ecology of these early communities, I analysed the spatial distributions of the fossils on two of the key bedding surfaces, known as D and E.

Differentiated GPS was used to map out the position of 4360 fossils on 110m^2 of bedding surfaces D and E, creating high resolution 3D data sets of these two distinct 'communities'. The resulting data sets were analysed using two statistical approaches: 1) Bayesian network inference to find the key interactions within the ecosystem and 2) pair correlation functions to identify the ecological processes behind these interactions.

This work builds on previous work by Clapham *et al* (2003) in three different ways. First, Bayesian network inference finds the underlying ecological network using species abundances. Second, Bayesian analysis only identifies primary relationships, so that each interaction found corresponds to an underlying ecological process. Third, using pair correlation functions it is possible to determine the distribution of the interactions over a large spatial scale allowing the identification of ecological process. By contrast, nearest neighbour analysis, performed by Clapham *et al*, is limited to the largest distance between two species, which is typically much smaller than the area studied.

The Bayesian analyses indicate that the fossil assemblage on E surface had a complex web of species interactions, with all but one species (Thectardis) interacting with at least one other, whereas the assemblage on D showed no interactions. The higher density of species on E resulted in density dependant interactions between species.

From our analysis of E surface, we were able to conclude Fractofusus and Primocandelabrum form clusters of 30cm radius that are distributed over 1m apart. This spatial pattern is interpreted as deriving from facilitation between species at small scales and competition at large scales. A double clustering of Ivesheadia and Fractofusus at both small (<20cm) and large scales is interpreted as Fractofusus feeding on DOC produced by the decay of the taphomorph Ivesheadia. The segregation of Charnia from lobate discs across all spatial scales indicates an environmental variable that affects each species in opposite ways. The small scale (<50cm) clustering of Charniodiscus and Primocandelabrum was apparently due to both species having similar requirements for establishment.

TEXTURAL EVIDENCE FOR MELT AT THE NANO-SCALE: TRANSMISSION ELECTRON MICROSCOPY OF POLY-ANATECTIC, META-PELITIC CONTACT AUREOLES, NORTHERN LABRADOR

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Rocks from the Tasiuyak paragneiss, near Nain, Labrador, are unusual in having reached granulite facies conditions twice: once during the Torngat Orogeny regional metamorphism at ca. 1.8 Ga and again at ca. 1.3 Ga during contact metamorphism, associated with multiple hot, dry intrusions of the Nain Plutonic Suite. Regional metamorphism (9.4 kbar, 820°C) induced biotite dehydration melting, during which some melt was lost. As inferred from microstructural evidence, contact metamorphism caused a second episode of partial melting. The assemblages associated with contact metamorphism (3.5-5.5 kbar, >900°C) are controlled by the distribution of the regional metamorphic assemblages on the scale of a single thin section and consist of Crd-Ksp-Pl-Opx-Qtz-Bt-Ilm. Former partial melt films from

the contact-related melting event are preserved locally. Many of the textural domains in the contact metamorphic assemblages are interpreted to be melt-related; however, the distribution of formal partial melt films do not account for the melt connectivity required to produce the multitude of melt-related textures observed throughout the rock.

Transmission electron microscopy (TEM), electron diffraction and energy dispersive X-ray spectroscopy studies of melt-related micro-structures place constraints on the degree of partial melting and melt connectivity during contact metamorphism, by evaluating evidence for the presence of melt along grain boundaries in different textural settings.

Direct evidence for former melt occurs as microstructures located on the boundary between a K-feldspar grain remnant from the regional metamorphism and a pocket of plagioclase-quartz symplectite, believed to have crystallized from melt. TEM imaging revealed a row of spherical 'bubbles' of K-feldspar, approximately 100nm diameter, which are interpreted to have nucleated on the regional K-feldspar grains. Furthermore these 'bubbles' and the entire grain boundary are coated with a film of K-feldspar, approximately 30nm in thickness. At the grain boundary, both the thin film of K-feldspar and the adjacent quartz grain extend into micro-fractures of the regional K-feldspar grain. Thin plagioclase films and/or nano-granitic grain clusters are observed along grain boundaries between regional K-feldspar grains and cordierite-quartz symplectites. Feldspar grains within the nano-granitic grain clusters are euhedral and locally twinned.

Nano-scale evidence for melt along grain boundaries, documented by TEM imaging, supports a higher degree of melt connectivity than that supported by the distribution of former partial melt films and confirms the involvement of melt in the formation of many textural domains in these rocks.

TESTING KENORLAND: EARLY PALEOPROTEROZOIC APPARENT POLAR WANDER COMPARISON OF SLAVE AND SUPERIOR CRATONS

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Is the early Paleoproterozoic Era characterized by a sprawling Kenorland supercontinent or separate, though large, supercratons? Paleomagnetism can quantitatively test the null hypothesis of a single large Kenorland: one unified apparent polar wander (APW) reference frame that juxtaposes cratons when accordingly reconstructed. One caveat, true polar wander (TPW), would also yield unified APW but cratons would not necessarily juxtapose when reconstructed to their relative positions. Recently, a new paleomagnetic pole for the 2193 Ma Dogrib dykes of Slave craton developed an APW path for Slave craton, establishing that Slave and Superior cratons reconstructed far from each other before 2 Ga (Mitchell *et al.*, 2012). We present a new virtual geomagnetic pole and U-Pb age (baddeleyite) of 2505 Ma for the Pensive Lake sheet of southern Slave craton, tentatively extending the Slave APW path back into Archean time. We find that from 2.5-2.0 Ga Slave and Superior craton experienced nearly identical APW, advancing the presence of either Kenorland or TPW in Paleoproterozoic time. At face value, the large arc distance (>60˚) between Slave and Superior cratons challenges the notion of Kenorland and would appear more consistent with the multiple supercratons hypothesis, suggesting that TPW may explain the unified APW. Both hypotheses, Kenorland or TPW, are imminently testable by developing early Paleoproterozoic APW paths for other key cratons.

PLATE TECTONICS BEFORE 2 Ga: EVIDENCE FROM PALEOMAGNETISM

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Laurentia, the core of Paleo-Mesoproterozoic supercontinent Nuna, has remained largely intact since assembly 2.0-1.8 billion years ago [Ga]. For earlier times, previous paleomagnetic data on poorly dated Paleoproterozoic mafic intrusions yielded ambiguous estimates on the amount of separation between key cratons such as the Slave and Superior. Recent developments in paleomagnetism and U-Pb on baddeleyite geochronology, including new results reported herein, yield sufficiently precise data to generate fragmental apparent polar wander (APW) paths for both Slave and Superior cratons from 2.2-2.0 Ga. Our new APW comparison confirms earlier speculations that processes similar to plate tectonics, with hallmark independent relative motions between internally rigid lithospheric blocks, were operative before the final assembly supercontinent Nuna.

AN ECLOGITE-BEARING FOLD STRUCTURE IN THE SVECONORWEGIAN OROGEN, SCANDINAVIA

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Occurrences of Sveconorwegian eclogite within the parautocthonous belt (Eastern Segment) are structurally bound by a major recumbent isoclinal fold structure, which is exposed for 60 km in the present N-S-direction and > 20 km in the present E-W direction. We interpret the structure as a non-cylindrical, east-plunging nappe with a fold nose located below the present exposure. The structure formed during east-directed translation.

Variably retrogressed eclogite occurs as tectonic lenses within the fold structure. The central and northern parts of the structure are dominated by stromatic migmatite gneiss with amphibolitized retroeclogite, whereas the southernmost part hosts remnants of kyanite eclogite in granulite and amphibolite facies mylonitic gneiss. 986±4 Ma and 983±6 Ma metamorphic zircon from eclogite in northern areas are in agreement with previous results from the southern area. Migmatization of host gneisses at 972±8 Ma was associated with amphibolitization, confirming previous data from southern areas.

Various gneiss units with mafic rocks outside the fold structure lack signs of eclogite metamorphism but were metamorphosed under high-intermediate pressure granulite and upper amphibolite facies conditions. Moreover, a pinch-and-swell shaped, heterogeneously deformed augen gneiss forms a tectonostratigraphic marker unit enclosing the southern and eastern margins of the eclogite-bearing domain. This boundary thus appears to represent a significant tectonic and metamorphic break.

The southern Eastern Segment, including the eclogite-bearing domain, underwent near-pervasive metamorphic recrystallisation under high-intermediate pressure granulite and upper amphibolite facies conditions and simultaneous heterogeneous formation (D_2). This deformation involved tight to isoclinal folding of the (S_1) layering, shearing along fold limbs, and pronounced stretching in the E-W direction. It produced isolated fold hinges enclosed by strongly strained zones on different scales up to a few km. Asymmetric augen and porphyroclasts indicate top-to-the-east and dextral movement.

The partial preservation of early eclogite assemblages within the fold structure demonstrates 1) the existence of different tectonometamorphic units in the deepest part of the Sveconorwegian Orogen, and 2) that it is possible to identify different tectonic units despite reworking under high metamorphic temperatures.

PALEOTECTONIC SETTING AND STRATIGRAPHY OF LOWER PERMIAN BASALTS WITHIN THE SVERDRUP BASIN, ARCTIC CANADA

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The Esayoo Formation consists of altered Lower Permian basalts that outcrop on northwest Ellesmere Island and northeast Axel Heiberg, within the Sverdrup Basin, Arctic Canada. Rifting in the Sverdrup Basin initiated in the Early Carboniferous and ceased during the Early Permian. Despite the extensional nature of the basin, geographically widespread sub-Middle Permian angular unconformities and extensive, yet local uplift and folding occurred during the Early Permian, prior to Middle Permian deposition. This suggests that compressional tectonics existed within the Sverdrup Basin during the Early Permian; however, previous geochemical work on the Esayoo Formation characterized these volcanics as being sourced from an extensional tectonic regime. During the 2011 July field season, ten stratigraphic sections of the Esayoo Formation were measured at four locations on northwest Ellesmere Island: Borup Fiord Pass, Oobloyah Bay, Ricker Glacier and Mount Leith. The Esayoo Formation reaches a maximum thickness of 450 m near Oobloyah Bay, and thins west, east and north of Oobloyah Bay with respective thicknesses of 140 m, 69 m and 75 m. Field work at Oobloyah Bay showed that two stratigraphic levels of the Esayoo Formation exist. The existence of two levels of the volcanic rocks, as well as the structural evidence for compressional tectonics during this time, suggests the Esayoo Formation may be related to the periods of tectonic quiescence between compressional tectonic episodes. The lower Esayoo unit is bounded below by the predominantly carbonate-rich Great Bear Cape Formation and above by sandstones of the Sabine Bay and Assistance formations, whereas the upper Esayoo unit lies above the Assistance Formation. Both the upper and lower Esayoo units are overlain by thin 1 to 2 m shales that indicate maximum flooding surfaces, which suggest contemporaneous high rates of accommodation space generation within the basin. Further work on the geochemistry of the Esayoo Volcanics will help piece together why intraplate volcanism was occurring between periods of compressional tectonics when the main phase of rifting had ceased. During the Early Cretaceous, the Sverdrup Basin underwent renewed rifting and extensional tectonic regimes once again became dominant. Evidence for this rifting consists of an extensive system of cross-cutting Cretaceous sills and dykes that regionally occur throughout the basin and a Large Igneous Province (LIP) on northern Ellesmere Island.

DEEP WATER GEOHAZARDS AND CONSTRAINTS TO DEVELOPMENT ALONG THE LABRADOR MARGIN

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In support of recent renewed interest in hydrocarbon exploration along the Labrador continental margin, its deepwater region was investigated to document geohazards and processes that may constrain hydrocarbon exploration and development. Between 2005 and 2011, ~7000 km^2 of EM300 swath bathymetric data were acquired in water depths from 500 to 2500 m. Additional geophysical and geological surveys were conducted in 2005, 2006, 2008 and 2010. Legacy public and industry seismic data were interpreted in this context as well. The resulting reconnaissance-level assessment provides a regional geological context to assess the nature, distribution and severity of seafloor conditions and seabed and subseabed instabilities.

The Labrador Sea is dynamic for both oceanographic and sedimentologic reasons. In addition to its relatively young age, subsidence and sedimentation history, it was also only recently (i.e. < 10000 years ago) deglaciated. The seabed along the Labrador slope is broadly divided into trough mouth and submarine fans, canyon incision, mass transport deposition, inter-canyon areas that include levees and sediment drift deposits, and detached sediment drifts or spurs. Transverse troughs ("saddles") on the Labrador Shelf were conduits for ice streams during glaciation and the sites of major sediment input to the basin. Erosional gullies and valleys on the upper slope coalesce downslope to create a heavily incised margin, locally resulting in coarse-grained sediment at or near the seafloor in the valleys. Slope angles reach up to 7° along the uppermost slope, particularly off of Hopedale Saddle. Similar to the southern Canadian margin, mass transport deposits form a significant proportion of the Quaternary sedimentary succession. Ice-rafted debris is common in shallow piston core studies. Shallow gas and gas hydrate bottom-simulating reflections are recognized within slope deposits. Strong bottom currents due to the Labrador Current and Western Boundary Undercurrent rework sediment at almost all water depths, generating sediment wave and drift deposits. Variable foundation/drilling conditions, boulder beds, sediment transport events, shallow gas, gas hydrates and slope instability are, therefore, all issues of exploration concern along the Labrador continental deep water margin.

Nd ISOTOPE MAPPING OF CRUSTAL SUTURES BETWEEN ACCRETED TERRANES OF DIFFERENT AGES WITHIN THE DEEPLY EXHUMED CORE OF THE GRENVILLE OROGEN IN LABRADOR

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The geological makeup of the eastern Grenville Province is the product of Makkovikian (1860-1790 Ma), Labradorian (1710-1600 Ma), Pinwarian (1520-1460 Ma) and Grenvillian (1085-985 Ma) orogenesis, plus intervening events not obviously related to orogenic activity. Much of the crust in this region has been dated to be Labradorian or Pinwarian, whereas, its present structural configuration was largely achieved by major translational movement of crustal terranes during the Grenville orogeny.

U-Pb geochronological investigations in the eastern Grenville Province have been summarized by Gower and Krogh (2002). This work established a framework for the timing of major crust forming events in the region. However, the time of separation of crustal material from the mantle and the spatial extents now represented by various mantle-separation events are much less well known. In other words, a map that represents the time of original separation of crustal material from the mantle is lacking.

Formation-age mapping of crustal terranes can be achieved by Nd isotope analysis of representative samples of the crust over a large geographical region. Previous Nd isotopic data produced crustal formation ages for the Makkovik Province (1.93-2.21 Ga), and within the eastern Grenville Province; the Groswater Bay, Hawke River, Lake Melville and Mealy Mountains terranes have overlapping ranges of TDM model ages (1.97-1.90 Ga). These overlapping mean compositions suggest that these terranes are representative of one crustal realm, probably the product of mixing between pre-Labradorian and Labradorian crustal components.

The data from the present study provide Depleted Mantle model (TDM) ages from within the Pinware terrane. In contrast to regions farther north, two discrete crustal-formation age signatures are indicated. The northern portion has Nd signatures similar to those from the Hawke River, Lake Melville and Mealy Mountains terranes, whereas the southern portion has ages indicating a juvenile Labradorian source. This data suggests that Makkovik crust extends into the northern part of the eastern Grenville Province, whereas juvenile Labradorian crust is present in southeast Labrador. The differing signatures suggest a boundary between the two crustal regions to be situated a few km north of Red Bay, and are interpreted to mean that the original edge of the Makkovik continental margin extended as far as southernmost Labrador.

NEOPROTEROZOIC-EARLY JURASSIC MAFIC MAGMATISM IN MAINLAND NOVA SCOTIA: TRACKING THE EVOLUTION OF MANTLE SOURCES

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The sub-continental lithospheric mantle (SCLM) may either underlie regions for a long period of time or may be replaced during processes such as delamination or plume magmatism. The occurrence and timing of mantle replacement may be identified by comparing the Sm-Nd isotopic signature of suites of basaltic rock within the same terrane over a range of time.

In mainland Nova Scotia, the early Jurassic North Mountain Basalt (NMB) straddles the boundary between two terranes (the Avalon and Meguma terranes) that accreted to Laurentia during the Paleozoic. NMB is widely recognized as the northernmost representative of the Central Atlantic Magmatic Province (CAMP) but Sm-Nd isotopic data yield ε_{Ndt} values (t=200 Ma) ranging from +0.1 to -2.7, which are typical of derivation from the underlying Proterozoic SCLM, rather than from the CAMP plume. Comparison with older mafic magmatic events indicates that the SCLM is isotopically indistinguishable from that inferred to yield Ordovician and Devonian mafic magmas in the Meguma terrane and Neoproterozoic to Devonian mafic magmas in the Avalon terrane. These data indicate that the same SCLM underlay mainland Nova Scotia from Neoproterozoic to Jurassic times, and that Paleozoic tectonic events did not significantly detach the mantle from the overlying crust. Taken together, the Sm-Nd isotopic data for the mafic rocks form and envelope that defines the evolution of the mantle sources beneath mainland Nova Scotia. The data suggest that the mantle source was enriched between 0.8 and 1.1 Ga and has an average Sm/Nd ratio of ca. 0.24 (a value that is typical of an enriched mantle source). Neoproterozoic paleocontinental reconstructions that this mantle originated in the (Mirovoi) ocean that surrounded the supercontinent Rodinia. More generally, the study points out the additional insights gained by tracking mantle evolution in a given terrane through time.

POTENTIAL GEODYNAMIC RELATIONSHIPS BETWEEN THE DEVELOPMENT OF PERIPHERAL OROGENS ALONG THE NORTHERN MARGIN OF GONDWANA AND THE AMALGAMATION OF WEST GONDWANA

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The Neoproterozoic-Early Cambrian evolution of peri-Gondwanan terranes (e.g. Avalonia, Carolinia, Cadomia) along the northern (Amazonia, West Africa) margin of Gondwana provides insights into the amalgamation of West Gondwana. The main phase of tectonothermal activity occurred between ca. 640-540 Ma and produced voluminous arc-related igneous and sedimentary successions related to subduction beneath the northern Gondwanan margin. Subduction was not terminated by continental collision so that these terranes continued to face an open ocean into the Cambrian.

Prior to the main phase, Sm-Nd isotopic studies suggest that the basement of Avalonia, Carolinia and part of Cadomia was juvenile lithosphere generated between 0.8 and 1.1 Ga within the peri-Rodinian (Mirovoi) ocean. Vestiges of primitive 760-670 Ma arcs developed upon this lithosphere are preserved. Juvenile lithosphere generated between 0.8 and 1.1 Ga also underlies arcs formed in the Brazilide Ocean between the converging Congo/São Francisco and West Africa/Amazonia cratons (e.g. the Tocantins province of Brazil). Together, these oceanic arc assemblages with similar isotopic characteristics may reflect subduction in the Mirovoi and Brazilide oceans as a compensation for the breakup of Rodinia and the generation of the Paleopacific. Unlike the peri-Gondwanan terranes, however, arc magmatism in the Brazilide Ocean was terminated by continent-continent collisions and the resulting orogens became located within the interior of an amalgamated West Gondwana.

Accretion of juvenile peri-Gondwanan terranes to the northern Gondwanan margin occurred in a piecemeal fashion between 650 and 600 Ma, after which subduction stepped outboard to produce the relatively mature and voluminous main arc phase along the periphery of West Gondwana. This accretionary event may be a far-field response to the breakup of Rodinia. The geodynamic relationship between the closure of the Brazilide Ocean, the collision between the Congo/São Francisco and Amazonia/West Africa cratons, and the tectonic evolution of the peri-Gondwanan terranes may be broadly analogous to the Mesozoic-Cenozoic closure of the Tethys Ocean, the collision between India and Asia beginning at ca. 50 Ma, and the tectonic evolution of the western Pacific Ocean.

RISE AND FALL OF CAMBRIAN–ORDOVICIAN TRILOBITE EXTINCTION PATTERNS: FACIES PATTERNS AND ROLE OF PALEOGEOGRAPHY

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Cambrian biomeres and their associated stage boundaries display patterns of trilobite extinction and radiation that took place within Laurentia in the Late Cambrian to earliest Ordovician. Numerous hypotheses exist for these patterns, although very high-resolution stratigraphic, sedimentological and geochemical data are commonly lacking. Hypotheses include changes in oxidation potential of marine water, sea surface temperatures, and eustasy. We provide high-resolution (decimeter-scale) data from (1) strata that span the critical interval at the top of the Ptychaspid Biomere, the last of the Cambrian Biomeres, and the base of the Ibexian Series; and (2) deposits that span the base of the Lower Ordovician Stairsian Stage, which also records a biomere-like extinction. Our integrated sedimentological, biostratigraphic, and carbon-isotope chemostratigraphic analysis of these and other sections from the inner detrital belt of western North America are used to contrast depositional and paleogeographic patterns of sedimentation that evolved across the Cambrian–Ordovician boundary interval. The older event is recorded in well developed, meter-scale, deepening upward, subtidal cycles of shale and limestone that correlate across a broad area of the inner detrital belt. Deposition of shale is linked to the introduction of mud from reactivated rivers during lowstand conditions, and upward replacement by carbonate reflects reduced terrigenous input. Sub-meter-scale resolution of the biostratigraphic data establishes that the horizons of faunal change (subzonal boundaries) from within the critical interval at the top of the Ptychaspid Biomere coincide with the upper parts of the upward-deepening cycles. Although the biomere occurs within a third-order lowstand, precise biostratigraphic data indicate that each component extinction occurred during the late stages of fifth-order highstands. Thrombolitic microbial mounds, which are absent from the critical interval, reappear at the top of the Ptychaspid Biomere. In contrast, trilobite extinction patterns at the base of the Ordovician Stairsian Stage do not culminate in a nadir of diversity, but instead record rapid diversification. Such a pattern may represent the last gasp of Cambrian extinction processes, in part due to the demise of the continent-wide Cambrian paleogeographic pattern, including a well-developed inner detrital belt.

MANTLE SIGNATURES IN LATE-ARCHEAN ALKALINE MAGMATIC-HYDROTHERMAL SYSTEMS: IMPLICATION FOR GOLD SOURCES

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Field relations, trace elements and isotopic compositions as well as radiogenic isotope dating suggest that syn- to late-orogenic, 2676 to 2688 Ma old, auriferous syenites, lamprophyres (*sensus stricto*) and carbonatites of the Abitibi greenstone belt are genetically related. Chondrite-normalized

REE patterns of carbonatites, lamprophyres and syenites of the Province of Superior are very similar. La/Yb ratios for lamprophyres and carbonatites range from ~10 to 100 whereas those for coeval syenites show La/Yb ratios of ~10. Preliminary results on rocks from Duquesne Au syenite porphyry show La/Yb ratios of 10 for the syenites and 100 for the lamprophyres. A survey of isotope data in the literature reveals ε_{Nd} values that are consistent with derivation of these suites from a depleted mantle: +1 to +2 for lamprophyres, +2 to +3 for syenites and +2 to +4 for carbonatites. Initial $^{87}Sr/^{86}Sr$ values for these three types of lithologies also suggest mantle sources, with values ranging from 0.70122 to 0.70135 for the gold-bearing Lac Shortt and Dolodau carbonatites, 0.70146 for the Kamiskotia-Montcalm area lamprophyres, and 0.70106 to 0.70136 in clinopyroxenes of the Murdock Creek Complex syenites. Preliminary $^{87}Sr/^{86}Sr$ data obtained from carbonates in lamprophyres from Duquesne Au deposit show mantle-like values ranging from 0.70468 to 0.70530 but also show some carbonates with more crustal values such as 0.72641.

The literature data, along with the above preliminary results allow us to shed light on the petrogenesis of these rocks and their possible relationship to the metallogenesis of gold deposits. It is commonly accepted that carbonatites and lamprophyres are derived from the depleted mantle. Lamprophyres (*sensus stricto*) are quenched, volatile-rich, hypabyssal, mafic porphyric rocks that appear to interact very little with the crust as they rise from the mantle. Radiogenic isotope data indicate that syenites are also derived from a depleted mantle source and that they too interact very little with the crust as they evolve. We thus propose that the syenites were produced by fractional crystallization of lamprophyre-carbonatite magmas in the crust. This would also provide physical pathways for magmatic-hydrothermal activity from the mantle to shallow level porphyries during the late Archean. In this model, gold could have been carried from the mantle to its site of deposition in shallow level syenitic porphyries via a mantle-derived, carbothermal fluid. This model also finds support in the presence of carbonic-fluid-saturated, hybrid silicocarbonatites of Lac Shortt, Abitibi.

CESSATION OF ARC-NORMAL MID-CRUST EXTRUSION AND ONSET OF ARC-PARALLEL OROGENIC EXTENSION IN FAR NW NEPAL HIMALAYA

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The Grenville system is argued to be a deeply-exhumed equivalent of the Himalayan orogen. Both orogens can be subdivided into two distinct evolutionary phases: (1) significant crustal thickening leading to the growth of an orogenic plateau, followed by extrusion of mid-crustal material, and (2) cessation of arc-normal mid-crustal flow marked by the onset of extensional faulting. Locating areas that record the transition between these two phases can be problematic in all orogens, particularly those deeply exhumed, such as the Grenville.

Field mapping, structural and microstructural analysis, geochronology, and thermochronology confirm the existence of the Gurla-Mandhata-Humla fault, an orogen-oblique strike-slip dominated fault in the High Himalaya of northwestern Nepal. Detailed across-strike transects reveal shallow-dipping mylonitic foliations and intense shallow plunging mineral stretching lineations consistent with orogen-parallel deformation. Furthermore, this fault system overprints the exhumed metamorphic and anatectic core of the Himalaya and its upper bounding fault, thus documenting the transition from arc-normal directed extrusion of mid-crustal material to orogenic extension.

This transitionary shear zone is characterized at upper structural levels by well-developed type-1 cross-girdle quartz c-axis fabrics and symmetric a-axis fabrics, indicating plane strain conditions. C-axis fabrics transition to type-2 cross girdles at ~ 1.2 km below the fault, suggesting an ostensible contribution of constrictional strain at depth. Quartz c-axis opening angles and quartz and feldspar recrystallization mechanisms show a progressive increase in deformation temperatures from ~ 350°C along the zone of maximum strain, to upwards of ~ 630°C at depths greater than ~ 5.5 km below the fault. Abundant asymmetrical fabric elements and conjugate shear bands in conjunction with a calculated mean kinematic vorticity number of 0.60 (c. 58% pure shear) attest to an important contribution of pure shear. U-Th-Pb in situ monazite geochronology, U-Pb whole rock zircon geochronology and $^{40}Ar/^{39}Ar$ muscovite thermochronology reveal rapid crystallization, decompression melting, and cooling within $\leq$ 7 Myr. This cooling is interpreted to represent the cessation of orogen-normal mid-crustal extrusion and the onset of orogen-parallel upper-crustal extension.

These observations suggest this tectonic transition occurs over a geologically short time period and is characterized by important contributions of coaxial strain, invoking the following question: Can the same tectonic processes that govern this transition be applied to the Grenville and what, if at all, will these structures look like in the deeply exhumed Grenville orogen?

CONTRIBUTIONS OF AVALONIAN NEWFOUNDLAND TO OUR GLOBAL UNDERSTANDING OF THE EDIACARAN PERIOD

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The first Ediacara-type megafossil named anywhere in the world was Billings (1872) description of Aspidella terranovica from Duckworth Street in downtown St. John's. This was a bold move - Billings recognized that Aspidella was nonmineralized, that it occurred in extraordinary abundance in undoubted pre-Cambrian strata, and that it did not resemble any described Phanerozoic fossils. However many of Billings' contemporaries were less receptive to the concept of Precambrian megascopic life, and Aspidella lapsed in obscurity as a "pseudofossil" for more than a century until it was resurrected in 2000 as probably representing the base of an Ediacaran frond. The discovery of even older fossils at Mistaken Point during thesis research at Memorial University of Newfoundland was at first even more contentious, but we now recognize the Mistaken Point biota as the oldest representatives of the Ediacara biota and among the oldest large and complex eukaryotes known anywhere. Subsequent studies have shown that the Mistaken Point fossils first appear immediately above the highest Proterozoic glacial deposits (Gaskiers Tillite) and coincident with evidence for a massive oxidation of the deep-sea, providing a causal mechanism for "when life got big" after 3 billion years of mostly microbial evolution. Most of the Mistaken Point fossils were rangeomorphs, an extinct clade of fractal organisms whose affinities remain delightfully controversial, and who formed tiered communities strikingly like those of modern suspension-feeding animals to extract nutrients from the seawater. The end of the Ediacaran is formally defined at the GSSP at Fortune Head on the Burin Peninsula, and is marked by an increase in complex burrowing and predatory strategies that signalled the end of the Ediacaran and the beginning of our Phanerozoic world.

THE "BRITISH COLUMBIA CALEDONIDES": MID-PALEOZOIC OROGENY IN THE SOUTHERN ALEXANDER TERRANE

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The Alexander terrane (AT) in southeastern Alaska is a Neoproterozoic–Early Devonian primitive arc terrane with faunal and geochronological affinities to western Baltica / Polar Urals. Permian faunas place it in the northern Pacific, and it was accreted to the western Cordillera by the mid-Jurassic. Bedrock mapping and geochronology in the lesser-known AT of coastal NW British Columbia provide constraints on its mid-Paleozoic tectonics. The lowest stratigraphic unit is the Cambrian-Ordovician Descon Formation (Moira Sound unit?) (ca. 460-520 Ma) – arc-related andesitic breccia, tuff, felsic volcanics, volcanogenic sediments and hypabyssal rocks. It is unconformably overlain by a Devonian clastic succession of mixed Paleozoic arc and pericratonic provenance, the Mathieson Channel unit (MCU). MCU includes lithic feldspathic sandstone, local plutonic-volcanic clast conglomerate, abundant carbonate,

basalt and minor rhyolite. Detrital zircon populations from eastern MCU near Grenville and Mathieson channels are ca 400-460 Ma, with a peak at 423 Ma, sourced primarily from Late Ordovician-Silurian plutonic rocks like those of AT in southeastern Alaska. Farther west towards and on Banks Island, detrital zircon spectra show both mid-Paleozoic peaks like eastern MCU, and a set of peaks between 2.0 to 1.0 Ga, including populations in the NAMG. Rare quartzite-clast conglomerates contain exclusively Precambrian signatures. MCU was derived from two source terranes: mid-Paleozoic AT arc granitoids to the east, and a pericratonic (Baltican?) source to the west (present coordinates).

The Ogden Channel plutonic-metamorphic complex occurs as a fault-bounded panel on Porcher Island, near the western limit of typical Alexander stratified rocks, and east of the pericratonic Banks Island outcrop belt. Evidence for Early Devonian tectonism is shown by epidote amphibolite-facies metamorphism and synplutonic ductile deformation affecting both Descon-age strata and plutonic bodies as young as ca 413 Ma, cut by post-tectonic tonalite (ca. 410 Ma). Synmagmatic shear zones preserve evidence for sinistral and/or oblique sinis tral-reverse motion. It may represent a mid-Paleozoic accretionary boundary between the AT and a pericratonic fragment, while MCU represents the associated clastic overlap. In southeastern Alaska, this Late Silurian-Early Devonian event is termed the Klakas orogeny. Observed features of the Klakas orogeny in NW BC - widespread shallow-water clastic-carbonate deposits of the MCU, restricted occurrence of coeval ductilely-deformed plutonic rocks, and sinistral strain indicators – highlight the significance of oblique motions. This mechanism is consistent with evidence for Silurian-Devonian sinistal transport of terranes of the northernmost Caledonides (e.g. Pearya) westward towards the Pacific realm.

TAPHONOMY AND EARLY DIAGENESIS OF ANCIENT DEEP-WATER SPONGE MOUNDS

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Important components of the rock fabric of ancient deep-water sponge mounds are: a) calcified siliceous sponges, b) a secondary cavity system, c) various generations of infiltrated carbonate mud, d) crusts of marine cement, e) molds of bio-opaline silica, and f) replacive silica that ranges from microsopic traces to macroscopic chert.

Calcification of siliceous sponges (lithistid and non-lithistid demosponges, hexactinellids), although still poorly understood, relates to the degradation of sponge connective tissue that serves as a non-living organic substrate for the precipitation of microcrystalline carbonate. This kind of organomineralisation results in net-accretion and patchy consolidation. The degree of connective tissue calcification varies from complete, thus preserving spicular architecture and canal system, to incomplete, hence leading to mechanical collapse in association with the formation of a secondary (stromatacid) cavity system. Ongoing sedimentation and benthic sediment cycling results in a highly structured succession of infiltrated carbonate mud. Late stages of sediment infiltration co-occurs with initial marine cement formation. The mechanisms and controls of marine cementation in such deep-water, low-energy environments are underexplored. The conventional view of an actively circulating shallow marine-phreatic environment does not match instead internal waves and/or advective fluid flow should be considered. Dissolution of sponge spicules, an opaline-proteic composite, co-occurs with early stages of marine cement formation. Pore-water dissolved silica might be held in place if stagnant conditions prevail, which is usually the case for the conditions of a condensed section (transgressive systems tract). By contrast, pore-water dissolved silica might be rapidly lost if the mound deposits are succeeded by a shallowing- and coarsening-upward sequence (highstand systems tract, diffusion + advective flux). Silica flocculation depends on acidification of pore-waters (sulfide oxidation) and the availability of Mg-bearing carbonate substrates and might result in important substrate-selective chertification. The time scale between sponge taphonomy and silicification is on the order of several tens to hundreds of thousands of years.

GEOGRAPHIC AND ENVIRONMENTAL VARIATION IN GORGONIAN CORAL SKELETAL GROWTH RATES

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Gorgonian corals are widely distributed colonial marine organisms whose growth forms and rates vary according to intrinsic and/or environmental factors. They can have three types of skeleton: proteinaceous (gorgonin), calcareous, and mixed; which have been used to assess their growth rates. To examine which factors seem to be related to growth in these organisms we compared published linear and radial growth rates among gorgonian taxa, skeleton types, and along environmental gradients using environmental data from the World Ocean Database. We analyzed growth rates in 16 genera from the families: Acanthogorgiidae, Briareiidae, Coraliidae, Isididae, Paragorgiidae, Plexauridae and Primnoidae in relation to latitude, temperature, depth, salinity, nitrate and phosphate concentrations in the depth ranges from which corals were collected. Growth rates were significantly different among skeletal types. Linear growth rates differed significantly among cold-water gorgonian families and genera, but radial growth rates did not. Tropical gorgonians had significantly higher growth rates than cold-water species. The analysis between all samples and environmental variables showed negative correlations with depth, phosphate and silicate concentrations (radial growth), latitude (linear growth), and a positive correlation with salinity (linear growth). Using data from cold-water gorgonians only in relation to environmental variables we found a positive correlation between radial growth and phosphate, and a negative correlation with depth. Tropical gorgonians linear growth rates were negatively correlated with phosphate and nitrate concentrations. The negative correlations with phosphate and nitrate with growth rates in tropical gorgonians reflects the reliance of these dominantly zooxanthellate animals on photosynthesis by their algal symbionts. Conversely, the positive correlation between cold-water gorgonian growth rates and phosphate concentrations reflects the relationship between phosphate concentrations and particulate organic matter (POM), the main food source for cold-water gorgonians. Production of gorgonin depends directly on food supply, and gorgonian calcification requires metabolic energy, as does calcification in cold-water scleractinians. Similarly, the negative correlation between cold-water gorgonian growth and depth probably reflects decreasing food availability in deeper waters. Examining the influence of current strength in particular could represent a potential source of information on the role of environmental variables in gorgonian growth, considering that it plays an important role in the delivery of food and in the mechanical stress experienced by their skeletons through their lives.

IMPLICATIONS OF AND OBSERVATIONS FROM THE POST-MINERALIZATION WEATHERING, DENUDATION, AND BURIAL OF CARLIN-TYPE AU-MINERALIZATION

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The economic viability of shallow depth mineral deposits is strongly affected by their post-mineralization history. Important influences include exhumation to near surface depths, weathering/oxidation, erosion/ resedimentation, and/or burial. The complex tectonic history at Cortez Hills (Battle Mountain-Eureka gold trend, NE Nevada, USA) presents a unique opportunity to study the results of each of the aforementioned processes, which have together produced a world-class ore body. The Cortez Hills deposit is located in the hanging wall of NNW striking Cortez Hills fault and footwall to the NE striking Crescent Valley fault, which is associated with Basin and Range faulting. This work lends itself to a larger integrated study of regional spatial and temporal tectonic evolution of the late Cenozoic Basin and Range extension.

Apatite Fission Track (AFT) and apatite (U-Th/He) (AHe) thermochronology of samples from the footwall of the Crescent Valley fault constrain the timing and magnitude of exhumation along the Cortez Range. AFT data indicates that the northern Cortez Range was largely exhumed during the mid- to Late-Cretaceous, AHe data from the southern Cortez Range indicate two additional episodes of exhumation occurred in this area. The first major began in the Oligocene and early Miocene and was associated with the formation of the proto-Cortez/Pediment basins. This event brought the Cortez Hill deposit to the surface, subjecting the ore body to supergene modification, erosion, and resedimentation into the newly formed Pediment/Cortez basins. The last significant episode of exhumation occurs around 10Ma and is associated with the onset of Basin and Range extension, and was responsible for the dissection of Oligocene and Miocene basins in the region.

By mapping stratigraphic indicators and reconstructing the evolution of the sedimentary basins we are able to document the post-mineralization supergene processes that have affected the Cortez Hill ore body. We interpret thermochronologic data and regional stratigraphic sequences to indicate that the Cortez Hills deposit was at depths no greater than 1 km from surface at ~34Ma. Carlin-type deposits in Nevada are generally considered to have formed at 42-37Ma suggesting Cortez hills formed in the near sub-surface. Oxidation and supergene modification of the deposit began prior to the Miocene as oxidized clasts of mineralized material occur in the Miocene Pediment Basin. Deep oxidation of the orebody, likely did not begin until the late Miocene, after significant relief had developed and relatively oxygenated surface water was driven down topographical gradients from the main Cortez Range into adjacent basin through the deposit.

COMPARING AURIFEROUS AND BARREN FLUID VEIN SYSTEMS AT THE 007 ZONE GOLD DEPOSIT, BISSETT, MANITOBA

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The Rice Lake Greenstone Belt (RLGB) has been producing gold for almost a century. It is the most prominent gold district in Manitoba (1.77 million oz produced). The RLGB is located approximately 230 km northeast of Winnipeg, Manitoba, within the western Uchi Subprovince of the Superior Province and is composed primarily of mafic to felsic volcanic and volcaniclastic rocks of tholeiitic and calcalkaline affinity. The 007 Zone gold deposit was discovered in 2009 and has an indicated mineral resource of 230,330 ounces of Au and inferred mineral resource of 186,980 ounces of Au (October 2010). The deposit is located within Townsite Dacite of the Bidou Assemblage (ca. 2.72-2.73 Ga) and mineralization occurs within quartz veins at the contact with the Shoreline Basalt.

The objective of this project is to compare barren and auriferous vein systems. Alteration minerals (e.g., sericite and ankerite) associated with barren and mineralized veins are similar. Mineralized and barren veins contained two generations of quartz: primary coarse grained quartz and secondary fine-grained quartz. However, mineralized veins have a higher proportion of secondary quartz relative to barren veins. Gold mineralization is generally associated with secondary quartz. Using Secondary Ion Mass Spectroscopy (SIMS), *in situ* oxygen and sulphur isotopic analysis of the two generations of quartz and pyrite were obtained from auriferous and barren samples. Primary quartz from mineralized samples gave higher $\delta^{18}O$ values (average 11.07 ± 2.90 ‰) than the barren primary quartz (average 7.74 ± 1.77 ‰). However, secondary recrystallized quartz in both barren and mineralized samples generally gave higher $\delta^{18}O$ values relative to primary quartz. $\delta^{18}O$ values of secondary quartz from barren samples are generally lower (average 9.26 ± 3.38 ‰) than secondary quartz from the auriferous veins (average 12.93 ± 2.79 ‰). Pyrite from auriferous veins has slightly higher $\delta^{34}S$ values (1.81 ± 1.02 ‰) relative to pyrite from barren veins (-1.56 ± 2.21 ‰). The sulphur isotopic composition of pyrite is consistent with a magmatic source of sulphur.

Based on petrography, the alteration mineral assemblage is related to the primary quartz and is not associated with gold mineralization. However, the higher $\delta^{18}O$ value of secondary quartz that is associated with gold suggests that the auriferous fluid had a distinct $\delta^{18}O$ value relative to barren fluids. Therefore, it is possible to distinguish between barren and auriferous systems using the $\delta^{18}O$ values of quartz and to a lesser extent the $\delta^{34}S$ values of pyrite.

OROGENIC Ni-Cu-PGE: CA-TIMS U-Pb ZIRCON GEOCHRONOLOGY OF THE GIANT MASCOT ULTRAMAFIC INTRUSION, BRITISH COLUMBIA - PRELIMINARY RESULTS

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The Giant Mascot mine (1958-1974), the only past-producer of nickel in British Columbia, is situated in the Coast Mountains approximately 20km north of Hope. The mine produced over 4Mt of ore from 22 distinct pipe- to tabular-shaped bodies grading 0.77 wt % Ni and 0.34 wt % Cu along with minor cobalt, silver, gold and an unknown quantity of platinum-group elements. The magmatic sulphide ores are hosted by the Giant Mascot ultramafic intrusion (~3 × 2 km) comprising mainly pyroxenite, peridotite and dunite. A discontinuous hornblendite rim separates the ultramafic intrusion from the mid-Cretaceous, dioritic Spuzzum Pluton, except to the east where it lies in contact with Late Triassic, amphibolite-grade metasedimentary rocks (Settler schist). The origin of the ultramafite and contact relationships with the Spuzzum diorite are controversial: previous interpretations include an early ultramafic cumulate phase of the Spuzzum; a fragment of Late Paleozoic ophiolite (Cogburn Assemblage) engulfed by the Cretaceous pluton; or a raft of cumulates belonging to the Late Triassic Wrangellia flood basalt province.

New CA-TIMS U-Pb zircon geochronology of Giant Mascot pyroxenite and Spuzzum diorite has been used to evaluate these competing hypotheses. A sample of Giant Mascot pyroxenite gives an age of 93.04±0.06 (2σ) Ma based on five concordant and equivalent $^{206}U/^{238}Pb$ dates. Another sample from the same pyroxenite unit collected 100m away yields a spread of $^{206}U/^{238}Pb$ dates (88-119 Ma) with results on or close to concordia, and one significantly discordant grain with a $^{206}U/^{238}Pb$ date of 216 Ma. A regression through this latter grain, anchored through 93 Ma, suggests that it may contain an inherited core as old as 1.4 Ga. The spread of ages both older and younger than the accepted age of 93 Ma for the pyroxenite is interpreted to result from older inheritance in some grains combined with incomplete removal of Pb loss even though all zircon grains were subjected to chemical abrasion. A diorite collected close to the margin of the pyroxenite gives a U-Pb zircon age of 95.47±0.13 Ma based on a weighted average of three concordant and overlapping $^{206}U/^{238}Pb$ dates which is interpreted as a maximum age for the diorite, and is similar to previous dates reported for the Spuzzum Pluton. Although preliminary, our geochronological results indicate that the Giant Mascot ultramafic body is mid-Cretaceous in age and apparently younger than the Spuzzum Pluton, and clearly eliminate an ophiolitic origin or affinities with the Wrangellia flood basalt province.

THE FUTURE OF GLOBAL GEOPARKS IN NORTH AMERICA

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A Global Geopark is a defined area with geological heritage of international significance. Key sites in a geopark may be protected under local, regional or national legislation, as appropriate. Within the geopark some sites are used to promote the sustainable development of the local communities who live there, through education and geotourism. The Global Geopark brand is supported by UNESCO but it is not a formal program. However, the UNESCO General Assembly voted in late 2011 to establish a task group to examine what it would take to make Global Geoparks into a formal program; this task group will be formed in early 2012. Stonehammer Global Geopark in southern New Brunswick was established as North America's first Global Geopark in 2010. This geopark is based on the billion year history represented within it (Proterozoic to Recent with only the Jurassic missing) and the strong historical connection

to science in the nineteenth century. It has been flourishing ever since and regularly catches the eye of Canadian and American media. It won an Innovation Award from the Tourism Industry Association of Canada in 2011 drawing further attention to the idea of geoparks. This is a great start for geoparks in North America and the Canadian National Committee for Geoparks is working hard to encourage other communities to adopt the concept and develop proposals. The committee has prepared guidelines for the establishment of geoparks in Canada that are based closely on those for Global Geoparks, but reflect the Canadian context. It has worked closely with U.S. counterparts to ensure that the guidelines for the two countries are as similar as possible, with the long-term goal of establishing a North American Geopark Network that would be self-governing. The committee has received expressions of interest from communities in many parts of Canada and has been working to make the concept of geoparks better known across the country. Explaining and distinguishing the geopark concept is crucial because North Americans are used to the long-established array of federal, provincial (state) and municipal parks, which contrast markedly with the concept of a geopark. The future for geoparks in Canada looks bright, but it will take time to establish new ones. Stonehammer Global Geopark has given us an excellent example to follow.

RESULTS OF AN AIRBORNE BIOGEOCHEMICAL SURVEY OVER BURIED URANIUM AND RELATED MINERALIZATION AT THE JACQUE'S LAKE AREA, LABRADOR

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The recent positive uranium market outlook has rekindled interest in uranium exploration. Renewed exploration activities involving the reevaluation of previously known deposits and/or the search for new deposits, has pushed prospecting into more challenging terrains such as areas covered by unmineralized cap rock, or buried beneath transported overburden such as glacial fluvial outwash. The mineralized bedrock in the Labrador Central Mineral Belt (CMB) and in particularly, the Jacques Lake area, is buried beneath thick layers of recently deposited glacial till and peat. These materials present a challenge to exploration because they effectively obscure direct observation of mineralized outcrops and accompanying alteration haloes. The area also has rugged topography with dense coniferous forest cover, lacks access roads, and is characterized by long and extreme winter weather conditions with very high precipitation. Successful evaluation of uranium resources requires cost effective and efficient exploration strategies capable of detecting buried mineralization.

This study used airborne helicopter sampling of black spruce twigs (7 – 10 year growth), black spruce stem bark, and shoots of Labrador Tea. Samples were collected at 100 m intervals along ten 1.6 km long, NW-SE transects that lay over, and perpendicular to the bedrock radiometric uranium anomaly that constitutes the Jacque's Lake deposit. Black spruce twigs had maximum uranium concentrations of 60 ppb, whereas the ground level samples recorded mean concentrations close to their individual limits of detection with a few elevated concentrations ranging from 10 – 18 ppb. Elevated uranium concentrations in the treetop samples coincided with the airborne magnetic and radiometric uranium anomalies of the Jacques Lake deposit. Additional elevated biogenic uranium anomalies were located outside the radiometric anomaly at the northeastern and southeastern edges of the property. Geochemical relationships (pathfinder elements) between U and Pb, Ag, Cu and Be in the tree samples were also established.

COMMUNITY ANALYSIS OF THE TULIP BEDS (BURGESS SHALE) – PRELIMINARY REPORT

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Burgess Shale-type deposits provide critical clues about the early evolution and ecology of metazoans directly in the aftermath of the Cambrian Explosion. The Burgess Shale itself has been intensively studied, but our understanding of ecological patterns at the scale of entire fossil assemblages and communities remains limited. This study quantitatively examines the Tulip Beds locality on Mount Stephen. This locality is slightly older in age and more distal in stetting than the Walcott Quarry and this allows examination of changing patterns in evolutionary time at a small regional scale. Almost 9,000 specimens representing about 90 species have been examined from the Tulip Beds so far. Like at the Walcott Quarry the arthropods and sponges dominate in terms of number of species and relative abundance of specimens, although the most abundant taxon, *Siphusauctum gregarium*, is a problematic organism only known from the Tulip Beds. Preliminary observations suggest marked differences in species identity per phyla. These patterns, which will be explored in greater details during the course of this ongoing doctoral project, will hopefully shed some light on the structure and function of the Burgess Shale biota in different temporal and geographical settings.

EVOLUTION OF THE ARCHEAN SLAVE CRATON: INSIGHTS FROM SEDIMENTARY BASINS AND THEIR DETRITAL ZIRCONS

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The growth of a craton is recorded by episodes of juvenile magmatism. The reworking and destruction of cratonic material through time may be preserved as detritus in sedimentary basins. As detrital zircon U-Pb dating and Lu-Hf isotopic tracing have become the 'fossil' record of Precambrian environments, key stratigraphic horizons and their zircons can enable the decoding of Archean lithospheric evolution. Presented here is previously reported and unpublished detrital zircon U-Pb ages (SHRIMP, LA (MC) ICP-MS, and ID-TIMS) from three distinct sedimentary sequences within and on the Archean Slave craton, forming a dataset in excess of 5000 individual analyses. The oldest unit is quartzite from the ca. 2820 Ma Central Slave Cover Group (CSCG) that rests unconformably on Mesoarchean basement throughout the central and western part of the craton. The second is the ca. 2660 and <2640 Ma Package I and II greywacke-mudstone turbidites that are ubiquitous throughout the Slave craton. The <2600 Ma conglomerates (e.g., Jackson Lake, Keskarrah formations) are important stratigraphic horizons in the craton, but currently there is only limited U-Pb detrital zircon data available. The third horizon is Paleoproterozoic quartzite preserved unconformably on Archean basement at the eastern edge of the Wopmay orogen.

We have screened the compilation to only include data with concordance between +15% and -5%, errors <50 Ma (1σ) and ages older than their constrained depositional age (younger ages are interpreted to be isotopically out of equilibrium). For the precise ID-TIMS ages, we augmented error margins to a minimum of ±7.5 Ma (1σ) to be more consistent with the analytical uncertainty of the microbeam techniques (reported errors greater than ±7.5 were not modified). Data is plotted by stratigraphic horizon and in the Neoarchean and Paleoproterozoic sedimentary units we remove any ages in the dataset older than the next oldest stratigraphic horizon to relieve the effects of recycling and dilution. The major episodes of crustal growth recorded in the CSCG are at 3.65-3.20 Ga, 3.18-3.16, 2.98-2.94, 2.90, and 2.85-2.82 Ga. Within the Package I-II turbidites the major zircon populations are at 2.74 Ga, 2.72-2.70, 2.68-2.66, and 2.64-2.63 Ga. The Wopmay quartzite contains significant zircon populations at 2.63 Ga, 2.61, 2.60-2.59, and 2.57 Ga. The largest populations in the Mesoarchean data are at 3.15 Ga and 2.94 Ga and in the Neoarchean at 2.70 Ga, 2.68-2.66 Ga, and 2.59 Ga. Within our assigned parameters, only three grains older than 3.90 Ga have been identified.

Keynote THE ROLE OF TERRESTRIAL ANALOGUE ACTIVITIES IN A GLOBAL SPACE EXPLORATION PROGRAM

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These are exciting times for planetary exploration. The robotic exploration of the Solar System continues at an unprecedented pace with active missions extending from Mercury to Pluto. Over the past decade, Canada has contributed several high-profile instruments for specific robotic planetary missions, including the meteorological station on the Phoenix Mars lander and the Alpha Particle X-Ray Spectrometer instrument on the Mars Science Laboratory "Curiosity" rover. The CSA has committed to support the Mars Atmospheric Trace Molecule Occultation Spectrometer instrument to fly on the 2016 Mars Trace Gas Orbiter and advanced plans are underway for a lidar instrument contribution to the OSIRIS-REx asteroid sample return mission scheduled for later this decade. Future planetary exploration, as described in the Global Exploration Strategy, will increasingly be through a series of partnerships and collaborations targeted at the Moon, asteroids and Mars. Robotics is expected to be a key technology Canada will contribute as part of this effort. In addition, in order to prepare for future missions and to position Canada as a major partner, terrestrial analogue activities offer a high profile and uniquely Canadian contribution to the global space exploration program.

Terrestrial analogues are places on Earth that approximate the geological, environmental and putative biological conditions on Mars and other planetary bodies, either at the present-day or sometime in the past. They are obviously important for purely scientific reasons, for comparative planetary geology and for astrobiology. However, and perhaps most importantly, terrestrial analogues are important for various aspects of "exploration". They can be used to train the next generation of planetary scientists, engineers, managers, and astronauts; to test and develop technologies and techniques for future missions; and to provide unique education and public outreach opportunities that can engage the public while developing actual flight opportunities. Critically, terrestrial analogue activities represent a critical niche that Canadians are known for on the international stage. The role of analogue studies in planetary exploration is expanding and gaining importance as we prepare for future exploration missions and it is critical that Canadian academia, industry, and government work together to ensure that Canadians remain at the forefront of such activities.

In this Invited contribution, I will provide a brief overview of the history of terrestrial analogue activities in Canada and beyond, outline some of the unique Canadian analogue sites, and provide a vision for a renewed Canadian analogue program that can provide a stepping stone towards a global space exploration program.

THREE YEARS OF CONTINUED GROWTH: THE EDUCATION AND OUTREACH PROGRAM AT THE CENTRE FOR PLANETARY SCIENCE AND EXPLORATION

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The Centre for Planetary Science and Exploration (CPSX) at The University of Western Ontario (Western) continues to develop a comprehensive education and outreach program focusing on planetary science and exploration. With funding from the Canadian Space Agency and Western, the program strives to: 1) use planetary science as a way to raise general interest in science, 2) increase awareness of career opportunities in planetary science and exploration research, 3) offer educational resources to teachers, and 4) train graduate students in education and outreach practices.

The CPSX education and outreach program has sustained extensive growth over its first three years. This is due to a number of factors including the hiring of a full-time education and outreach coordinator, increasing the number of partnerships with other organizations such as Let's Talk Science, the London Children's Museum, and the Thames Valley District School Board Itinerant Gifted Program, continued development of a wide-range of interactive presentations and activities, and offering new large-scale events such as a full-day high school symposium, hosting an exhibit at the Children's Museum, and the introduction of a weekly radio program on astronomy.fm.

As the program enters its fourth year, many new activities and initiatives are being developed, including two large-scale projects. The Interactive Mapping of the Planets (IMaPS) program – which recently received funding from an NSERC PromoScience grant - will consist of multiple inquiry-based workshops, a web-based activity using Google Earth, Moon, and Mars, pre-prepared kits to be sent out to teachers in rural and remote areas, and a summer camp offered in association with Sports Western. Funding is also being sought for a program that would bring primary- and secondary-school teachers on field research excursions so they may learn first-hand the importance of field-work in planetary and earth sciences.

INDICATOR MINERAL AND TILL GEOCHEMICAL SIGNATURE ASSOCIATED WITH THE PINE POINT Pb-Zn MISSISSIPPI VALLEY-TYPE (MVT) DEPOSITS, NORTHWEST TERRITORIES, CANADA

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This study was initiated to determine the till indicator mineral and geochemical signature of the world class Pine Point Pb-Zn MVT deposits and is part of the Geological Survey of Canada's R&D of indicator mineral methods for base metal exploration. Mineralized bedrock and metal-rich till samples were collected from 5 of the more than 100 deposits in the district. Indicator minerals recovered from mineralized bedrock samples include sphalerite, galena and pyrite, as well as barite and anglesite. The majority of these grains occur in the 0.5 to 1.0 mm fraction. Till on the bedrock surface proximal to the O28 deposit contain ~35,000 sphalerite grains and ~53,000 galena grains/10 kg sample, in all size fractions, while samples collected from sample pits at surface proximal to the deposit contain 0 to 3 grains of each mineral.

Ice-flow data consist of striation measurements recorded from bedrock surfaces in the immediate sample area as well across the region. These data indicate an earliest sustained ice flow direction to the southwest (~230°) with an intermediate phase to the northwest (~300°) followed by the last phase, during deglaciation, to the west- southwest (~250°). Previous regional surficial mapping in the Pine Point area had identified only the latest ice flow to the west-southwest, which formed the streamlined landforms in the region.

Pathfinder elements in the <0.063 mm till fraction include Pb, Zn and Fe, and to a lesser extent Cd and Ba. Zinc and Pb concentrations are highest in till directly down-ice (southwest) of the O28 deposit. Elevated Zn values in till range up to 3497 ppm while Pb values are up to 2015 ppm. The highest values for all pathfinder elements occur along the bedrock surface down-ice of the O28 orebody. Some values are higher to the northwest, indicating additional dispersal or reworking by the second, northwest trending ice-flow.

PROTEROZOIC GEOMAGNETIC FIELD GEOMETRY FROM MAFIC DYKE SWARMS

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North America is home to many large dyke swarms. The vast areal coverage of these dyke swarms, commonly emplaced in a few million years, are ideal for investigating the nature of the global geomagnetic field geometry and testing the reliability of the time-averaged geocentric axial dipole (GAD) assumption, which is relied on critically for pre-Mesozoic continental reconstructions and paleoclimatic inferences from paleomagnetism. We have been testing the GAD assumption and localized non-dipole components, by compiling paleomagnetic remanence directional variations within the Matachewan (2.45 Ga), Mackenzie (1.27 Ga) and Franklin (0.72 Ga) dyke swarms. Our analysis varies the quadrupole and octupole values of the generalized paleolatitude equation to determine a minimal angular dispersion and maximum precision of

paleopoles from each dyke swarm. As a control, paleomagnetic data from the Triassic-Jurassic (0.20 Ga) central Atlantic magmatic province (CAMP) show the sensitivities of our method to non-GAD contributions to the ancient geomagnetic field. Within the uncertainties, CAMP data are consistent with independent estimates of non-GAD contributions derived from global tectonic reconstructions (Torsvik & Van der Voo, 2002). Current results from the three Proterozoic dyke swarms all have best fits that are non-dipolar, but they differ in their optimal quadrupole/ octupole components. Treated together under the hypothesis of a static Proterozoic field geometry, the data allow a pure GAD geodynamo within the uncertainty of the method. Global volcanic rocks within the age range of 0-5 Ma will be used as another test for the robustness of this method. Current results were performed using Fisherian statistics, but Bingham statistics will be included to account for the ellipticity of data.

THE PETROLOGICAL EVOLUTION OF THE REE-ENRICHED A-TYPE GRANITES OF THE LATE PALEOZOIC WENTWORTH PLUTON, COBEQUID HIGHLANDS, NOVA SCOTIA

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The Wentworth Pluton in the Eastern Cobequid Highlands consists principally of metaluminous to peralkaline A-type granite (~362 Ma), a large part of which was remelted by a major gabbro intrusion (~357 Ma). Magmatic minerals like allanite-(Ce), chevkinite-(Ce), zircon, and hingganite-(Y) and post-magmatic mineral phases, such as REE-epidote, samarskite, aeschynite-(Y), fersmite, thorite, and hydroxylbastnäsite-(Ce), were identified.

The presence of fluorine, kept the rare metals in solution and changed the behavior of the REE, increasing the solubility of monazite and xenotime and thus the rare earths and rare metals remained in the magmatic system for prolonged periods. The fractionation of allanite-(Ce) and chevkinite-(Ce) led to a magma enriched in HREE, from which hingganite-(Y) crystallized during late magmatic stages. The remelting of the early granite led to fluorine and sulfur release in volatile phases, which circulated with hydrothermal fluids, thus mobilizing the REEs and rare metals. Reduction of fluorine activity during the late to post-solidus crystallization resulted in the precipitation of HREEs and rare metals in samarskite, thereby enriching the residual hydrothermal fluids in LREEs. Post-magmatic LREE-minerals such as hydroxylbastnäsite-(Ce) either replaced earlier minerals or precipitated from these hydrothermal fluids. Carbonate fluids involved in a late regional hydrothermal circulation along the Cobequid-Chedabucto fault (320-315 Ma) resulted in titanium mobility and the formation of titania minerals and probably of aeschynite-(Y).

Modelling of batch partial melting of a feldspar-dominated rock, such as a tonalite, with a REE composition similar to that of the Neoproterozoic quartz diorites of the region, shows that the resulting melt would have REE concentrations similar to those of the Wentworth granites. Partial melting of tonalitic rocks in the lower crust would produce alkaline granitic magmas, such as the A-type granites of the Wentworth Pluton.

The geochemistry of the Wentworth granites indicates that the REE-enrichment can be of magmatic origin. This is further supported by the unusual REE-mineral assemblage, which records a sequence from magmatic REE-silicates to post magmatic oxides. The complex geological history of the pluton provides a unique opportunity to correlate the formation of these minerals to different stages of pluton evolution and record the transition of an enriching system from magmatic to mainly hydrothermal.

FLUCTUATIONS IN PRECAMBRIAN ATMOSPHERIC AND OCEANIC OXYGEN LEVELS: A NEW PRECAMBRIAN PARADIGM EMERGING?

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The Precambrian atmosphere and oceans are traditionally thought to have undergone a progressive increase in oxygen content after ~2.4 Ga. This progressive transition from anoxic conditions to more oxidizing conditions is assumed to have occurred in two incremental steps, one at the beginning and one at the end of the Proterozoic Eon. This paradigm is changing. Enrichments of the redox-sensitive element uranium in organic matter-rich shales through time shows that the Earth's surface oxidation had a much more dynamic and unexpected history. The initial rise of atmospheric oxygen ~2.4 billion years ago was followed by a dramatic decline to less oxidizing conditions during the mid-Proterozoic, beginning after the cessation of the Lomagundi excursion, ~2.05 Ga. The subsequently established steady-state redox state persisted for nearly one billion years, ending with a second event in the latest Neoproterozoic. Utilizing the ubiquitous geological shale record, the U record demonstrates unprecedented temporal resolution to reveal Earth's dynamic path to its present well-oxygenated state. We present evidence for a precipitous rise and (previously unrecognized) fall in atmospheric oxygen early in the Proterozoic, which is in direct contrast to conventional models predicting a unidirectional oxygen rise. With this new paradigm in mind, future models will need to reexamine the links between the co-evolution of biology and chemical composition of the Precambrian oceans.

BASIN EVOLUTION OF THE PALEOPROTEROZOIC PENRHYN AND PILING GROUPS: IMPLICATIONS FOR TECTONIC EVOLUTION AND PALEOGEOGRAPHIC RECONSTRUCTION

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Tectonic processes that operated in the western Churchill province during the Paleoproterozoic can be revealed by the study of sedimentary basins that developed over the Rae and Hearne cratons and filled during and prior to the Trans-Hudson Orogeny (THO). To that end, the Penrhyn and Piling groups offer a window into understanding the tectonic mechanisms that led to basin initiation, subsidence, and closure during the opening of the Manikewan ocean and protracted continent-continent collision of the THO. Geological, geochemical, and geochronological investigation of the Penrhyn and Piling groups, on Melville Peninsula and Baffin Island, respectively, was carried out under the Geo-Mapping for Energy and Minerals (GEM) Program.

An understanding of the evolution of the Penrhyn and Piling basins (including mechanisms and timing of basin initiation, sediment sources, and mechanisms and timing of basin closure) is important when reconstructing the tectonics and paleogeography of the surrounding microcratonic blocks at that time. The recognition of extension-related mafic and ultramafic volcanism in the Piling Group helps to elucidate tectonic regimes associated with early stages in the THO. The Piling basin shows a transition from a passive margin to an extensional continental back-arc basin, and finally to a foreland basin during the collision with the Meta Incognita microcraton presently located on southern Baffin Island. Subsidence of the Penrhyn basin, in turn, was influenced by far-field tectonic stresses, likely associated with those occurring in the Piling basin. Both the Penrhyn and Piling strata show a ca. 1.9 Ga arc-derived detrital zircon population, in addition to Archean and older Paleoproterozoic zircon populations, though Penrhyn strata record only a minimal influence of these younger zircons, suggesting a more distal source of arc-derived detritus. Both basins began to close between ca. 1.9 and 1.89 Ga in response to Meta Incognita docking. Combining revised stratigraphy and results from geochronology and geochemistry of the Penrhyn and Piling groups together allows for an integrated synthesis of the basin evolution and evaluation of potential metal endowment of these basins.

AWARUITE - A NICKEL DEPOSIT CONCEPT: GEOLOGICAL TARGETS AND EXPLORATION STRATEGIES IN NEWFOUNDLAND

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Awaruite is a nickel-iron alloy mineral, with the formula Ni_2-3Fe, that forms through the breakdown of nickel-bearing olivine or sulphide in the extremely low oxygen and sulfur conditions produced during serpentinization of ultramafic rocks. Although ore deposits of awaruite are conceptual at this stage and no economic deposits are currently known, exploration for such mineral deposits is ongoing across Canada. Awaruite generally occurs in low concentration (<0.25%) in many ultramafic rocks, but the strongly magnetic and high density characteristics of the mineral may allow for relatively simple extraction, ultimately producing a concentrate suitable for production of stainless steel yet bypassing the smelting process. Moreover, the geology of many ultramafic bodies, notably the large volume of the units and the relative homogeneity, suggests that large deposits suitable for open pit mining techniques may exist. Finally, as awaruite and the ultramafic rocks it occurs in have very low sulphide contents, acid mine drainage is not likely to be an issue.

An exploration program has been designed based on the distinctive mineralogical characteristics of awaruite. The program consists of a first phase of systematic till and stream sediment sampling and regional rock sampling over selected areas. Rock samples are sawed making the awaruite more readily identifiable with a microscope or the naked eye. Tills and stream sediment samples are processed to yield heavy mineral concentrates and subsequent magnetic separates. Grain mounts are then examined with a petrologic microscope where a count of the awaruite grains is measured. Grain counts are plotted on maps to indicate areas that have the greatest abudance of awaruite for further follow up. Geochemical plots of the samples using elements such as Ni and other elements are helpful but less reliable due to the multiple Ni-bearing phases that may exist. Hence, petrological observations are critical as to determine both the presence and the qualitative aspects of the awaruite occurrences, such as grain size and whether the awaruite is monominerallic or part of multi-phase systems (eg., mixed awaruite-silicates-sulphides). In this regard, we have used SEM-MLA analysis to provide a more rigorous analysis of awaruite bearing samples. As this exploration model is in its infancy, despite much technical success to date, further improvements to the methodology are anticipated.

DIFFERENTIATION OF NEOARCHEAN FROM PALEOPROTEROZIC BASALT IN THE URANIFEROUS AMER AND WHITEHILLS BELTS, NORTHEAST THELON REGION, NUNAVUT

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Distinction of Paleoproterozoic from Neoarchean mafic volcanic units in the Amer and Whitehills fold and thrust belts has been challenged by complex structures, yet developing unique criteria to characterize them is critical to unraveling those structures. Mapping these belts under the Geomapping for Energy and Minerals Program aims to improve knowledge of basement geology for exploration of basement hosted uranium and lode gold deposits in the northeast Thelon Basin region. Greenschist to amphibolite facies mafic metavolcanic rocks within the Paleoproterozoic portions of these belts have variably been interpreted as single or multiple extrusive events during the Paleoproterozoic, or as structurally intercalated Neoarchean basalt. Analysis of new and heritage map data from many sources has shown that field criteria can clearly distinguish a range of Neoarchean volcanic rocks from products of a single Paleoproterozoic mafic event with a crustally contaminated continental tholeiite signature.

The Neoarchean basalt is an aphyric and very finely crystalline, integral component of 2.6 Ga and older suites ranging from komatiite through komatiitic basalt and high-Mg tholeiite to quartz-feldspar-phyric rhyolite. The Neoarchean suites include granitoid to pyroxenitic intrusive components and the volcanic units are interlayered with metagreywacke and banded chert-magnetite iron formation. The aeromagnetic expression of the basalt to rhyolite phases is negative whereas the ultramafic rocks and iron formations are powerful, complex highs. The Neoarchean igneous rocks unconformably underlie basal conglomerate and/or schistose facies of the early Paleoproterozoic quartzarenite in both the Whitehills and Amer belts.

The Paleoproterozoic tholeiite flows are invariably plagioclase phyric, have amygdules filled with calcite and rimmed by epidote, and commonly overlie dolomitic mafic tuff. Gabbro sills locally intrude underlying rocks and the tuff. The basalt gradationally overlies dolostone in some places; in others the underlying and overlying schist contains graphite, feldspathic and lithic meta-sandstone to -mudstone with disseminated magnetite. In the Amer Belt, randomly oriented rip-ups of dolostone within the metabasalt demonstrate their depositional inter-relationship. The basalt and the stratigraphically close, magnetite-bearing fine clastic rocks form strong, relatively continuous linear magnetic highs. This assemblage stratigraphically overlies laterally extensive, magnetically low quartzarenite, separated in the Whitehills belt by polymict metaconglomerate. Geochronology of several sills within the Paleoproterozoic sequences, and extensive new geochemical analyses are testing the compositional distinctions summarized above; whether the 2153 ± 4 Ma Schultz Lake metagabbro is a deeper expression of the Paleoproterozoic tholeiite event; and if these units are related to the 2.19 Ga Tulamelu / MacQuoid dyke swarm.

INFLUENCE OF PALAEOGEOGRAPHY ON VMS DEPOSIT FORMATION AND PRESERVATION

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Understanding the processes leading to the amalgamation of crust in the past has always been hampered by the disseminated nature of information and by a lack of technology to draw together data in formats suitable for systematic study. The IGCP 509 project initiated some databases which have facilitated the structured compilation of global data and new technologies have become available to reconstruct and illustrate past palaeogeographies in a GIS environment. The reconstructions utilise published palaeomagnetic data, augmented by regional structural vergence direction information which permit the 'explosion' of crustal domains at times dictated by geology and geochronology. Known ore deposits, lithostratigraphy and sample locations move with the continental fragments so that one can 'watch' the processes and events as they change in time and space.

Nuna was formed by closure of the Manikewan Ocean from 2.2 to 1.8 Ga. Diachronous accretion occurred from 2.2 to 1.95 Ga, starting in the southern parts of Nuna and progressing northwards. Orogenic gold deposits formed in the collisional zones of southern Nuna at the same time that VMS mineralisation was occurring further north. A second phase of accretion from 1.95 to 1.88 Ga is evident in Laurentia and Baltica as other crustal blocks joined proto-Nuna. Many of the major, global Ni-Cu-PGE and VMS deposits formed during this stage. Final closure of the Manikewan Ocean occurred from 1.88 Ga to 1.60 Ga and subduction switched from a dominantly interior domain to the peripheral, western margin of Laurentia.

In a similar pattern, Palaeozoic VMS mineralisation in eastern North America (New Brunswick) and in Scandinavia are preserved on either side of the pre-Caledonian Iapetus ocean. Mineralization occurred in extensional settings associated with multiple island arcs, subsequently accreted

to Laurentia and Baltica. Palaeogeographic reconstructions suggest that both the New Brunswick and Norwegian VMS deposits formed along-strike in a single major accretionary island arc system which may also be traced into Ireland, illustrating the potential use of palaeogeographic investigations for greenfields exploration.

Both the Nuna and Iapetus examples exhibit mineralization associated with the closure of interior oceans. Additional, regional features such as ocean basin palaeogeography may have influenced seawater chemistry and VMS preservation. Iapetus and its marginal/successor basins had a restricted east – west orientation that favoured development of a stratified water column. A similar orientation for Nuna's Manikewan Ocean and numerous cratonic blocks and microcontiental fragments highlights that particularly productive VMS periods may reflect the geometry of supercontinent amalgamation.

PETROLOGIC–GEOCHEMICAL EVOLUTION OF THE URANIUM MINERALIZED PEGMATITES OF THE UNGAVA BAY, NORTHERN QUEBEC

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A new uranium district has recently been discovered in the Rae Province in the Superior Craton. The region was explored for uranium-bearing pegmatites, emplaced between an Archean basement and a Proterozoic cover. These deposits and those of Areva to the north (Cage area) are often compared with those of Rossing. The metamorphic basement is dominantly tonalitic. The cover is mainly a quartz-feldspar gneiss, rich in femic minerals and sulfides with local occurrences of metabasic rocks, marbles, calc-silicates and graphitic schists.

Two types of mineralized pegmatites are recognizable by their mineralogy, petrology and geochemistry and structural setting. The Puqila-type pegmatites are characterized by a laccolithic shape and a high proportion of rounded feldspars in a matrix of biotite, quartz, apatite and zircon. The uranium minerals are uraninite, uranothorite or uranium-rich mobilisate between the minerals. The Aqpiq-type pegmatites are more dyke-like and are characterized by a very quartz-rich matrix, with minor amounts of Fe-Mg minerals, variable feldspar contents and high concentrations of monazite, blue apatite and uraninite. Scanning electron microscope analysis show apatite-bastnaesite alteration halos around the monazite crystals, which indicate the influence of F-rich fluids. Other non-mineralized pegmatites containing tourmaline, garnet and apatite also occur in the vicinity of the mineralized types.

The pegmatites are generally weakly peraluminous, garnet bearing ones (Agpik) are the most peraluminous, and some are slightly metaluminous indicating interaction with the Ca-rich lithologies during their injection or emplacement. REE geochemistry of the pegmatites suggests that monazite has a strong control over REE patterns with large fractionation of the light and heavy rare earths elements and a strong negative europium anomaly. Seagull-like REE patterns in some pegmatites indicate a tetrad effect caused by the F-rich fluids. REE patterns also show that the Aqpiq-pegmatites are much more richer in REE, than the Puqila-Type.

The geometric relationships suggest that the formation of these pegmatites results from the early emplacement of Puqila-Type pegmatites, followed by the extraction of a melt corresponding to the Aqpiq-type pegmatites with variable interaction with enclosing lithologies. Uranium enrichment in the pegmatites of the Ungava Bay corresponds to a forming a polyphased event related to local partial melting and limited differenciation.

LATE GLACIAL TO HOLOCENE ENVIRONMENTAL HISTORY OF EASTERN KAMCHATKA PENINSULA, THE NORTH PACIFIC

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We present a 14,000 year-old pollen and tephrostratigraphic record - the longest to date in the Kamchatka Peninsula – and used this to infer vegetation and climate dynamics as well as eruptive history around the eastern seaboard of the peninsula. The Late Glacial environment was characterized by wet tundra while the Late Glacial – Holocene transition was probably drier and equally treeless. The Early Holocene landscape is marked by the expansion of shrubs, mainly alder but also dwarf birch and dwarf pine. The arrival and expansion of trees in Kamchatka took place around 8000 cal BP and these are represented by *Betula ermanii* forests. The absence of conifers is a distinct feature of the eastern seaboard of the peninsula and contrasts with Central Kamchatka where conifers were an important part of the regional vegetation during this period. The Middle Holocene is defined by a warmer climate with strong oceanic influence and the dominance of the *Betula ermanii* forests, while the Late Holocene is marked by relative climatic instability between cool and wet periods, when forests retreat and shrub vegetation expands considerably, and warmer periods characterized by an opposite trend. The eruptive history of eastern Kamchatka, inferred from high-resolution radiocarbon dating of tephra layers, is characterized by at least 20 major eruptions, most of them originating from the proximal Shiveluch- Kliuchevskoi volcanic group. Tephra deposition had a major impact on wetland plant communities and to a lesser extent on upland vegetation.

EARLY CRETACEOUS VOLCANISM IN THE SCOTIAN BASIN SYNCHRONOUS WITH RIFTING OF THE NORTH ATLANTIC OCEAN

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Early Cretaceous volcanism is widespread in the eastern part of the Scotian Basin, synchronous with and spatially related to the prolonged rifting between the Grand Banks and Iberia that began in the Tithonian and gave way to normal sea-floor spreading at the beginning of the Albian. The stratigraphy of volcanic rocks in wells was re-evaluated and their volcanology refined by study of cuttings and well logs. Principally Hauterivian volcanic rocks on the SW Grand Banks and principally Aptian volcanic rocks in the Orpheus Graben are the result of Strombolian type eruptions. More extensive Hawaiian type flows have been mapped from seismic profiles on the SW Grand Banks, derived from local volcanic basement highs with a positive magnetic anomaly, and accumulating in small Hauterivian rift basins. Subaerial basalt flows in Orpheus graben wells are of mid Aptian age and extended to the paleoshoreline at the Hesper wells. They were derived from Scatarie Bank to the north, which has a positive magnetic anomaly and known Cretaceous mafic dykes.

Cretaceous detrital zircon is widespread in the Scotian Basin, together with detrital lithic clasts and feldspars of apparent subvolcanic origin. U-Pb laser ablation ICPMS dating of shows two clusters of dates at ~105 and ~120 Ma, but their stratigraphic position suggests that the determined dates are ~10 Ma too young and the true ages correspond to late Aptian and Barremian. Zircon grain size (~130 μm) implies fluvial transport rather than air fall. Two magnetic anomalies similar to, but east of, Scatarie Bank might be the sources of the Barremian volcanic material.

In the central Scotian Basin, fluid inclusions in and the C-isotope composition of carbonate cements indicate a period of flow of hot (< 175°C and <23 wt % NaCl) basinal brines in the Aptian–Albian. Although no direct link with volcanism is known, the timing of these hydrothermal fluids corresponds to a period of regionally high heat flow in the Northern Appalachians, that resulted in high vitrinite reflectance in the lower Chaswood Formation and widespread paleomagnetic resetting.

DETRITAL ZIRCONS FROM A LATE PALAEOZOIC ACCRETIONARY COMPLEX OF SW IBERIA (VARISCAN BELT): HISTORY OF CRUSTAL GROWTH AND RECYCLING AT THE RHEIC CONVERGENT MARGIN

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In this study we present new U-Pb ages of detrital zircons from greywackes and quartzites of the Pulo do Lobo Anticline (PLA) that have been interpreted to represent a Late Paleozoic accretionary complex in SW Iberia. The PLA separates the Ossa Morena Zone, which has a North-Gondwana affinity throughout Late Ediacaran and Early Paleozoic times, from the South Portuguese Zone, which is considered to be underlain by Laurussia basement. The PLA stratigraphy most likely represents a synorogenic basin that records the closure of the Late Paleozoic Rheic Ocean and the amalgamation of Pangaea. The youngest formations of the PLA contain upper Devonian microfossils.

The results obtained indicate that the detrital zircons from the PLA represent a wide range of Precambrian and Paleozoic crystallization ages. Recycling of older sedimentary units of the Late Ediacaran active margin (Cadomian/Pan-African orogenies) as well as of the Early Paleozoic rifting and passive margin (Rheic Ocean) stages, accounts for the older populations with North-Gondwana affinity (Cambrian, Neoproterozoic, Paleoproterozoic and Archean, with a gap of Mesoproterozoic-age). However, the Mesoproterozoic detrital zircon ages found in the greywackes of the Pulo do Lobo Formation (< 7%) that do not correspond to any substantial source within North-Gondwana, could come from recycled sedimentary deposits or from denudation of Grenville-age basement (Laurussia?). The more recent formations present in the northern limb (Ferreira-Ficalho Group) of the PLA show a significant age cluster in the upper Devonian (c. 378 Ma), whereas on the southern limb (Chança Group), samples have from base to top of the stratigraphic sequence: a minor age cluster in the middle Devonian (c. 390 Ma), a significant age cluster in upper Devonian (c. 380 Ma) and very significant age cluster in the upper Devonian (c. 372 Ma). The presence of middle-upper Devonian detrital zircons in combination with very low abundances of Mesoproterozoic detrital zircon suggests that the PLA sedimentary rocks were not derived from exotic sources but rather have a North-Gondwanan origin. The zircon population in the interval c. 390-380 Ma has no identified corresponding magmatic or stratigraphic source in SW Iberia. Considering that, during the development of the upper Devonian basins of SW Iberia, Laurussia basement was not exposed and that there was no magmatic arc on the North-Gondwana margin, we suggest that the c. 390-380 Ma detrital zircons are most probably derived from denudation of a (intra-oceanic) magmatic arc related to the closure of the Rheic Ocean.

THE ATOMIC STRUCTURE AND HYDROGEN BONDING IN WILCOXITE, FROM RICO, COLORADO

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Wilcoxite $MgAl(SO_4)_2F•17H_2O$ is a secondary sulfate mineral that occurs in hydrothermal systems containing significant amounts of fluorine. The mineral sample was collected from abandoned mine workings east of Rico Colorado. Wilcoxite occurred within a timber crib that protected the material from direct exposure to rain and snow but not from changes in the humidity and temperature of the atmosphere. It is remarkable that this highly hydrated mineral has remained stable under these conditions. Cell dimensions are a = 6.644(1) Å, b = 6.749(2) Å, c = 14.892(3) Å, α = 79.664(4) °, β = 80.113(4) °, γ = 62.487(3) °, V = 579.6(2) $Å^3$, P-1. The atomic structure of wilcoxite consists of isolated sulfate tetrahedra, magnesium-containing octahedra and aluminum-containing octahedra connected through hydrogen bonding involving additional water molecules. Wilcoxite has 1.5 water molecules per sulphur tetrahedron that do not participate in the formation of an aluminum or magnesium-containing octahedra. The water molecules held within the epsomite ($MgSO_4•7H_2O$) structure are lost if the relative humidity drops below 50% at 298K. In fact hexahydrite ($MgSO_4•6H_2O$) loses water to form starkeyite ($MgSO_4•4H_2O$) at 40% RH at 298K. The fact that wilcoxite, with such a high water content, is stable when the magnesium sulfate with which it coexists has become starkeyite indicates that these water molecules are more tightly bonded within the wilcoxite structure. If epsomite crystals are warmed slightly they slowly become translucent and then an opaque white powder. Wilcoxite, however, behaves quite differently. Williams and Cesbron (1983) describe this break down. "If a hot or bright light source is employed, crystals dissolve in their own waters of crystallization". Wilcoxite does not dehydrate but melts when warmed. This behaviour is similar to the incongruent melting of meridianiite on warming above 2° C. The details of the hydrogen bonding within these structures will be discussed.

GOSSAN HILL, VICTORIA ISLAND, NORTHWEST TERRITORIES: AN ANALOGUE FOR MINE WASTE REACTIONS WITHIN PERMAFROST AND MINERAL PERSISTENCE IN THE SUB-SURFACE OF MARS

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Gossan Hill is located within the Minto Inlier on northwestern Victoria Island, Northwest Territories (N 71.36697° W 114.95155°). From above, the hill stands out because of the topographic relief of 75m and the orange-brown colour of the surficial rocks. The hill is underlain by inter-bedded carbonate and sulfate-evaporite sedimentary rocks of the Kilian formation in the upper part of the neoproterozoic Shaler Supergroup. The sedimentary rocks were intruded by diabase sills of the 723 My Franklin igneous event which crop out ~1km to the south of Gossan Hill. The surface of the hill is marked by areas of concentric colour zonation up to 3 meters across, with light grey centers surrounded by a yellow-orange ring which is, in turn, surrounded by a red-orange colour that covers the rest of the surface of the hill. Trenches dug into these areas reveal that the central zone contains quartz and pyrite ± native sulfur in a loose aggregate of sand-sized grains. This is surrounded by a zone dominated by gypsum and quartz with some jarosite. Beyond this, the surrounding surface consists of quartz, hematite and amorphous iron oxides. The radial arrangement of the mineral assemblage indicates an increase in oxidation of sulfur from the center outward. Analysis of isotopic composition of the sulfur is underway to assess the involvement of bacteria in the formation of the Gossan Hill deposit. The soft friable nature of these deposits and the topographic relief of the hill indicate a post-glacial (Pleistocene) age of formation. Crustal flexure, as the result of isostatic rebound after the loss of the ice sheet, could have created fluid migration pathways from the sulfate-evaporite deposits in the lower part of the Kilian Formation. Permafrost has maintained this disequilibrium mineral assemblage since the cessation of fluid flow. Extraction of the permafrost ice from the central zone yields a liquid with a pH of 2.0. The observed long-term persistence of pyrite encased within the acidic permafrost indicates that oxidation and dissolution reactions common in mine waste are slowed if not stopped in such an environment. Water ice just below the Martian surface would also preserve such mineral disequilibrium for very long periods of time. No region exists on Earth where ice has existed continuously for millions of years, but on Mars, some sub-surface ice may be very old and could be a repository of ancient fluid compositions and reactive mineral assemblages.

REGIONAL POTASSIC ALTERATION CORRIDORS SPATIALLY RELATED TO THE 1750 Ma NUELTIN SUITE IN THE NORTHEAST THELON BASIN REGION, NUNAVUT – GUIDES TO URANIUM, GOLD AND SILVER?

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Shallow granitic intrusions commonly generate mineralized, hydro-thermally altered zones in porous roof rocks. Typically the alteration involves potassic metasomatism, which can be revealed as enhanced K/Th

and K/U ratios in airborne gamma ray maps. 1.75 Ga Nueltin granite plutons in the Dubawnt-Baker-Aberdeen lakes area are subvolcanic, intruding co-magmatic rhyolitic carapaces of the Pitz Formation. A north-opening triangle of enhanced K/Th extends from the Pamiutuq intrusion at Tulemalu Lake (65O) toward Mallery Lake, and a corridor of enhanced K/Th extends north from Dubawnt Lake (65N). These domains coalesce south of Abderdeen Lake (66B,C) at an east-west high-K domain. Although large exposures of Pitz Formation and Nueltin granite constitute portions of these domains, broad tracts with high K/Th have no obvious relation to silicic intrusions.

The Geomapping for Energy and Minerals Program has demonstrated that the 65O triangle contains previously known basaltic intrusions (McRae Lake Dyke and an unnamed intrusion east of it) and newly recognized hi-Ti basalt flows within the Pitz Formation (SE of Tebesjuak Lake, in 650, on Thelon River south of Beverly Lake, and at Mallery Lake), all correlated with the mafic trigger that generated silicic Nueltin/Pitz magmas. Two sets of dykes correlated with the Pitz basalts (~015° parallel to the McRae Lake dyke, and ~075° parallel to the Thelon Fault) are prominent in the high K/Th domain in 66B. We postulate that regional potassic metasomatism is a result of alteration driven by the basaltic phase of the Nueltin event, which is unusually prominent in these domains, with local enhancement by Nueltin granites.

Geochronological tests of this hypothesis are in progress at the University of Manitoba. Fluorite from the Au-Ag deposit at Mallery Lake, located above the roof of a Nueltin pluton near its contact with Pitz Formation basalt, has been dated by Nd-Sm isochron at 1434 ± 60 Ma. Uraninite at Kiggavik, which has a close spatial association with hypabyssal Nueltin bodies, has been dated by a U-Pb method at 1.4 Ga; this age is also represented in Athabasca Basin uranium deposits. The driver for the 1.4 Ga event is uncertain, but it must reflect a crustal scale disturbance which has no known relation to igneous activity in these areas. We speculate that at Kiggavik, this age represents low T resetting of an original higher-grade metasomatic event in wall rocks of the Nueltin Suite which is proposed as an exploration guide to U-Au-Ag deposits.

ZIRCON U-Pb, Hf AND O ISOTOPE CONSTRAINTS ON GROWTH VERSUS RECYCLING OF CONTINENTAL CRUST IN THE GRENVILLE OROGEN, OHIO, USA

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Combined U-Pb, O and Hf isotope data in zircon allows discrimination between juvenile and recycled crust, and is therefore a useful tool for understanding formation and evolution of the continental crust. The crustal evolution of basement rocks in central North America (Laurentia) is poorly constrained as it is almost entirely overlain by a Palaeozoic cover. In order to improve our understanding of the evolution of this region we present U-Pb, O and Hf isotope data from zircon in drill-core samples from the subsurface basement of Ohio. The Hf isotopic data provide evidence for juvenile crust formation at ~1650 Ma followed by continued reworking of a single reservoir. 1643 ±54 Ma igneous zircon in pegmatite provides evidence of a late Palaeoproterozoic continental reservoir within the Grenville province. This 1650 Ma reservoir was tapped in a second igneous event at ~1450 Ma and subsequently reworked during the Grenvillian orogeny. The ~1650 Ma crust formation model age and presence of ~1650 Ma magmatic rocks suggests an eastward extension of the Mazatzal province and makes it a possible protolith to the subsurface basement of Ohio and surrounding Mesoproterozoic (i.e. Grenville-age) rocks. The eastward extension of this ~1650 Ma crustal reservoir into Ohio requires a revision of the crustal boundary defined by Nd isotopic data to be located further east, now overlapping with the Grenville front in Ohio. The easternmost sample in this study is derived from a more depleted reservoir however, which limits the extent of >1.5 Ga basement in subsurface Ohio and defines the location of the crustal boundary.

Syn-orogenic magmatism at ~1050 Ma suggests an extrapolation of the Interior Magmatic Belt to incorporate Ohio.

During Grenvillian metamorphism, zircon recrystallisation occurred in the presence of heavy $\delta^{18}O$ fluids increasing the $\delta^{18}O$ value of metamorphic zircon, which also appears to have been in Lu-Hf equilibrium with the surrounding host rocks.

THE NATURE OF REE MINERALIZATION IN THE MISERY SYENITIC INTRUSION (QUÉBEC)

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The Misery Syenitic Intrusion, located 200 km east of Schefferville, Québec, is host to an interesting, recently discovered REE-Zr-Nb prospect, which locally contains up to 8.56 wt% TREO, 3.05 wt% ZrO_2, and 0.72 wt% Nb_2O_5. The intrusion is conspicuous on aeromagnetic maps as a well defined, ring-shaped anomaly. It was emplaced within the Mistastin Batholith, a large Mesohelikian age igneous body, which intrudes Paleoproterozoic rocks of the Churchill Province. A recent U-Pb radiometric determination on zircon from the intrusion yielded an age of 1409.7 ± 1.2 Ma (David and Dion, 2011).

The core of the intrusion is largely covered by Misery Lake. Country rocks consist of coarse-grained potassic granite characterized by some rapakivi texture and the presence of fayalite. The contact between this country rock and Misery Syenitic Intrusion is gradational. The dominant lithology outside the lake is a coarse-grained syenite composed of idiomorphic perthite with 1 to 10 volume % mafic minerals, comprising fayalite, annite (iron rich biotite), hedenbergite and ferrohornblende. The accessory minerals are quartz, iron oxides (magnetite, titanomagnetite and ilmenite), zircon, fluorite, apatite, britholite, gittinsite and allanite. Other syenites have been observed near the centre of the intrusion (medium-grained syenite, fine-grained syenite and ferrosyenite). Their textures are different but the mineral proportions are similar, except for the ferrosyenite, which contains up to 50 volume % mafic minerals and exhibits a cumulate texture with either fayalite or hedenbergite. This unit seems to form a layer in the intrusion. The geochemical characteristics of the various lithologies in the Misery Syenitic Intrusion suggest that the syenites are alkaline; they are characterized by a very high Fe/(Fe+Mg) ratio (0.8 to 1). Textures in which hedenbergite was replaced by ferrohornblende indicate that the oxygen fugacity of the system increased during subsolidus alteration.

The REE mineralization is concentrated mainly in iron oxide-rich lenses, pods and veins as the mineral britholite ($(Ce,Ca,Th,La,Nd)_5(SiO_4,PO_4)_3(OH,F)$) or in apatite cumulates, which have been partly replaced by britholite. However, some rare metal mineralization also occurs within evolved pegmatitic syenite in the form of cumulate zircon, pyrochlore ($(Na,LREE,Ca)_2Nb_2O_6(F,OH)$), allanite ($(Ce,Ca,Y)_2(Al,Fe)_3(SiO_4)_3(OH)$), gittinsite ($CaZrSi_2O_7$), and REE-fluorocarbonates. Except for zircon and pyrochlore, these minerals are secondary and represent the hydrothermal transport of the rare metals from an as yet unidentified source. Our preliminary observations indicate that magmatic and hydrothermal processes were both involved in rare metal concentration.

OVERVIEW OF VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSITS OF THE CENTRAL MOBILE BELT, NEWFOUNDLAND APPALACHIANS

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The Newfoundland Appalachians host >40 volcanogenic massive sulfide (VMS) deposits with >100,000t, with an aggregate geological resource of ~112 million tonnes. Deposits are hosted in numerous groups of rocks ranging from Cambrian to Ordovician, and have formed within volcanic arc, arc rift, and back-arc basin assemblages within the Dunnage zone. Deposits are of five classes: 1) mafic type – Cu(Zn)-rich deposits hosted

by ophiolitic rocks (e.g., Little Deer); 2) bimodal mafic type - Cu-Zn-rich deposits hosted by bimodal sequences dominated by mafic rocks but hosted in felsic rocks (e.g., Ming, Rambler); 3) bimodal felsic types – Zn-Pb-Cu-rich deposits hosted by bimodal sequences dominated by felsic volcanic rocks (e.g., Buchans, Lemarchant); 4) felsic siliciclastic Zn-Pb-Cu-rich deposits hosted in felsic volcaniclastic-rich sequences with abundant shale and iron formation (e.g., Boomerang); and 5) hybrid VMS-epithermal deposits where deposits have features similar to both VMS and epithermal ore systems (e.g., Ming 1806 zone, Bobby's Pond and Daniel's Pond).

There has been considerable exploration for VMS deposits in the Newfoundland Appalachians resulting in new discoveries in the last decade (e.g., Boomerang deposit, new zones at Lemarchant, Ming, and Little Deer). New research has also resulted in scientific advances including: 1) recognition of the importance that stratigraphic environment plays in the emplacement mechanisms of different ore systems (e.g., subseafloor replacement versus exhalation); 2) recognition of the importance of magmatic fluids in the genesis of precious metal rich VMS systems; 3) the importance of shales in the localization of mineralization in volcaniclastic-rich environments; 4) better documentation of the ore mineralogy and trace metal budgets of Newfoundland ore systems; 5) utilization of field portable technology (e.g., TerraSpec) to better understand the mineralogy of alteration associated with mineralization; and 6) microanalytical work to better understand the sources of S, Pb, and other ore metals within the deposits. Although the Newfoundland Appalachians has experienced significant exploration and VMS deposit research, numerous questions remain unanswered and provide the fuel for many years of research and future exploration.

SUBSEAFLOOR REPLACEMENT ORIGIN FOR THE BOUNDARY VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, TALLY POND GROUP, CENTRAL NEWFOUNDLAND, CANADA

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The Boundary volcanogenic massive sulfide (VMS) deposit (0.50 Mt @ 3.5%Cu, 4% Zn, 1%Pb, 34.00g/t Ag), Tally Pond Group, Victoria Lake Supergroup, central Newfoundland, Canada represents one of the best preserved subseafloor-replacement style VMS deposits in the northern Appalachian Orogen. The deposit is hosted within a late Cambrian (~510 Ma) volcanic sequence consisting predominantly of rhyolitic flows and associated volcaniclastic rocks. The deposit consists of a footwall dominated by rhyolitic lapillistones, tuffs, and lesser rhyolite flows and in-situ rhyolite breccias. The hanging wall consists of massive, quartz-bearing, flow banded, lobe and breccia facies rhyolite. The deposit occurs at the contact between these two units and consists of pyrite, chalcopyrite, and lesser sphalerite that have partially to fully replaced the footwall lapillistone and tuff units. The sulfides contain abundant clasts of the surrounding host rocks, including chlorite-sericite-quartz altered rhyolite lapilli and ash. Hydrothermal alteration consists of variably intense chlorite with lesser sericite and quartz alteration. Chlorite alteration occurs in both a discordant form, likely representing hydrothermal upflow zones, and as blankets that parallel the volcanic stratigraphy, likely representing alteration associated with replacement. Sericite and quartz occur in the hanging wall in similar geometric form, but more distal from mineralization. The hanging wall rhyolite flows (where present) also contain moderate to intense, pervasive, quartz and sericite alteration. Both the hanging wall and footwall are characterized by strong Na_2O-Sr depletions, K_2O-MgO-Fe_2O_3-Ba-enrichments, and enrichments in base metals and volatile metals (e.g., Hg, Tl). The presence of abundant remnant wallrock/host rock clasts within the ore, intricate sulphide replacement of porous tuff laminations and sand dykes, replacement fronts in host lithofacies, and intense alteration in both the footwall and hanging wall (where the hanging wall is present) of the deposit are all features consistent with formation of the bulk of the deposit via subseafloor replacement, a genesis style originally posited by industry geologists. The Boundary deposit likely formed as a result of cooling of metal bearing VMS fluids, mixing with ambient seawater and pore water/entrained seawater within the volcanics at a permeability interface between young, unlithified, highly permeable footwall volcaniclastic rocks and relatively impermeable hanging wall rhyolitic flows. This permeability boundary was likely an important feature in stimulating subseafloor replacement within the deposit.

GEOLOGY, LITHOGEOCHEMISTRY, AND *IN-SITU* S AND Pb ISOTOPE GEOCHEMISTRY OF HYDROTHERMAL SEDIMENTARY ROCKS FROM THE DUCK POND VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, TALLY POND GROUP, NEWFOUNDLAND APPALACHIANS

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Pyrite- and pyrrhotite-rich mudstones are a common element throughout the Tally Pond Group, Victoria Lake Supergroup, central Newfoundland many of which are spatially associated with volcanogenic massive sulfide (VMS) mineralization. At the Duck Pond VMS deposit, the Upper Block, despite not hosting the deposit or having significant mineralization, contains abundant hydrothermal mudstones. These mudstones are dominated by laminated, variably carbon-bearing mudstones with layers of pyrrhotite and pyrite with lesser chalcopyrite, spalerite, and galena. The mudstones occur as 10-30cm wide beds atop of variably epidote-quartz-chlorite altered pillow lavas. The mudstones have anomalous base metals, volatile metals, and high Fe/Al values consistent with deposition from metalliferous fluids. However, they have high Y/Ho (>>27), Ce/Ce*<1, and Eu/Eu*<1, indicating deposition from lower temperature fluids that have likely interacted significantly with seawater (i.e., Fe-oxide particles scavenging REE+Y from seawater). Paragenetically constrained *in situ* S isotope data on pyrite, pyrrhotite, and chalcopyrite obtained via secondary ion mass spectrometry (SIMS) indicate complex mixing between biogenically-derived sulfur from bacterial sulfate reduction of seawater sulfate and hydrothermal sulfur derived from thermochemical sulfate reduction of seawater sulfate. *In-situ* Pb isotope data for galena in hydrothermal sediments overlap Pb isotope values for both bulk rock Pb and *in-situ* Pb values for galena in the Duck Pond ores, lie between the orogene and upper crust Pb isotope growth curves, and are consistent with derivation from upper crustal sources along the margin of Ganderia. Despite not hosting significant mineralization, the geological, geochemical, and isotopic features of the Duck Pond mudstones indicate that they have a hydrothermal origin, albeit a low temperature origin, and suggests that there may be potential for VMS mineralization in the Upper Block at Duck Pond and correlatives regionally within the Tally Pond Group.

PETROLOGY AND GEOCHRONOLOGY OF THE TAY RIVER PLUTONIC SUITE, SOUTHEAST YUKON

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A southeast-trending belt of mid-Cretaceous granitic plutons from central Alaska across the Yukon have been classified by age, physical characteristics, mineralogy, whole rock composition and oxidation state. Suites within this belt include the Tombstone, Mayo, Tungsten, Tay River, transitional Tungsten-Tay River, Anvil and Hyland. Plutons in the Coal River map area at the southeast end of the belt belong to the Tay River suite, a coherent belt 465 km long and approximately 120 km wide.

Granodiorite to quartz monzodiorite 99-95 Ma predominate. The dacitic South Fork volcanic calderas north of Ross River hamlet are coeval.

During mapping in 2009 and 2010 several previously unrecognized intrusions were located following regional aeromagnetic anomalies. Most stocks are small and roughly circular, ranging from 335 m to 8400 m in diameter. Three larger intrusions to the north extend into the map area. All are grey-weathering, fine- to medium-grained, unfoliated to slightly foliated, biotite ± hornblende quartz monzodiorite to granodiorite. Texturally the intrusions include equigranular and porphyritic variants. Equigranular variants locally have K-feldspar megacrysts. Porphyritic variants are typically crowded with plagioclase phenocrysts up to 5 mm across in a fine-grained, grey matrix. Hornblende, biotite, and minor quartz also occur as phenocrysts in the porphyritic phases.

U-Pb dates were obtained by the isotope dilution thermal ionization mass spectrometry method with chemical abrasion (CA-TIMS) of single zircon grains. Five or six grains were analyzed from each of eight samples. All analyses are concordant and $^{206}Pb/^{238}U$ dates from six samples are equivalent within each sample. Weighted mean U-Pb zircon dates from eight plutons range from 99.80 ± 0.03 to 97.70 ± 0.03 Ma (97.70 ± 0.03, 97.83 ± 0.03, 98.20 ± 0.03, 98.26 ± 0.03, 98.34 ± 0.03, 98.52 ± 0.03, 99.38 ±0.03, 99.80 ± 0.03 Ma). The results suggest slightly younger ages are to the south (0.5 Ma over 10 km).

Mid-Cretaceous plutonism in southeast Yukon reflects a back-arc area of the continental crust above an east- to northeast-dipping subduction zone located to the west. The Tay River suite marks the position of back-ark plutonism and volcanism between 97 and 100 Ma. The plutonism then shifted eastward and ceased at ~90 Ma.

THE MAIN SOURCES OF METALS AND SULFUR IN ARCHEAN – EARLY PROTEROZOIC ORE DEPOSITS

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The absolute majority of Archean – Early Proterozoic ore deposits contain Cu, Ni, Cr, Co, Pb, Fe, Zn, Hg, Au, Ag, platinum group elements (PGE), etc, as native metals and compounds (primarily sulfides). Ore deposits contain different combinations of major metals along with mining by-products. There are numerous mineralizations and small mostly non-economic ore deposits of Early and Middle Archean age, but much greater deposits of Late Archean and Early Proterozoic.

During early stages of magma-ocean solidification, the atmosphere was composed of layers of SO_2, HCl, HF, CO/CO_2 and H_2O stratified by density ($\sigma SO_2 \approx 292$ kg/m^3, $\sigma HCl \approx 454$ kg/m^3, $\sigma HF \approx 566$ kg/m^3, $\sigma CO \approx 314$ kg/m^3 and $\sigma CO_2 \approx 135$ kg/m^3, and $\sigma H_2O \approx 60$ kg/m^3 at temperature 1273 K and pressure ≥35 MPa) and generating partial pressures of ≤5.44 MPa, ≤2.72 MPa, ≤4.35 MPa, ≤2.99 MPa, and ≥27 MPa, respectively. During crustal/lithospheric cooling, the surface interacted with such leaching agents as SO_2 (S0, SO_3 and H_2SO_4 at lower temperatures), HCl and HF, before their redistribution into the earth and formation of the water-ocean. Based on analysis of ratio of sedimentary to magmatic deposits thicknesses of Barberton Greenstone Belt, South Africa and Pilbara Craton, Australia, water-ocean formation took place between 3.42 and 3.26 Ga. It was mostly formed by ~3.2 Ga when the early Earth atmosphere's sulfur-layer was completely redistributed, evidenced by formation of significant amounts of barites. During the Hadean – Early Archean, most highly reactive metals (alkali, alkaline earth, etc.) were leached from surface and near-surface rocks as part of the redistribution of HCl-, HF- and sulfur-layers yielding a concentration of least reactive metals. The main metals of Archean – Early Proterozoic ore deposits have a resistance to mineral acids, which considerably increases when they form alloys (Ni-Cu-, Fe-Ni-, Cu-Zn-based alloys, etc.), especially by alloying with Au and PGE. Komatiite magmatism provides excellent conditions for the formation of such alloys. The main sources of sulfur after its redistribution are related to the decomposition of certain sulfides and sulfates at high temperatures. Felsic magmas cause limited decomposition and formation of sulfur-poor ore deposits; while komatiites and Mg-rich basalts cause almost complete decomposition of sulfides and sulfates, with release of sulfur during komatiite magmatism peaks in ~2.8-2.7 Ga (second generation of sulfur) and ~1.9 Ga (third generation of sulfur). Absence of water-ocean in the Hadean – Early Archean means absence of hydrothermal activity, which led to concentration of great amounts of important metals and formation of significant ore deposits starting from Late Archean.

AN EXAMINATION OF AWARUITE (Ni_3Fe) FORMATION DURING SERPENTINIZATION OF THE PIPESTONE POND COMPLEX IN THE ATLANTIC LAKE AREA, CENTRAL NEWFOUNDLAND

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There are several well exposed ultramafic complexes in Newfoundland, some of which have been important to mineral exploration and mining activities for decades. These ultramafic bodies have undergone variable degrees of serpentinization: low grade, retrograde metamorphism during which the Fe-Mg silicates olivine and pyroxene break down to form one of the serpentine-family of minerals and magnetite. Strongly reducing conditions produced by the release of H_2 during magnetite formation can provide the conditions amenable to the formation of Ni-rich mineral phases such as the nickel-iron alloy awaruite (Ni_3Fe). The stoichiometric nature of Ni-minerals formed during serpentinization is also influenced by the amount of sulphur available in the system. Awaruite forms under reduced conditions in the absence of sulphur from the hydrous-metamorphic remobilization of nickel from olivine and/or the breakdown of primary sulphides such as pyrrhotite and pentlandite.

The scope of this project is i) to document awaruite and associated nickel-bearing mineral phases in the Atlantic Lake area of the Pipestone Pond Complex, central Newfoundland, and ii) to constrain the geological conditions under which Ni-Fe alloys form. Petrographic and SEM-MLA analyses were utilized to locate awaruite and define its associated mineral assemblages. XRF data of the serpentinized lithologies indicate greater nickel contents present than those that could solely be sequestered in sulphides, and probably in silicate phases. Sequential acid digestions are being conducted to identify whether the nickel source for awaruite was produced through the breakdown of either olivine or sulphides or a combination of both. By providing some insight on the controls of on awaruite formation, this research will be used to help guide exploration for Ni-Fe alloy minerals.

GEOCHEMICAL ALTERATION AND STRUCTURAL INTERPRETATION AS AN EXPLORATION VECTOR AT THE LAC CINQUANTE URANIUM DEPOSIT, NUNAVUT, CANADA

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The Lac Cinquante uranium deposit is located in the Hearne Subprovince of the Western Churchill Province. The deposit is hosted within an Archean greenstone belt that is unconformably overlain by the northeast trending Angikuni sub-basin of the Paleoproterozoic Baker Lake basin in the western Churchill Province. Uranium mineralization at Lac Cinquante consists of a 43-101 compliant inferred mineral resource estimate of 1,779,000 tonnes grading 0.69% U_3O_8, making Lac Cinquante Canada's highest grade uranium deposit outside the Athabasca Basin. Mineralization is hosted within a zone of strong tectonic transposition. Specifically it occurs as pitchblende in discrete veins along or at small angles with the transposition foliation and in tensional gash veins cutting the transposition at high angles. Mineralization also occurs weakly in Paleoproterozoic basal conglomerates. In this study we present results for oxygen stable isotope analyses of silicate whole-rock samples, and examine surface and sub-surface features to determine the structural controls on the deposit. Through integration of these techniques we investigate the implications for fluid flow, alteration, and mineralization of the main ore zone at Lac Cinquante.

Oxygen stable isotope analyses are effective in documenting zones of increased low-temperature fluid flow which resulted in hydrothermal alteration associated with the main zone of mineralization. Oxygen stable isotope analyses of silicate whole rock samples have identified 20 – 50 meter wide alteration envelopes where values are elevated by almost 2‰ within, and surrounding, the main zone. Several tuffaceous units not associated with the current main zone also show anomalous enrichments up to 2.5‰. Additionally, 1‰ enrichment halos can be traced around structural zones in the basaltic basement rocks.

Mineralization forms linear, shallow west-plunging ore shoots within the Lac Cinquante and Western Extension prospects, and steeply east-plunging ore-shoots within the Eastern Extension. The orientation of these ore-shoots potentially corresponds to the intersection of hematite-stained tensile fractures trending 050° and high-strain zones trending 110°, which are proposed to reflect areas of increased fluid flow.

Combined, structural interpretation and geochemical analysis can be utilized as an exploration vector to define future drill targets. This strategy can be further applied to historic drill core to identify possible near misses during past drilling as well as geophysical targets in the region not directly associated with the main zone mineralization.

GEOMETRY OF THE APPALACHIAN TECTONIC WEDGE IN THE ST. LAWRENCE ESTUARY AND ADJACENT AREAS

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In Quebec, the St. Lawrence Estuary roughly follows the Appalachian deformation front. Its northwestern shore predominantly consists of Late Proterozoic Grenvillian metamorphic rocks with a few outliers of Ordovician autochthonous carbonate – siliciclastic rocks of the St. Lawrence platform, whereas Early Paleozoic sedimentary rocks that belong to the Appalachian tectonic wedge occur along its southeastern shore. In detail, however, the submarine boundaries between the Grenvillian basement, the St. Lawrence platform and the Appalachians were not precisely documented.

A recent aeromagnetic survey adds significant constraints on the geometry of the Appalachians. Magnetic data in the St. Lawrence Estuary highlight a belt of relatively long (15-30 km) wavelength positive anomalies reaching 100's nT above the regional field and take the form of disconnected ovoid anomalies separated by faults.

Maps that enhance short wavelength magnetic anomalies associated with near-surface sources allow tracing the generally NE-trending offshore extent of the Appalachian-St. Lawrence Platform boundary, which includes a ENE segment in the northern part of the studied area. Within the Appalachian wedge, WSW-trending faults are documented on the basis of truncation of short wavelength anomalies. These faults trend obliquely compared with the main structural grain and extent onshore where their significance and length were underestimated in previous field mapping programs. These structures that were previously mapped as 'short' second-order structures correspond to deformation zones up to 90 m wide with kinematic indicators (C-S structures, asymmetric folds; slickensides, drag folds and strike separation of passive markers) demonstrating right-lateral motion.

Additional constraints on the geometry are provided by seismic reflection profiles collected on the south shore, both parallel and perpendicular to the estuary. The maximum depth of the base of the Appalachian tectonic wedge may be estimated from these profiles that mainly image seismic markers within the St. Lawrence Platform succession.

Keynote HOW GEOLOGICAL FRAMEWORK EXPLAINS THE DISTRIBUTION OF GEOHAZARDS, GEOCONSTRAINTS AND GEOINSIGHTS FOR OFFSHORE DEVELOPMENT IN THE DEEP-WATER EASTERN CANADIAN MARGIN

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A geohazard is "A geological state that represents or has the potential to develop further into a situation leading to damage or uncontrolled risk." In offshore development, geohazards are of four inter-related types: (1) seabed interaction with moving water and ice; (2) slope instability; (3) pore-pressure phenomena; and (4) seismicity. In offshore development, geoconstraints are aspects of geology that have substantial economic consequences, even if there is no damage, such as strength properties of the seabed and boulder beds. Geoinsights are the use of geological information to solve environmental issues in other disciplines, such as near-bottom dispersal of pollutants by bottom currents and habitat for vulnerable marine ecosystems. Assessment of all these geological issues is built on an understanding of the regional geological framework. First-order control of seismicity, petroleum basin sedimentation and tectonics, and regional seafloor gradients are a direct consequence of the rifting and sea-floor spreading history of the margin. These parameters in turn influence most of the major categories of geohazards. Assessment of enhanced risk of seismicity or pore-pressure geohazards in particular regions should trigger enhanced regulatory response. Geological issues associated with the uppermost part of the geological column are strongly influenced by the peculiarities of glacial and post-glacial geological processes. Seabed morphology and sediment types that affect shallow drilling conditions are largely a consequence of processes at glacial maxima. The observed distribution of submarine slides of different types is strongly influenced by shallow morphology and geology, but their frequency does not appear responsive to geological setting, implying an important role for seismicity. Modern sedimentation processes in submarine canyons are poorly understood, as is their influence on geohazards. The value of a regional perspective on these geological issues will be illustrated with type examples, as well as how experience in one region can be applied to another region in the light of differences in geological framework.

PROTEROZOIC REDOX CONDITIONS AND EVOLUTION

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The chemical composition of the ocean changed dramatically with the oxidation of the Earth's surface, and this process has profoundly influenced the evolutionary and ecological history of life. The early Earth was characterized by a reducing ocean-atmosphere system, while the Phanerozoic Eon (<542 million years ago) is known for a stable and oxygenated biosphere conducive to the radiation of animals. The redox characteristics of surface environments during the Earth's middle age (1.8 to 1 billion years ago) are less well known, but over the past decade it has been commonly assumed that the mid-Proterozoic was home to a globally sulfidic (euxinic) deep ocean. Here, we will present evidence that anoxic and Fe(II)-rich conditions were both spatially and temporally extensive across diverse paleogeographic settings in the mid- Proterozoic ocean. Further, we will explore the how the Earth transitioned from this reducing state that characterized most of the Precambrian to the oxidized state typical of the Phanerozoic.

SERPENTINIZATION OF MANTLE PERIDOTITE IN THE BAY OF ISLANDS OPHIOLITE: IMPLICATIONS FOR THE ORIGIN OF LIFE

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Life arose on Earth about 4 billion years ago and has flourished ever since. In contrast to the present nitrogen and oxygen-rich atmosphere on Earth, the atmosphere on primitive Earth was composed primarily of carbon dioxide, hydrogen and water vapor. For life to have emerged in this environment on the early Earth, a sustained source of chemical energy that could drive metabolism by chemosynthetic organisms was vital. The serpentinization process is proposed as the likely source of that energy.

The Bay of Islands Complex is a well preserved ophiolite complex comprising rocks of the oceanic crust and mantle located in western Newfoundland. The mantle peridotite from the complex exposed on the mountains of the Tablelands is composed largely of the minerals olivine [$(Mg,Fe)_2SiO_4$] and pyroxene [$(Ca,Mg,Fe)_2Si_2O_6$] which are in chemical disequilibrium at the Earth's surface and react with H_2O and CO_2 in near surface environments producing Mg–HCO^{3-} type waters. Reaction of Mg–silicates and these Mg–HCO^{3-} waters out of contact with the atmosphere consumes H^+ and leads to the precipitation of magnesite and dolomite. The

waters formed from these reactions are progressively richer in Ca and OH^-, are supersaturated with respect to brucite, serpentine and diopside, and have a high pH of c. 12. When these Ca–OH^- type waters flow near the surface and mix with Mg–HCO^{3-} waters and the atmosphere, they precipitate calcite and dolomite in near surface veins and carbonate cement in unconsolidated sediments and travertine. The Ca–OH^- type waters are incompatible with minerals in adjacent country rocks and form a Ca–rich metasomatic zone or rodingite assemblage along the contact.

The oxidation of iron through metamorphism of olivine (Fe^{2+}) to magnetite (Fe^{3+}) during serpentinization occurs at temperatures <200°C and provides a readily available source of electrons to create a highly reducing environment leading to the reduction of water to H_2 and abiotic production of hydrocarbons. Similar elevated abiogenic hydrocarbon concentrations have been reported from submarine ultramafic hosted systems in which geological, chemical and biological processes are intimately interlinked and support dense microbial communities. The conditions associated with serpentinization of ultramafic rocks by meteoric waters are analogs for potential early biochemical ecosystems on both Earth and other telluric planets, and could be a common means for producing a broad array of microorganisms that may represent the earliest chemolithoautotrophic life forms on Earth.

CAMBRIAN-ORDOVICIAN SUCCESSIONS AND DETRITAL ZIRCON GEOCHRONOLOGY OF NORTH WALES AND NOVA SCOTIA: TERRANE INTERACTIONS BETWEEN GANDERIA AND MEGUMIA

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The Harlech Dome and St. Tudwell's Peninsula, in North Wales, and the Meguma Terrane of southern Nova Scotia, in Atlantic Canada, preserve similar sedimentary successions of Cambrian age. All three areas display thick early Cambrian continental-derived sandstone turbidites, overlain by early to middle Cambrian alternating mud-rich and sand-rich units in which manganese is locally concentrated. The manganiferous interval is everywhere marked by a diverse and abundant assemblage of trace fossils, including locally abundant Teichichnus. Above, the successions comprise anoxic, organic-rich turbidites, shallowing upward into paler, early Ordovician mudstone and siltstone with the graptolite Rhabdinopora.

Meguma detrital zircon assemblages display strong peaks in the late Neoproterozoic (common to many peri-Gondwanan terranes) and in the Paleoproterozoic (2.0 - 2.2 Ma), suggesting derivation from the Eburnean orogens of West Africa. Detrital zircons from the Harlech Dome reveal closely similar clusters of ages. Within the limited constraints of the available biostratigraphic and geochronologic data, major changes in environment occurred synchronously in the two successions in the Cambrian. These areas show much greater similarity to each other than to Cambrian successions in now-adjacent "Avalonia", suggesting proximity between the Harlech Dome and Megumasuccessions on the margin of Gondwana. The two areas are included in the domain "Megumia", which was dispersed during subsequent Appalachian/Caledonian movements.

In the Ordovician the histories diverge. The highest parts of the Nova Scotian succession record shallowing conditions with shelf sedimentation extending through the Early Ordovician, whereas the Welsh successions are overlain with angular unconformity by Tremadocian volcanic rocks, and then by Floian sandstone and younger Ordovician volcanic rocks. In the Welsh successions a strong component of Mesoproterozoic zircon indicates that the basin was juxtaposed with Ganderia in the Monian/Penobscot events in the Early Ordovician.

ALTERATION MAPPING IN IOCG SYSTEMS: FAB LAKE CASE STUDY

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Building on a lengthy heritage of mineral exploration and production of vein-type uranium and silver deposits, the Great Bear magmatic zone (GBmz) is now known to have a very high potential for undiscovered magnetite- and hematite-group iron oxide copper-gold (IOCG) deposits and affiliated iron oxide-apatite and albite-hosted uranium systems. Detailed mapping of the Fab Lake hydrothermal system was undertaken, east of the community of Gamètì, NT, to test the applicability of an alteration to brecciation and mineralization evolution model developed under the GEM IOCG/Multiple Metals project. The Fab system was selected due to its relative simplicity, numerous mineral showings, ease of accessibility and restricted spatial extent. Alteration was mapped by systematically documenting alteration type, style, mineral paragenesis, breccias, cross-cutting relationships and determination of K (%), eTh (ppm) and eU (ppm) concentrations and volumetric magnetic susceptibility.

The alteration footprint of the Fab IOCG system has now been defined over an area of almost 10 by 5 km, with the long axis trending in a southeast-northwest direction. Within this area, field mapping identified seven alteration assemblages: 1) high temperature albite and albite-amphibole±magnetite; 2) amphibole-magnetite±apatite and amphibole-magnetite-K-feldspar; 3) K-feldspar; 4) K-feldspar-magnetite±hematite; 5) chlorite; 6) hematite; and 7) low temperature epidote-K-feldspar-quartz. These alteration assemblages are manifested by the development of incipient to pervasive alteration, veins, hydrothermal breccias and transient to intense, texture-preserving and texture-destructive replacements of the host rocks. All of the historic mineral showings (U-Cu) fall within zones characterized by intense, texture destructive alteration comprising multiple episodes of high temperature albite/albite-amphibole (Na and Na-Ca-Fe) and amphibole-magnetite±apatite/amphibole-magnetite-K-feldspar (Ca-Fe and Ca-Fe-K) overprinted by K-feldspar-magnetite±biotite (K-Fe) assemblages.

The conceptual alteration to brecciation and mineralization model is key to understanding the alteration assemblages documented in the Fab IOCG system. These assemblages record the build-up of a magnetite-group IOCG system: early high-temperature Na/Na-Ca-Fe and Ca-Fe/Ca-Fe-K alteration, overprinted by high temperature K-Fe alterations and incipient to well-developed hydrothermal breccias. As field observations indicate that lower-temperature K-Fe alteration associated with hematite-group IOCG systems is only weakly developed, the Fab Lake region is most prospective for magnetite-group types of IOCG mineralization.

While petrographic studies are planned to complement field observations, these initial field observations clearly document the ability of the alteration to brecciation and mineralization zoning model to overcome the inherent complexity of these hydrothermal systems and provide field evaluations of their maturity and fertility.

BORATE MINERALS; HILGARDITE, VEATCHITE AND VOLKOVSKITE FROM MARINE EVAPORITE DEPOSITS OF NEW BRUNSWICK; NEW DATA AND GEOLOGICAL INTERPRETATION

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Chemical composition, and optical and X-ray crystallographic data were collected for borate minerals; hilgardite ($Ca_2B_2O_9Cl{\bullet}H_2O$), veatchite ($Sr_2[B_2O_8](OH)]_2B[OH]_3{\bullet}H_2O$, and volkovskite, ($KCa_4B_{22}O_{32}[OH]_{10}Cl{\bullet}4H_2O$) primarily from the Sussex mine (Penobsquis) and Millstream deposits, New Brunswick. Hilgardite and veatchite both possess polytypes, an important area of study in crystallography. Polytypism is unique to

layered structured minerals and can provide information relevant to conditions of crystal growth. For hilgardite, with three polytypes (-1A, -3A, - 4M), from two different locations, the Sussex mine and Millstream deposit in New Brunswick, were examined. These three polytypes show different X-ray powder diffraction (XRPD) patterns. The patterns of -1A and -3A polytypes indeed show differences in the d values ranging from 5.5 to 5.8 Å and from 3.1 to 3.2 Å. In the latter range, polytype -1A displays one single peak, whereas polytype -3A shows multiple peaks. The XRPD pattern of polytype -4M varies greatly from the -1A and -3A structures due to an increase in symmetry and cell dimensions. For veatchite, three polytypes have been identified by Grice (2012). Among three, two polytypes were examined; veatchite-2M from the Sussex mine, New Brunswick, veatchite-1M from Reyershausen, Germany and veatchite-1A from Emet, Turkey. These three are expected to show different XRPD patterns and our study of polytypes -1A and -2M confirmed clear differences between the two. Differences in d-values (Å) are observed in the ranges from 5.2 to 5.6, from 3.2 to 3.3 and from 2.7 to 2.9. The emergence of additional peak(s) in these select ranges confirms the prediction from XRPD patterns calculated from the structure determinations. Thus XRPD can be used directly to determine which polytype is present without involving crystal structure analysis. Knowing the polytype can be used as an indicator of the hosts' environment (Grice 2012). In the present study a crystal structure refinement of volkovskite confirms the basic model of Rastsvetaeva *et al.* (1992). Greatly improved data allows for a refinement of H positions that is used to elucidate H-bonding, a factor critical in better understanding of crystal structure of borate minerals and the development of efficient extraction techniques of boron. The volkovskite structure obtained in this study is applicable to many layered borates, such as biringuccite, nasinite and gowerite as previously studied by Grice *et al.* (1999).

GEOCHEMICAL ANOMALIES IN SURFACE MEDIA AND UPPERMOST SANDSTONES OVERLYING THE CONCEALED PHOENIX URANIUM DEPOSIT, ATHABASCA BASIN, CANADA

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The Wheeler River Property, host of Denison Mine's Phoenix uranium deposit, is situated near the southeastern rim of the Athabasca Basin in northern Saskatchewan. Discovered in 2008, the deposit currently has an indicated resource of approximately 35 million lbs U_3O_8. Mineralization occurs as mainly monominerallic uraninite within four pods termed the A, B, C and D ore zones. This deposit has no surficial expression, and occurs near the unconformity between the crystalline basement rocks and overlying Athabasca sandstones at approximately 400 meters depth. The surficial environment, within the region of discontinuous permafrost, consists of gently rolling hills covered by glacial till and moraines, with overburden varying in thickness from 25 to 100 m. In September 2011, we initiated a study to evaluate whether geochemical anomalies related to such a deeply seated deposit exist in surface media or the overlying sandstones. A total of 226 soil samples (humus, B, E, and C-horizon) from 59 sites along 3 transects over the "A" and "B" ore zones were collected approximately 10 meters apart. In addition, traverse sampling was done to determine "background values" in the study area setting.

Geochemical analyses of the samples revealed the presence of strong U, Mo, Co, Ag and W anomalies in humus, B-horizon soil and uppermost sandstones not only overlying the A and B zones, but also over a nearby northeast-trending "WS Hanging Wall" Shear Zone. Peak to background ratios were up to 6 times (5.7 ppm) for U, 5 for Mo (4.8 ppm), 4 for Co (5.2 ppm) 20 for Ag (0.98 ppm) and 18 for W (100 ppm), respectively, in the various surface media. The geochemical anomalies in the surface media and the uppermost sandstones over the shear zone suggest that the fault is acting as a conduit for upward movement of fluids from the deposit. This fluid movement and resulting geochemical expression in surface media provides excellent exploration tools for deeply seated unconformity-related uranium deposits in Proterozoic sedimentary basins.

The 5.7 ppm U anomaly by aqua regia digestion method of the humus layer yielded among the strongest and most robust geochemical anomalies, and therefore is recommended as the leach of choice in this well-drained area of the Basin.

BIOCHEMICAL COPPER (HEMOCYANIN) IN THE MIDDLE CAMBRIAN ARTHROPOD MARRELLA

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The Burgess Shale, a fossil Lagerstätte famous for its diversity of advanced Cambrian animals, onlaps a submarine fault scarp cutting the margin of a drowned carbonate platform in southeastern British Columbia. We conducted reconnaissance synchrotron X-ray fluorescence imaging of a handful of specimens belonging to several taxa. This technique has an advantage over conventional elemental mapping with the electron microprobe in that much smaller quantities can be detected. We focussed on Marrella splendens Walcott 1912. This small trilobite-like arthropod has an elaborate, non-mineralized exoskeleton and, where well preserved, typically exhibits a dark stain emanating from the head region or the tip of the thorax. This stain represents a body fluid—most likely blood—that was expelled upon death or that leaked out early during decay.

Our analysis revealed that Fe and S concentrations, for example, are especially high in the fossils, indicating precipitation of diagenetic pyrite influenced by decay. Most other elements show no preferential distribution. However, elevated concentrations of Cu, as chalcopyrite, were observed in the four specimens of Marrella scanned, mostly confined to the dark stain, but essentially not in other taxa or the matrix.

We interpret this Cu enrichment as the remnants of Cu-containing blood, hemocyanin. Hemocyanin occurs widely in mollusks and arthropods, especially chelicerates and crustaceans, and it is utilized for transporting oxygen in the respiratory cycle. It was likely present in other Burgess Shale animals, but because they were not so blood-rich, most of the Cu was recycled back into the water column during biodegradation instead of lingering long enough in the sediment to be fixed by bacteria into chalcopyrite.

Because hemocyanin is a less efficient oxygen-binding protein (compared to Fe-containing hemoglobin) but a far better transport mechanism than simple diffusion, it is reasonable to suppose that Marrella lived in well-oxygenated waters. Its exceptional blood-rich nature might have allowed it extra vigour of movement than other members of the community. It also may have allowed Marrella to tolerate exposure to reducing fluids that may have issued from submarine springs at the base of the fault scarp.

TECTONOSEDIMENTOLOGY

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Students can hunt hither and yon in textbooks for basic information on the role of earthquakes and tsunamis in sedimentology and good illustration of the variety of telltale structures, but chances are they will come up empty-handed. For example, the index of Facies Models 4 (2010) contains only a few entries in which these are mentioned just in passing. Why is this? Are senior textbook authors reluctant to incorporate what might strike them as unconventional interpretations, awaiting some magic moment of validation and acceptance? Is it because these features are not considered important or common in the rock record? Or have authorities deemed 'seismites' and 'tsunamites' impossible to distinguish from slump and storm deposits respectively, so just fuggedaboudit?

Meanwhile, for more than a decade, research on ancient seismically deformed and tsunami-generated deposits has been proceeding vigorously. Deformation features ranging in size from millimetres to kilometres in scale have been well characterized and reliably interpreted from all manner of settings and geological ages. Certain coastal deposits, impact-related facies, and anomalous beds in subtidal shelf successions have been fingered as tsunami-generated. Modern events underscore their commonplace occurrence. Indeed, the case could be made for earthquakes and tsunamis as the default explanations in place of gravity and storms in certain situations.

Sedimentologists studying the rock record work backwards, combining lithological observations with hydraulic and mechanical

principles, modern analogues, biological attributes, laboratory simulation and mathematical modelling. These are all in operation in tectono-sedimentology. Naturally, interpetation is still bedevilled by unknowns and plenty of controversy is enjoyed. Nonetheless, the implications are legion, for tectonosedimentology opens new windows on syndepositional fault activity, sediment rheology, shoreline configuration, paleoclimate, paleoceanography, diagenesis, fluid flow and so on.

GEOLOGICAL HERITAGE PROTECTION IN IRELAND: THE WORK OF THE IRISH GEOLOGICAL HERITAGE PROGRAMME OF THE GEOLOGICAL SURVEY OF IRELAND

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The Geological Survey of Ireland (GSI) achieved recognition of geology as an intrinsic part of the heritage definition through the Heritage Act 1995.

GSI subsequently set up the Irish Geological Heritage Programme (IGHP) in 1998 to document the wealth of geological heritage, and recommend appropriate protection measures in the Republic of Ireland, based on European best practice. The programme is a partnership between GSI and the National Parks and Wildlife Service (NPWS), who has the statutory authority to designate sites as Natural Heritage Areas (NHA).

16 themes were identified to best evaluate and categorise sites of geological heritage interest. Panels of experts were set up to recommend the best representative sites within each theme and they identified about 1200 sites.

The original aim of IGHP was to document and achieve designation of sites of national and international importance as NHA through NPWS, and sites of local and regional importance as County Geological Sites (CGS) through local authorities. The Wildlife (Amendment) Act provided the statutory basis for NHA in 2000 and the National Heritage Plan (NHP) recognised the value of CGS and GSI's work in 2002.

Due to ongoing limited resources in NPWS and the priority given to European designated sites, NHA designations have been largely shelved.

Documentation of sites has instead been pursued through the CGS system. This is achieved through county audits in which site boundaries are surveyed and their status assessed. Audits are largely funded by the Heritage Council, thereby fulfilling its responsibility to address the geological part of heritage. Audits are carried out and completed following GSI/IGH guidelines to ensure continuity and quality control. Data are then integrated in the planning system of the local authority, thereby helping planners to make informed decisions. They also have the responsibility to include policies, with GSI's advice; ensuring geological heritage is protected from inappropriate development (as per NHP).

IGHP also coordinates, in GSI, submissions to consultations received for Environmental Impact Assessments and advises on mitigation measures for geological heritage sites, when applicable. IGHP has published collaborative guidelines with the Irish Concrete Federation aimed at helping all quarry operators to follow best practice in addressing geological heritage issues.

Derived products from these audits include travelling exhibitions and booklets to help raise awareness of a county's geological heritage, and data are also provided to support Geoparks, geotourism and educational initiatives.

LESSONS LEARNT FROM AN IRISH GEOPARK: THE COPPER COAST GEOPARK, COUNTY WATERFORD, IN SOUTH EAST IRELAND

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Located in rural South East Ireland, the Copper Coast joined the European Geoparks Network as one of its earliest members in 2001, and remains its smallest territory. The local communities identified the unspoilt landscape, varied geology and mining heritage as their unique selling point to attract visitors to their otherwise undervalued tourism destination. The Geological Survey of Ireland was one of the first partners to support the project.

Geological sites of international importance benefited from the initiative as they were included in the county development plan as an integrated part of the local heritage, insuring their protection against inappropriate development. The local authority put measures in place to protect those sites exposed to coastal erosion.

The Geopark's activities and educational resources helped to develop awareness of the linkages between geology and people's everyday life, through various means but notably by tapping into the local knowledge, and thereby increasing a sense of place and pride.

Successful European funding bids in partnership with other Geoparks provided much needed financial support, allowing recruitment of staff and infrastructure to be put in place. Once on the map, the Copper Coast brand name gained recognition, triggering business opportunities for inspired entrepreneurs. The Geopark might not be the sole reason for business success, but it contributes additional income. There may not be an influx of tourists overnight and understanding of the needs of the targeted markets is required. Partners on board, including tourism bodies, can help in channelling visitors.

With the Geopark acting as a facilitator, the communities feel empowered; fundraising events take place and services delivered to the communities improve. Twinning activities bring people together beyond geology, with exchanges with other European countries and further afield, on a cultural and business basis.

Can this be replicated in rural Newfoundland? Possibly, but it will require a lot of effort. In supporting world-class geology, interested communities will have to find adequate support and guidance to launch the project. Sustained financial support is necessary as cash flow is often an issue. Employed staff are required to avoid exhausting the good will of volunteers. Bringing relevant partners in geology, heritage, education, tourism, management, finance and marketing on board at an early stage gives weight to the project. It will require long-term commitment and faith, but with increasing international recognition of the Geopark status, Newfoundland can benefit from a wider market including tapping into its Irish connections.

A DYNAMIC SULPHATE RESERVOIR AT THE START OF THE CRYOGENIAN

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The Cryogenian (850Ma-635Ma) is one of the most enigmatic periods of Earth's history; glacial deposits and isotopic data from this time period suggest that the entire Earth may have been completely covered by ice at least two times. Much recent work has focused on the late Cryogenian and the complex life associated with the subsequent Ediacaran (635-542Ma). However, the initial conditions for this suite of earth system changes have so far received much less attention. Here we investigate the marine sulphur cycle at the beginning of the Cryogenian in order to constrain atmospheric and environmental conditions. The size of the marine sulphate reservoir is thought to respond to atmospheric oxygen concentrations. Neoproterozoic evaporite deposits are rare and are not easily preserved, however the upper Shaler Supergroup of Victoria Island, NWT, Canada is host to two evaporitic formations, the Minto Inlet formation (>250m thick) and the Kilian formation (>500m thick). The evaporite units are separated by approximately 500m of carbonate-dominated strata of the Wynniatt Formation. We use the variability in the S-isotopic composition of sulphate evaporites to assess changes in the size of the early Cryogenian marine sulphate reservoir and by association atmospheric oxygen concentrations.

Deposition of the two evaporite units was synchronous with the break-up of Rodinia and the restricted basins where evaporite deposition took place were tectonically controlled shallow rifts. The Minto Inlet and Kilian Formations have similar sedimentary characteristics indicating deposition in shallow subaqueous to subaerial environments with characteristic high frequency alternation between sulphate rich evaporites and carbonate. However the Kilian Formation is richer in stromatolitic limestone and siliciclastic sediment while the Minto Inlet Formation preserves thick successions of bedded white gypsum/anhydrite.

During the 2010 and 2011 field seasons, we measured and logged 11 stratigraphic sections through these intervals and sampled them at high resolution (3m intervals). The S isotopic data from the two formations

suggest large scale environmental changes during their deposition. The marine sulphate reservoir and by association concentrations of atmospheric oxygen were relatively large during the deposition of the Minto Inlet evaporites but both had shrunk considerably during the deposition of the Kilian evaporites. A decrease in oxygen concentrations would have a profound effect on the carbon cycle, increasing organic carbon burial and therefore decreasing atmospheric CO_2 which is an important greenhouse gas. We propose that a decrease in p_{O2} at the start of the Cryogenian was a catalyst for plunging the earth into the snowball glaciation.

PROVENANCE AND PALEOGEOGRAPHY OF THE UPPER PALEOZOIC AND LOW MESOZOIC SUCCESSIONS OF THE VERKHOYANSK PASSIVE CONTINENTAL MARGIN

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Based on U-Pb isotope geochronology of detrital zircons, paleogeographic reconstructions of clastic provenance in the Verkhoyansk passive continental margin for Late Paleozoic and Mesozoic time show that sediment was transported by a large paleo-Lena river system that existed in the eastern North Asian craton for over 200 Ma. The main sources were granitoids of the Central Asian foldbelt, Angara-Vitim batholith, granitoids of East Sayan and northern Pribaikalia, the Siberian platform basement uplifts, and the Aldan shield. The clastic material was also supplied into the distal part of the passive margin (In'yali-Debin synclinorium and Kular-Nera terrane) from the south sourced from the South Verkhoyansk and the Okhotsk terranes. This indicates that the Triassic and Jurassic rocks composing the In'yali-Debin synclinorium and Kular-Nera terrane respectively were deposited in the distal part of the Verkhoyansk paleobasin rather than on the margin of the Kolyma-Omolon microcontinent as was thought before. This casts doubt on the existence of the Oimyakon ocean separating the Kular-Nera slate belt and the In'yali-Debin synclinorium and the assumption that the In'yali-Debin synclinorium made part of the Kolyma-Omolon microcontinent and is there fore exotic to North Asia.

GREY-ZONE ALTERATION AT THE MIDWEST A UNCONFORMITY-TYPE URANIUM DEPOSIT, NORTHERN SASKATCHEWAN

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The "grey reduced alteration zone" related to many unconformity-type uranium deposits has been interpreted from drill core observations to be a "chlorite-illite ± sooty pyrite" alteration zone. Around the Midwest A ore body at, the grey zone is the most proximal to the ore zone of three host-rock alteration zones (bleached, quartz dissolution, grey) present in the sandstone.

However, the mineralogy of grey-zone alteration is more complex. Sooty aggregates of fine-grained hematite are locally present and are often associated with hydrothermal quartz overgrowth material. Coarse-grained, basket-weave illitic matrix clay, likely diagenetic-hydrothermal and hydrothermal alteration of precursor kaolin-illite matrix clay, often contains abundant very fine-grained anhedral anatase and/or APS minerals. The illitic clay is variably overprinted by cloudy coarser-grained chlorite grains and very coarse-grained, pore-filling chlorite clots are locally present. The anatase and APS are mostly removed during chloritization, while scattered grains of very fine-grained anhedral pyrite occur in the matrix clay, primarily the chlorite. The grey coloration of the sandstone is due to the presence of variable proportions of hematite, anatase, APS, pyrite, and chlorite.

Geochemically, the grey zone is enriched in uranium and related mineralization elements like Pb, Bi, V, Mo, Ni, Co, As, Sb, Cu, Zn, Ag, mid-heavy REE+Y, and several major oxides (Al_2O_3, K_2O, TiO_2, Fe_2O_3, MgO). Uranium and lead are variably elevated, while sulphide-related elements (Pb, Cu, Mo, Zn, Ag, S), arsenide-related elements (Ni, Co, As, Sb), and APS-related elements (Sr, LREE, P) are also typically elevated, commonly up to 10 times greater than background values that are typically in the single-digit ppm range, or lower.

The elevated major oxides mostly represent increases in total clay content (Al_2O_3 up to ~10%) at the expense of detrital quartz. The grey zone is argillized: variably illitic (K_2O) and chloritic (MgO, Fe_2O_3) clay. Hematite and pyrite (Fe_2O_3), anatase (TiO_2), and APS minerals (P_2O_5) are present in variable amounts.

The Midwest A grey alteration zone is a bleached zone that is variably, but at best weakly, mineralized. It, at the same time, contains oxidized (hematite) and reduced (pyrite) components. It displays a geochemical signature similar to that observed for many other unconformity-type uranium deposits suggesting that it is syn-mineralization in timing.

A WIDE-ANGLE SEISMIC SURVEY OF THE HECATAEUS RIDGE, SOUTH OF CYPRUS: A MICROCONTINENTAL BLOCK FROM THE AFRICAN PLATE DOCKED IN A SUBDUCTION ZONE?

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Cyprus lies at the southern edge of the Aegean-Anatolian microplate, caught in the convergence of Africa and Eurasia. Subduction of the African plate below Cyprus has probably ceased and this has been attributed to the docking in the subduction zone of the Eratosthenes Seamount microcontinental fragment on the northern edge of the African plate. In early 2010, on R.V. Maria S. Merian, we conducted a wide-angle seismic survey to test the hypothesis that the Hecataeus Ridge, another possible microcontinental block lying immediately offshore SE Cyprus, might be related to an earlier docking event. The upper crust of Cyprus is dominated by ophiolites, with seismic velocities of up to 7 km/s. A wide-angle seismic profile along Hecataeus Ridge was populated with 15 Canadian and German ocean-bottom seismographs at 5 km intervals and these recorded shots from a 6000 cu. in. air gun array, fired every 100 m or so. Rough topography of the seabed has made picking of phases and their modelling a demanding task. Model results will be presented: preliminary results show no evidence of true velocities approaching 7 km/s below the Ridge. We suspect from this that Hecataeus Ridge is indeed derived from the African plate and is not characteristically ophiolitic Cyprus (upper plate) crust.

SAMPLING LAURENTIA REVISITED: SHRIMP DETRITAL ZIRCON GEOCHRONOLOGY OF SANDSTONES FROM THE AMUNDSEN BASIN OF NORTHWESTERN CANADA

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One of the first multi-grain U-Pb detrital zircon geochronology studies was published 20 years ago using sandstones from the early Neoproterozoic Shaler Supergroup of northwestern Canada. At that time, 25 zircon grains from 3 samples were analyzed by ID-TIMS. The conclusions of that study were speculative, suggesting that most grains were transported from the Grenville orogen, more than 3000 km to the southeast, by a pan-continental river system. Since, there has been an explosion of research in this field, owing largely to the advent of new instruments and techniques for analyzing large numbers of grains, quickly and cheaply. Some of this research included analysis of correlative sedimentary successions in North America and abroad, which largely supported the original hypothesis. Recent field mapping through the GSC's Geo-mapping for Energy and Minerals program has allowed us to re-sample and re-analyze the Shaler Supergroup via modern techniques to: 1) test the original hypothesis; 2) understand observed stratigraphic changes in provenance in greater detail, and 3) establish maximum depositional ages (MDA) for key stratigraphic horizons. In this study, we analyzed >400 zircon grains from 10 samples using SHRIMP. Quartz-arenites from throughout the ~4000m-thick

section, including (in ascending stratigraphic order) the Escape Rapids, Nelson Head, Fort Collinson, Wynniatt, Kilian and Kuujjua formations. An arkose from the unconformably underlying Husky Creek Formation, in the Coppermine Homocline, has a MDA of about 1230 Ma and exhibits an age profile that suggests reworking of underlying successions, such as the Coppermine River, Hornby Bay and Goulburn groups. The lowermost sample from the Escape Rapids Formation has similar provenance to the Husky Creek, but the upper Escape Rapids displays a wholesale change to mainly 1600-1400Ma sources. Many of these grains are euhedral indicating local provenance, but zircon-bearing rocks of this age are unknown in this region, suggesting a non-Laurentian source. A fluvial sandstone from the overlying Nelson Head Formation preserves northwesterly paleocurrents and characteristically well-rounded grains of Grenvillian age (1400-1000Ma). The Fort Collinson Formation is a marine sandstone with similar provenance to the Nelson Head, suggesting reworking (MDA~900Ma). The lower Wynniatt Formation sample shows almost no Grenvillian signature and a dominant mode at 1870Ma, (Great Bear magmatic zone?), possibly indicating a tectonic event with associated sedimentary by-pass of Grenvillian detritus. The upper Wynniatt (identical to the Nelson Head) and overlying fluvial Kuujjua formations signal a rejuvenation of the Grenvillian source (strong 1080 peak; MDA~780Ma) and/or recycling of underlying units.

INTEGRATED SEDIMENTOLOGICAL, STRATIGRAPHIC, GEOCHEMICAL AND PALEONTOLOGICAL STUDIES OF THE SHALER SUPERGROUP IN THE MINTO INLIER OF NORTHWESTERN VICTORIA ISLAND, NORTHWEST TERRITORIES, CANADA

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A re-examination of the Neoproterozoic (late Tonian-Cryogenian) Shaler Supergroup was conducted during the summers of 2009, 2010 and 2011 as part of the GSC's Geo-mapping for Energy and Minerals (GEM) Program. The Shaler Supergroup, up to 4km-thick, includes fluvial sandstones and deltaic siltstones, shallow-marine carbonates and shales and both basinal and supratidal sulphate evaporites. Strata are intruded by diabase sills and capped by flood basalts of the ~720Ma Franklin igneous event. Facies analysis and sequence stratigraphy suggest deposition within a relatively shallow epicontinental basin or epeiric sea (Amundsen Basin) that was periodically connected to an exterior ocean. Fieldwork included measurement of stratigraphic sections, detailed sampling of outcrop and drillcore and geological mapping. Studies focused in the western half of the Minto Inlier, on Victoria Island, where only the upper half of the stratigraphic section is exposed. Thematic studies of the Shaler Supergroup include: U-Pb detrital zircon geochronology, Re-Os geochronology, sequence stratigraphy and sedimentology, stable isotope chemostratigraphy, trace element geochemistry, organic biomarker analysis, and micro-paleontology. Ten sandstone samples were collected for detrital zircon analysis from the complete succession to assess provenance and to establish minimum depositional ages for key stratigraphic units. Re-Os analysis of organic-rich shales will establish depositional ages of units where U-Pb analysis cannot be accomplished. Stable isotopes of C, O and S are being analyzed to produce secular evolution curves for correlation with other sections and to assess both global and local evolutionary changes in sea-water chemistry. Analysis of redox-sensitive trace elements such as V, Mo, U and Fe speciation analysis are being conducted to assess the redox state of the ocean at the time of deposition. Organic matter from shales and carbonates is being extracted to recover sedimentary lipids that can be used as molecular fossils to provide insight into past organismic diversity (e.g. evolution of algae and early metazoans). This work will be done in conjunction with extraction and identification of microfossils (e.g. organic-walled cyanobacteria and acritarchs) from shales and carbonates. Initial results from these studies will be summarized on this poster. Data and interpretations generated from this project will be compared with similar studies being conducted elsewhere in northwestern Canada (e.g. Mackenzie, Ogilvie and Wernecke Mountains inliers), with further comparisons to similar-age sedimentary sections in Siberia, and Australia in order to test tectonic plate reconstructions of the ancient supercontinent, Rodinia.

STRUCTURE AND STRATIGRAPHY OF THE DIETER BASIN, SAKAMI RIFT, PALEOPROTEROZOIC OF QUÉBEC, CANADA

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The Sakami basins consist of two parallel sets of northeast trending basins that are remnants of early Proterozoic rifts. The Dieter Basin measures 10 by 50 km, with the basin axis parallel to the trend of the set, to the NE. Internally, deposition was from WNW to ESE in a series of compartments, suggesting deposition as a segmented transtensional rift. The basin was deformed by the New Québec Orogen, and again by the Grenville Orogen, increasing the chance that it has a complex internal structure, and that a simple half-graben model may have only local applicability.

Two sets of dykes cross the basin: a NS trend that crosses the basin at nearly right angles, and a NE trending set that parallels the depositional axes of the basin segments.

The Dieter Basin sediments have previously been divided into a clay-rich Lower- Sakami and a sand-dominated Upper Sakami Formation. The Lower Sakami is based by thin fluvial conglomerates of local derivation from the NW, N, and NE. These are overlain by a 400 m thick silt and mudstone to marl sequence with paleocurrents to the NE, axial to the basin segments, but transverse to the preserved overall basin outline. The mudstones contain playa facies with bacterial mats, and traces of evaporites. The Upper Sakami is a thick, coarse-grained largely eolian quartz-rich sandstone, with grain-size distributions similar to other rift basin eolian sandstones with proximally derived sand. The eolian cross-sets are very thick, at times over 20 m, and were formed by large transverse dunes, with the result that bedding planes are rarely visible, and that crossbedding has in the past been mistaken for bedding. Thus, the sedimentary environment of the Upper Sakami has been controversial, and the estimated thickness of the unit may have been greatly overestimated (1 rather than 4 km, assuming a half-graben cross-section).

As in other rift systems, the sedimentary fill varies greatly between coeval basins depending on the intensity of faulting and the geometry of the faults during basin development. The next Sakami rift basin to the west has a smaller percentage of eolian sediments, a much larger debris flow component, and an apparently internal rather than a marginal setting for the lacustrine deposits.

Uranium mineralization is found in the playa facies of the Lower Sakami.

Keynote PALEOPROTEROZOIC TO PHANEROZOIC STRUCTURAL AND STRATIGRAPHIC DEVELOPMENT OF THE ATHABASCA REGION, NORTHERN SASKATCHEWAN, CANADA

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The Athabasca Basin and surrounding area of northern Saskatchewan, Alberta and the Northwest Territories represents crustal fragments involved in 2 or 3 episodes of collisional tectonics and basin formation between 1.93 and 1.4 Ga.

During the Taltson transpressional orogeny (1.99 to 1.92 Ga), representing docking of the Buffalo Head terrane, and the passing of the Slave Craton to the northeast, early ca. 1.96 Ga backarc basins (Waugh Group) were overlain by a foreland basin around 1.93-1.92 Ga modified by

transtensional effects resulting in the preserved pull-apart basin fragments collectively known as the Nonacho, Thluicho Lake, and Burntwood groups. Deep burial and alteration to greenschist grade may have continued during the Snowbird Tectonic event or collision around 1.91-1.90 Ga. Unroofing, in places to the present erosional level occurred during the early phases of the Trans-Hudson Orogen (1.86-1.83 Ma) followed by deposition of the coarse clastics to lacustrine deposits of the Martin Group (ca. 1.82 Ga) in what may be Laramide type basins. In the late stages of the THO main event in northern Saskatchewan, the docking of the Sask Craton, the Athabasca Group Fair Point Fm was deposited in a late THO foreland in the Jackfish Basin perhaps in front of the main THO western thrust belt, or as another Laramide-type basin. Sequence 2 of the Athabasca Group (Read, Manitou Falls Fms) formed in escape basins perhaps during the late stages of the final Superior Hearne collision. The upper sequence in the Athabasca Basin is correlative to the Dismal Lakes Group of the Hornby Bay Basin, perhaps to the Dessert Basin west of Slave Lake, the basal Belt-Purcell sequences in S B.C., and may reflect a continental scale extensional event that may have proceeded to rifting, forming a first western margin to North America around 1.40 Ga, to be followed in the Late Precambrian by rifting during the Windermere event at 0.7 Ga.

Structures from these events left their record in the Athabasca Basin area, and structures formed up to and including deposition of upper Athabasca Sequence 2 were rejuvenated during formation of Sequence 3. These structures were the main loci of hydrothermal systems that emplaced the unconformity U orebodies.

Structures related to the Windermere rifting may have determined the present northern and southern basin limits in the Paleozoic. Burial and tilting during the Cretaceous and Laramide orogenies depressed the western side of the Athabasca basin significantly.

MULTIELEMENT GEOCHEMISTRY OF OUTCROP SAMPLES, DIAGENETIC MAPS, STRUCTURE AND BASIN DEVELOPMENT OF THE ATHABASCA BASIN, PROTEROZOIC, SASKATCHEWAN

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A 59 element geochemical data set of 634 non-mineralized outcrop samples of Athabasca Group clastics has been analyzed using Principal Component Analysis (PCA). The vast majority of samples are quartz arenites at present, but were derived from depositional lithologies ranging from sublithic arenites to arkose. Samples have been assigned to stratigraphic units and deposystems based on an analysis of over 1000 outcrops and hundreds of corelogs involving a re-evaluation of the EXTECH IV stratigraphic results. This enables a more precise characterization of the variation of the composition of the units, as well as an evaluation of the alteration processes in different parts of the basin.

Major PCA components may be interpreted as reflecting source areas, LREE fractionation associated with phosphate diagenesis, Mg and K clay suites, metal (including U) concentration in Fe-Mn rich zones, HREE fractionation, and quartz veining with Cu and Co.

Heavy minerals are indicated as a main source of REE and U with different suites characterizing Manitou Falls and Lazenby Lake to Locker Lake gravels and the various Manitou Falls deposystems. Quartz-rich samples with Cu and Co and Fe, Mn-rich samples with anomalous weakly held metals are more common near the major Snowbird fault systems and in Sequence 3, suggesting more intense alteration below the Wolverine Point aquitard. High LREE values are associated with P and may reflect source area, and/or an early diagenetic stage. HREE fractionation seems most common near major fault systems and in the Lazenby Lake strata, deposited just prior to the time of first U ore emplacement and the major basin deepening during deposition of the overlying McFarlane Group at ca. 1.5 Ga. It is noticeably absent in this data set (which avoided mineralized zones) in the general area of the U orebodies. Coupled with known HREE enrichment in hydrothermal ores, this suggests depletion zones.

The distribution of samples with high factor scores for these components provides basin wide source sediment composition and diagenetic maps. Factor score distribution when considered with isopachs, paleocurrents, reactivated basement and basin development structures provide insight to the hydrothermal systems that emplaced the U orebodies of the basin, their location, intensity, and development of depletion zones.

CALCIC GARNETS: AN IMPORTANT REPOSITORY FOR REE ELEMENTS IN CARBONATITES

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Calcic garnets are a relatively common accessory phase in carbonatites, and, where present, tend to sequester significant proportions of such economically important trace elements as Y, lanthanides, Nb, Zr, Th and U. Whereas the major-element composition of these minerals has been reasonably well studied, their trace-element chemistry has not. In this study, we examined Ca-Fe-Ti garnets from calcite carbonatites at Oka (Canada), Tamazert (Morocco), Magnet Cove (USA) and Afrikanda (Russia). Their composition ranges from 0.94 Ti atoms per formula unit, apfu) to Ti-rich≥schorlomite at Afrikanda (0.2 apfu Ti (Oka). The≤andradite (Magnet Cove and Tamazert) to andradite with examined samples differ in their trace-element composition. The material from the Oka Nb deposit is enriched in Nb (500-720 ppm), Ta (105-200 ppm) and Mn (7750-9130 ppm), and contains the lowest levels of U, Zr and Hf (< 12, 1660 and 10 ppm, respectively) among the studied samples. The highest abundances of Zr, Hf and Sc (up to 20000, 250 and 460 ppm, respectively), and the lowest levels of V (< 580 ppm) are observed in the Afrikanda schorlomite. Both Afrikanda and Oka garnets are enriched in REE (1400-1900 ppm) relative to those 600 ppm). The latter two samples are strongly≤from Magnet Cove and Tamazert (zoned. The Magnet Cove andradite exhibits irregular zoning in back-scattered electrons, with high-AZ zones enriched in REE, Ti, Zr, Nb, Ta, U, Sr, Mn and V. Overall, the Magnet Cove andradite has the lowest levels of Nb (65-330 ppm), Sr (< 20 ppm) and Th (< 9 ppm) relative to three other localities. The Tamazert sample is characteristically enriched in V (up to 3300 ppm), Th (up to 57 ppm), U (up to 30 ppm) and Zn (up to 440 ppm). The Tamazert andradite is unusual in showing strong sector-controlled distribution of rare elements. The relatively Ti-rich {121} sectors contain higher levels of highly-charged cations (including Nb, Ta, Zr, Hf, REE, Th and U) relative to the {110} sectors. Niobium, U and Th exhibit the greatest degree of inter-sector fractionation (×1.4 or greater). This type of compositional zoning has not been previously recognized in garnets and can be explained by differences in bond strength between Ca^{2+} and Fe^{3+} on the one hand and highly-charged cations on the other. To summarize, our data show that, in some carbonatites, the bulk of rare-element budget is concentrated in garnet and, hence, not amenable to recovery.

ULTRAFERROUS SILICATE MAGMATISM AND IMMISCIBILITY: EVIDENCE FROM THE BUSHVELD COMPLEX, SOUTH AFRICA

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Iron-rich ultramafic pegmatites occur as replacement bodies throughout the layered sequence of the upper Critical Zone in the western Bushveld Complex, South Africa. Morphology and size very considerably, but sub-vertical veins and pipes are most common, often expanding outwards into sub-concordant sheets, particularly in the plagioclase rich cumulates under chromitite seams. Several petrographic types have been recognized throughout the interval from the UG1 footwall to the Merensky Reef at several platinum mines, ranging from wehrlites through a spectrum of gabbroic lithologies, several of which may be intimately associated with granite pegmatite. Dominant minerals include ferroaugite (Mg# >50), fayalitic olivine (Fa_{50-70}), calcic plagioclase (> An_{80}) and magnetite, with minor biotite, base metal sulphides (po, py, ccp), alkali feldspar and quartz. Textures and grain sizes are extremely variable, ranging from medium grained granular to megacrystic pyroxene prisms up to 40cm in length.

The combination of highly variable textures and grain sizes, extremely irregular morphologies and field relations with the host layered sequence, as well as the unusual mineral assemblages, all demand a complex replacement origin rather than a simple intrusive magmatic emplacement. It is concluded that the suite represents the products of liquid immiscibility that occurred in highly differentiated Fe-rich basaltic magmas responsible for the Upper Zone. Migration of the melts lead to their interaction with the Critical Zone, where the ultraferrous melt fraction reacted with the layered cumulates, producing the wehrlite – gabbro suite, while the felsic fraction either crystallised as granite pegmatite but sometimes remained mingled with its Fe counterpart and subsequently crystallized as hybrid or zoned assemblages.

PARAGENESIS OF THE CENTENNIAL UNCONFORMITY-RELATED URANIUM DEPOSIT AND THE POTENTIAL FOR IGNEOUS DRIVEN HYDROTHERMAL ACTIVITY IN THE ATHABASCA BASIN

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The Centennial unconformity-related uranium deposit in the south-central Athabasca Basin has a complex paragenetic history which differs, in some aspects from similar deposits in the basin. The paragenetically earliest uraninite appears to be broadly coeval with the diagenetic illite-sudoite-dravite-APS assemblage. However, the deposit is intruded by diabase, which is petrographically and chemically similar to the regionally extensive 1270 Ma Mackenzie dyke swarm. The dykes at the Centennial deposit provide a time constrain not observed at many other deposits in the basin. Clinochlore, euhedral quartz, carbonate and pyrite were precipitated after the diabase and overprint the earlier diagenetic assemblage. Chlorite geothermometry of the earlier sudoite indicates temperatures during diagenesis and mineralization likely reached 200°C whereas the later clinochlore formed at temperatures as high as 320°C probably due to additional heat provided by the intrusion. The latest alteration feature is the ubiquitous development of kaolinite along fractures and pervasively through the ore zone.

The paragenesis developed by other workers for the high-grade McArthur River unconformity-related uranium deposit and the 'apparently barren' Wheeler River Zone K is very similar to that observed at Centennial with clinochlore, euhedral quartz, carbonate and sulphide forming late relative to the diagenetic/primary mineralization assemblage. Fluid inclusions associated with late euhedral quartz at McArthur River reveal temperatures higher than those associated with diagenesis. Similarly, the composition of late clinochlore at Wheeler River indicates higher temperatures than the earlier developed diagenetic sudoite. Therefore, similar to Centennial, both areas record a period when temperatures were elevated after diagenesis and primary uranium deposition during the development of the later clinochlore, euhedral quartz, carbonate and sulphide assemblage. In addition, recrystallized uraninite and illite, and isotopically disturbed U-Pb and Ar-Ar systems at the two locations yield ages close to that of the Mackenzie dykes.

These observations imply that hydrothermal activity initiated by igneous events, such as the Mackenzie dykes, may be more widespread in the basin, even where dykes are not directly observed. Future studies in the Athabasca Basin should recognize the possibility that igneous activity may have played an important role in developing some of the post-mineralization alteration, including precipitation of sulfide minerals which, if formed around a uranium deposit may have aided in preservation.

ARCHEAN KOMATIITIC VOLCANISM OF THE PRINCE ALBERT GREENSTONE BELT, MELVILLE PENINSULA, NUNAVUT, CANADA

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Komatiitic rocks represent a significant portion of the ca. 2970 Ma Prince Albert Greenstone Belt (PAGB), a semi-continuous, northeast-trending metavolcanic and metasedimentary supracrustal Archean greenstone belt, outcropping on the eastern side of Committee Bay within the Rae Carton of the western Churchill Province, Nunavut. The present study focuses on one of the best-preserved komatiitic sequences within the PAGB on Melville Peninsula.

Spinifex textured and massive komatiitic flows of the PAGB were erupted onto a subaqueous pillowed mafic volcanic succession during an episode of extension. Localized, coarse, framework supported breccias containing both clasts of komatiites and basalts indicate early down faulting and the development of synvolcanic structural basins. During, or immediate following basin development renewed komatiitic volcanism was channelized within these basins resulting in thick, massive, undifferentiated flows that thin toward the channel margins, which are defined by flanking spinifex-textured lava lobes. Renewed subsidence and down faulting allowed the accumulation of felsic, mafic and komatiitic volcaniclastic deposits within a restricted fault-bounded basins, which developed on the surface of the channelized komatiitic flows. The komatiitic volcaniclastic deposits are ultramafic in composition and have been extensively altered to chlorite, amphibole, talc, and carbonate minerals; textures and the morphology of microscale particles are rarely preserved. The tuffs are largely massive or plane-bedded, and are uniformly fine-grained. Their fine grain size, their extensive nature (up to 2km), and their substantial thickness (up to 10m), coupled with a uniformly komatiitic composition indicating that they consist of particles of only one composition (single provenance), are consistent with an origin through explosive komatiitic volcanism. The komatiitic volcaniclastic lithofacies occur at two stratigraphic intervals indicating that they are a product of a least two pyroclastic eruptions. The komatiitic tuffs are conformably overlain by mafic and komatiitic flows and a thick succession of felsic volcaniclastic deposits. Subsequent deformation, including at least two phases of folding and faulting have folded and dissected the succession.

Although no significant sulphide mineralization was recognized, the along strike extension of the komatiitic succession to the north contains the newly discovered Adamson River Nickel showing. Samples collected from this occurrence returned values of up to 8.0% Ni, 1.8% Cu, and 2.2% Co.

CLAY ALTERATION AND URANIUM MINERALIZATION ALONG THE KIGGAVIK ANDREW LAKE STRUCTURAL TREND, (NUNAVUT, CANADA)

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The Kiggavik project (previously named Lone Gull), located 70km West of Baker Lake, Nunavut is a major uranium exploration project in the Canadian arctic. It hosts several significant uranium deposits (Kiggavik, End and Andrew) as well as very prospective areas, with an overall uranium content of approximately 58 000t U of historical resources delineated in the 70's and 80's along the SE border of the Thelon basin.

The Paleoproterozoic Thelon sandstones and the unconformity surface between the metamorphic basement and the sedimentary cover have been eroded. Uranium mineralization are hosted in the Neoarchean basement rocks in the vicinity of regional N080° fault showing specific features of alteration and crystallization such as thick quartz veining corridors, hydraulic breccias, strong hematization, and plurimetric zones of clay alteration.

Clay alterations are spatially controlled by secondary structures related to the main East-West fault trend and generally host the uranium mineralization. At the scale of the whole structural trend, the alteration paragenesis is composed of illite ± sudoite ± hematite ± aluminum phosphates sulfates minerals (APS). Such a paragenesis is similar to those identified in uranium deposits related to paleoproterozoic unconformities in the Athabasca basin (Canada) or the Alligator River (Australia).

The altered rocks surrounding the uranium mineralization contain two populations of phyllosilicates, both of them containing similar types of phyllosilicate (dioctahedral micas or illite and chlorites) but with distinct crystallographic and chemical properties. The first assemblage is attributed to the regional retrograde metamorphic stage while the second is related to the hydrothermal alteration associated to the mineralization event. From our investigation on these phyllosilicates it results that the crystal structure of phyllosilicates can been used to map alteration halos using the X-ray diffraction data (crystallinity along c-axis, polytypes). On another hand the crystal-chemical characterization of the hydrothermal phyllosilicates replacing the metamorphic ones evidence a strong release of ferrous iron during the mineralogical reaction. This last point is fundamental regarding the occurrence of hematite in alteration zones and points out the potential effects of iron redox state in the control of uranium precipitation during the hydrothermal event.

KIMBERLITES AS CONDUITS THROUGH MANTLE AND LOWER CRUST: ZIRCON FROM BRAUNAS 3 KIMBERLITIC PIPE, BRAZIL

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Serrinha Nucleus (SerN) is an Archean granite-greenstone terrain located in the São Francisco Craton (SFC) of northeastern Brazil. SerN lamprophyres and gold are in temporal and spatial association with 2.1 Ga potassic-ultrapotassic syenites. Enrichment on LILE and strong depletion of some HSFE suggest a subduction-modified source. This metasomatized mantle shows LREE concentrations typical of lamproitic rocks. The Braunas kimberlitic field comprises 30 kimberlite pipes and dykes, most diamondiferous, which intrude the south area of the TTG Nordestina Batholith (NB, 2.16 Ga). A Neoproterozoic age (~0.6-0.7 Ga) was suggested by Ar-Ar data.

Geochemical data on Braunas 3 (Nelio's) pipe are comparable to average kimberlitic rocks, although lower in TiO_2 and P_2O_5, and higher in Al_2O_3. Contamination, either by weathering or xenoliths, is a common problem in the interpretation of kimberlite geochemical data and SerN kimberlites show a contamination degree of 1.8 (Clements parameters). The heavy mineral concentrate includes apatite, zircon and carbonate. We recovered more than 300 zircon crystals, which are clear, transparent to translucid, euhedral to rounded. They range from short to long prisms and from colorless to pink and brownish small to large crystals. U-Pb SHRIMP data for 6 large crystals result in a concordant and consistent age of 2162±11 Ma, which is coincident with the age of NB. LA-ICP-MS (58 crystals) data obtained from distinct populations show a wide range of xenocrystic ages, grouped in four main periods: 2.06 to 2.11 Ga (33 zrs.); 2.15 to 2.40 Ga (13 zrs.); 2.5 to 3.20 Ga (8 zrs.); 3.25 to 3.44 Ga (3 zrs.). One zircon was dated at 0.57 Ga. Most of the crystals were assimilated from the underlying crust/mantle by the kimberlite during its ascent. They represent the diversity of Precambrian processes/magmas in SerN area and additional work is need to better understand the ages/rocks not exposed at surface. The age of the single Neoproterozoic crystal is probably the emplacement age for Braunas pipe.

Only a few Paleoproterozoic kimberlitic rocks have been described worldwide, eg. Ghana. The close spatial relationship with lamprophyres (with lamproitic signature), syenites, and gold formed during the ~2.1 Ga ultrapotassic alkaline event in SerN, as well as the predominance of ~2.11 Ga xenocrysts may be important regional characteristics favouring later kimberlite emplacement. Other lamprophyres/kimberlites are been discovered in spatial association with syenites in Bahia state but no other Neoproterozoic event has thus far been recognized in the SerN/Archean nuclei of SFC.

GEOTOURISM IN URBAN ENVIRONMENTS: SALVADOR, THE FORMER CAPITAL OF BRAZIL

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Salvador plays an important role in the history of Brazil, as it was the first economic and political capital of the Country. Its exuberant and diverse natural assets attract thousands of visitors. A maritime approach revel the splendor of All Saints' Bay in the scenic surroundings of a geological fault. Many other natural aspects contribute to our proposal of Salvador as a place for Earth Sciences promotion. It is located on the Salvador-Esplanada belt, part of the Sao Francisco Craton. Three main geological domains are exposed: (i) a horst of Precambrian rocks, the "Salvador High"; (ii) Mesozoic-sedimentary rocks represented by the Tucano-Reconcavo basin, the "Salvador Low"; and (iii) Tertiary-Quaternary sediments - creating kilometers of clear and calm blue-warm-water beaches - related to sea-level fluctuations and climatic changes. This work categorizes four geosites, describing and integrating them to geocultural sites to create an urban Geotouristic guide. They include: (1) The Salvador-Fault - a 74 meters high scarp that extends for almost 6 km; (2) the Mont-Serrat conglomerates; (3) the Abaete Lagoons, including an extensive area of white-sand dunes; and (4) mafic-dykes exposed from Farol da Barra to Forte beaches, recording Brazil-Africa extension. Associated Geocultural areas include: (1) historical and magnificent buildings - located in the Pelourinho, a World Heritage Site by Unesco - in which gold and precious stones were used along with rocks as ornamental/dimensional materials; (2) the Geological Museum of Bahia, (3) the Garcia d'Avilla Castle, with medieval characteristics that are singular on the American continent, and (4) the base for Projeto Tamar, that saved more than two million sea turtles from extinction. The oldest city in Brazil hosts a high populational density (>2.5 million habitants), a rich gastronomy and architecture, a mixing of cultures and increasing violence, ranking Salvador as one of the 50's more violent cities in the World. This initiative aims the sustainable development, increasing the (geo)educational standards for the young generation of Brazilians. The Geoheritage valuation and the creation of didactic materials are some of the possible strategies to change the future. By protecting this rich geological and cultural patrimony, Geotouristic initiatives will ensure the development of high quality tourism projects, promoting Earth Sciences education, and preventing destruction of unique geosites. Hope this initiative will put in evidence the importance of Geoconservation and to promote the concept of Geodiversity in Brazil, while giving the World an opportunity to meet our rich Geoheritage.

COLLAPSED OROGENIC PLATEAU IN THE MESOPROTEROZOIC GRENVILLE OROGEN – CRITICAL MARKER IN EVOLVING PROTEROZOIC TECTONIC STYLE?

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Evidence for the former existence of an orogenic plateau in the Grenville Province has become increasingly compelling over the last decade or so. Apart from the large size of the orogen, the long duration of orogeny, and the presence of high T mineral assemblages that formed at mid crustal levels, more recent support comes from the 'hot nappe' numerical models of large hot, long-duration orogens (LHOs) that appear to reproduce many

of the features of the Grenvillian mid crust, and from new interpretations of geological observations that point to widespread orogenic collapse.

Orogenic collapse, which implies the former existence of an orogenic plateau, is indicated by the juxtaposition of different levels of orogenic crust along normal-sense shear zones, giving rise to a crustal-scale horst and graben architecture. The horsts are underlain by exhumed orogenic mid crust and have the form of core complexes with sub-horizontal gneissic fabrics and granulite-facies assemblages that formed at 850 ± 50 °C and depths of ~30 km. The grabens preserve the down-dropped orogenic lid composed of high-level orogenic crust with steep to vertical pre-Grenvillian fabrics that lack evidence for penetrative Grenvillian strain, and in which peak Grenvillian temperatures were <500°C.

Formation of an orogenic plateau is contingent on the presence of crust and lithosphere of approximately double thickness prior to collapse, as in the Himalaya-Tibet Orogen. The existence of a plateau requires that the doubled crust and lithosphere be strong enough to support their own weight for a finite time before collapse is initiated. In the Grenville Orogen, crustal thickening took place by thrusting over a period of ~50 Ma, eventually leading to thermal and melt weakening at mid-crustal levels, thereby initiating orogenic collapse. This architecture contrasts with that of ultra-hot orogens (UHOs) of Paleoproterozoic age, described recently in the literature, in which despite their large size and long duration, crustal doubling does not appear to have occurred. Instead UHOs are characterised by large regions of approximately isobaric, low pressure–high temperature metamorphism, distributed homogeneous thickening, and no evidence for orogenic collapse, all features implying that the lithosphere was thin and weak and a orogenic plateau was not developed.

This contrast in structural style between UHOs in the Paleoproterozoic and LHOs in the late Mesoproterozoic may be a cryptic signal of planetary cooling and rheological strengthening of the crust and lithosphere, with the Grenville Orogen perhaps being the first (and biggest?) example of an orogen with a plateau in its hinterland in Earth history.

EVOLUTION OF THE GNEISSIC MID CRUST BENEATH AN OROGENIC PLATEAU - INSIGHTS FROM THE GRENVILLE PROVINCE

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The wide range of levels of Ottawan (~1090-1020 Ma) orogenic crust exposed at the erosion surface in the hinterland of the Grenville Province has recently been interpreted in terms of collapse of a former orogenic plateau. Collapse is indicated by the juxtaposition of the gneissic mid crust (P ~ 1000 ± 100 MPa) with the uppermost crust (Ottawan Orogenic Lid, OOL; P ≤ 400 MPa), and by the crustal-scale architecture in which the exhumed orogenic mid crust occupies large core complexes and the down-dropped OOL occupies adjacent basin-shaped grabens. Orogenic upper crust, with peak pressures between ~400-1000 MPa is under-represented at the erosion surface.

Exhumation of the granulite-facies mid crust during collapse was associated with widespread, but variable post-peak modification of its metamorphic, structural and igneous character. Important effects observed in the field include: (i) decompression and retrograde reactions; (ii) SE-plunging stretching lineations parallel to those formed during thrusting, but defined by post-peak retrograde assemblages; (iii) asymmetric porphyroclasts and inclusions with SE-side-down sense of rotation; (iv) small-scale ductile to brittle, normal-sense shear zones and faults; (v) evidence for vertical flattening and orogen-parallel extension; and (vi) emplacement of leucogranitic and pegmatitic dykes, sills and small plutons. Collectively these features indicate the mid crust was shortened vertically (i.e., flattened), extended horizontally in two directions, and dilated by magma addition as pressure and temperature declined and mineral assemblages re-equilibrated during exhumation.

Moreover, on the basis of the grade and timing of peak metamorphism at different crustal levels, specifically granulite facies in the mid crust at ~1090-1050 Ma, amphibolite facies in the upper crust at ~1050-1020 Ma, and heating to ≤ 500 °C in the uppermost crust adjacent to the OOL at ~1020-980 Ma, exhumation of the hot mid crust brought it into contact with progressively higher crustal levels, which underwent prograde metamorphism by conductive heating as a result.

These results collectively suggest that collapse of the Ottawan orogenic plateau took place over ~50 Ma, comparable to the duration of Ottawan crustal thickening and prograde metamorphism in the mid crust. Moreover, they also imply that all crustal levels beneath the former orogenic plateau, including the gneissic mid crust, were profoundly modified during orogenic collapse. Recognition that the post-peak modification of mid-crustal rocks encodes an integral part of their tectonic history has been largely overlooked in the past, but is essential for a complete understanding of their complex evolution.

CHARACTERIZATION OF INDICATOR MINERAL AND TILL GEOCHEMICAL SIGNATURES OF THE KIGGAVIK URANIUM DEPOSIT, NUNAVUT

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In 2010, a drift prospecting study was initiated at the Kiggavik uranium deposit under the Geomapping for Energy and Minerals Program. The objective of this study was to determine the till indicator mineral and geochemical dispersal characteristics within the zone affected by the migration of the Keewatin Ice Divide of the Laurentide Ice Sheet. Mineralized bedrock and surface till samples (n=71) were collected directly overlying, up-ice and at distances of (50 m, 100 m, 200 m, 500 m, 1 km, 2 km, 3 km, 5 km, 10 km) in a fan-shaped pattern down-ice from the deposit with respect to the dominant NNW, NW, and W ice flows.

Petrographic work on mineralized bedrock confirmed the fine-grained mineralogy (<0.1 mm) of the Kiggavik mineralization and discovered Pb-rich apatite (~10-50 µm), rimmed by uraninite, in strain shadows parallel to a well-developed phyllosilicate fabric. These features have led to the current development of a method to observe the heavy mineral concentrate of the <0.063 mm till fraction, which better reflects the grain size of ore minerals at the deposit, providing a representative indicator mineral suite for drift prospecting.

Sand-sized heavy mineral concentrations (HMC: 0.25 mm – 2 mm) of pyrite, chalcopyrite, and apatite are elevated in samples down ice of the deposit. Furthermore, gold grains may potentially be used as an indicator because there is an average of 14 grains per 10 kg sample (max = 114), exceeding the 7 gold grain per 10 kg sample obtained in an earlier regional study.

Till geochemistry was determined for both the <0.063 mm and <0.002 mm fractions to examine geochemical partitioning of U and its pathfinder elements. Results of samples directly above and down-ice of Kiggavik have higher concentrations of U, Mo, Au, Bi, Ag, Cu, and V compared to regional and local up-ice samples. These elements have moderate positive correlations with U and elevated concentrations up to a distance of 2 km down-ice of the deposit. Higher concentrations of these elements are observed in the finer fraction of till, reflecting the fine-grained mineralogy of the Kiggavik ore. The Kiggavik main zone is the only deposit to subcrop within the region, therefore the geochemical dispersion documented likely originates from this deposit.

A MID-DARRIWILIAN SUPER VOLCANO IN NORTHERN NEW BRUNSWICK, RAPID CLIMATE CHANGE AND THE START OF THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT

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The mid-Darrilwilian (c. 466 Ma) Flat Landing Brook Formation of the Bathurst Mining Camp (BMC), northern New Brunswick, constitutes the remnants of a supervolcano of comparable size and eruption rates with the largest known silicic volcanic provinces (i.e., Taupo; Yellowstone). The Flat Landing Brook Formation felsic volcanic rocks consist of aphyric to sparsely feldspar-phyric, dacitic to rhyolitic lavas, pyroclastic flows and volcaniclastic breccias that are interbedded with locally extensive basalt lenses and very minor light grey siltstone, red jasperitic shale and iron formation. Although the Flat Landing Brook Formation volumetrically dominates the polydeformed collage of dominantly volcanic sequences

that constitute the BMC, it was for the most part deposited very rapidly (probably over less than 2 m.y.). Accurate estimates of the volume of ejected material are impossible due to the combined effects of deformation, erosion and unconformable cover sequences, and similarly the number and duration of discrete eruptive events cannot be determined. However, comparisons with more recent volcanic sequences, given that geophysical models determine that the formation locally extends to at least 10 km deep and the dominance of pyroclastic deposits, imply eruptive events amongst the largest in earth's history.

Tectonic models determine that the BMC was formed on a series of relatively small crustal fragments contained within the predominantly "oceanic", late Floian to Sandbian Tetagouche - Exploits back-arc basin that formed behind the Victoria - Popelogan arc during closure of the main tract of Iapetus. The Flat Landing Brook felsic volcanic rocks formed by high-temperature partial melting of crust that was granulitized during partial melting that produced the underlying, c. 472-468 Ma Nepisiguit Falls Formation. This high temperature, second stage partial melting was induced following ridge subduction and slab window formation.

Though coeval bentonites occur in the South American Pre-Cordillera and elsewhere, no Flat Landing Brook distal deposits are recognised, as palaeogeographic constraints preclude substantial volcanic debris from reaching areas of platformal sedimentation where preservation is more likely. Flat Landing Brook volcanism is coincident with the Darriwilian 4a-4b stage boundary, rapid sea-level drop, global karst formation, a pronounced negative carbon isotopic spike and climatic cooling to modern-like conditions. This time period also marks the beginning of the Great Ordovician Biodiversification Event (GOBE). The causal trigger for the GOBE is contentious, but the temporal correlation with Flat Landing Brook volcanism dictates that it should be considered a plausible cause for climate change and biodiversification.

INVESTIGATING NEW METHODS TO DETECT HIDDEN INTRUSION RELATED MINERALISATION

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Targeted Geoscience Initiative 4 (TGI 4) is a 5 year Government of Canada program to conduct thematic, knowledge-driven ore systems studies aimed at discovering future resources through more effective targeting of buried mineral deposits.

Intrusion related (e.g., porphyry) deposits are the most important sources for Cu, Mo, W and Sn, along with Au, Ag, and PGEs. Porphyry deposits are large, low- to medium-grade deposits in which mineralisation is hosted within and immediately surrounding distinctive intrusive phases within larger intrusive complexes that commonly have a complex and prolonged emplacement history. The metallogenic contents of intrusion related deposits are diverse, reflecting a variety of tectonic settings.

The purpose of this project is to develop more effective exploration criteria to identify and evaluate fertile intrusive mineralizing systems at depth and/or that are hidden beneath surficial deposits. In order to achieve this studies are being undertaken at sites associated with the Triassic-Jurassic porphyry deposits of the BC interior and for the array of mineralised Canadian Appalachian Siluro-Devonian intrusions, for which the fundamental geoscience knowledge is often lacking.

The alteration halos and vein systems associated with intrusion related mineralization can represent a much larger exploration target than the actual economic orebody itself. In the right circumstances alteration and other vectors can be applied to identify hidden deposits. A common problem facing Cordilleran and Appalachian exploration is how to detect mineralised sequences through the extensive surficial coverage. Consequently research activities are focussing on surficial geochemistry, biogeochemistry, up-flow of volatiles, indicator mineral dispersal and the geophysical characteristics of intrusion related deposits. Indicator mineral dispersal is well established for diamond exploration, but has the potential to be applied to other mineralising systems within glaciated terrains. Furthermore, utilising mineral trace element fingerprinting, it might be possible to develop methods for common phases. Also as trees collect various elements through their roots, the chemistry of their bark can be used as a natural probe into the subsurface to help pinpoint buried mineral deposits and increase the effectiveness of deep mineral exploration.

LATE CAMBRIAN TO MIDDLE ORDOVICIAN GASTROPOD FAUNAS OF WESTERN NEWFOUNDLAND

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Gastropods and other mollusks are relatively common and diverse in the platform carbonate rocks of western Newfoundland. *Sinuopea*, the oldest gastropod known here occurs in the shallow-water, Late Cambrian Petit Jardin and Berry Head formations. *Sinuopea* has been reported from Greenland through Newfoundland and eastern North America and at least as far west as New Mexico.

The cosmopolitan genus *Lecanospira* is common in the Watts Bight Formation and the lower and middle members of the Boat Harbour Formation (Tremadocian). *Lecanospira nerine* is tiny and closely associated with algal mounds in one horizon in the middle member, but larger species are the rule.

Several long-ranging genera occur in the Barbace Cove Member of the (uppermost) Boat Harbour Formation and the Catoche Formation (Floian), including Euconia, "*Lytospira*" and *Plethospira*. *Euomphalopsis*, several species of *Maclurites* (shells and opercula), and *Polhemia* are known only from the Catoche Formation. These genera are common in Missouri and as far west as Nevada. *Malayaspira* occurs in the upper part of the Barbace Cove Member and continues into the Middle Ordovician strata. "Billings Second Operculum" (probably belonging to *Maclurites*) is found in the Catoche Formation, Arctic Canada, and possibly Scotland.

Gastropod opercula are particularly well preserved in western Newfoundland because of their preferential silicification. Species of *Ceratopea* (both shell and opercula) have shorter ranges within the Barbace Cove Member of the Boat Harbour Formation and the Catoche Formation. *Ceratopea billingsi* opercula also occur in the Durness Group of Scotland. *Ceratopea* species' opercula are known from Scotland, Greenland, Newfoundland and the U.S. Appalachians to New Mexico. Shells attributed to *Ceratopea* have also been found in western North America.

Opercula of *Ceratopea unguis* and *Teiichispira odenvillensis* are locally abundant in the Aguathua Formation. *Ceratopea unguis* is restricted to eastern North America including Arkansas, Missouri, Oklahoma, and Texas. *Teiichispira odenvillensis* opercula are more widespread, and they are known from western Canada, Malaysia, and Australia.

In contrast to the Early Ordovician gastropods of mostly eastern North American affinities, the Middle Ordovician (Whiterockian) species from the Table Point Formation are part of the Toquima-Table Head fauna of brachiopods, trilobites and gastropods that occurs in a carbonate belt that was peripheral to the trans-equatorial Ordovician North American continent and other areas in Europe and Asia. Among the gastropods present are large *Hormotoma*, *Lytospira*, *Maclurites* (shell and opercula), *Malayaspira*, *Monitorella*, *Straparollina*, as well as other cosmopolitan genera.

CONSTRAINING THE DURATION OF THE RAPITAN GLACIATION USING Re-Os GEOCHRONOLOGY – IMPLICATIONS FOR BASINAL AND GLOBAL OCEAN PROCESSES

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The lack of geochronological data hinders attempts to constrain the onset and duration of the Rapitan glaciation and to correlate associated stratigraphic units on a basin-wide scale. The Windermere Supergroup is a

overlying the Rapitan Group, the post-glacial Twitya Formation consists of an ~30-100 m thick 'cap' of organic-rich carbonates overlain by nearly 2 km of black and green shale, siltstone, and sandstone turbidites. A ~20 m thick interval of the Coppercap Formation along with two intervals (1 m and 10 m thick) of the Twitya Formation was sampled for Re-Os geochronology and Os isotope stratigraphy.

The Re-Os geochronology of the pre-glacial Coppercap Formation and the post-glacial Twitya Formation, coupled with existing U-Pb zircon dates, constrains the onset and cessation of Rapitan glaciation. The Os isotope stratigraphy from the pre-glacial Coppercap Formation reveals that the water column had an unradiogenic composition, whereby input from mantle sources e.g., hydrothermal vents and alteration of oceanic crust together with weathering of rift-related volcanics, dominated over riverine input. In contrast, the Os isotope signature from the post-glacial Twitya Formation reveals an increasingly radiogenic signal resulting from a dominantly riverine influx to the post-glacial global ocean. Together, the geochronology and Os isotope datasets yield crucial constraints on the duration of the Rapitan glaciation and provide insights into weathering regimes prior to and immediately after a Neoproterozoic glaciation.

NEW VMS EXPLORATION POTENTIAL TO THE SE OF NEVES-CORVO MINE, IBERIAN PYRITE BELT, PORTUGAL

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WITHDRAWN

VANADIUM MINÉRALIZATIONS IN THE BELL RIVER ARCHEAN LAYERED IGNEOUS COMPLEX, MATAGAMI, QUÉBEC

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The Bell River Complex is a large layered intrusion dated at 2725 Ma, located in the Matagami mining camp in the northern part of the Abitibi Subprovince. The complex consists of gabbronorite - anorthosite at its base, overlain by a layered gabbronorite zone containing layers with Fe-Ti-V oxides, and topped by a zone of granophyres. The oxides occur in the upper part of the complex.

The gabbronorite zone containing the oxides displays polarity to the north. It comprises mesogabbronorites with disseminated titaniferous-vanadiferous magnetite and layers of massive, semi-massive and disseminated titaniferous-vanadiferous magnetite and ilmenite, as well as leucogabbros and anorthosites locally injected into the other facies. The oxide zones can be up to 400 m thick and individual layers are centimetric to decimetric. Layers are several primary magmatic sequences directly related to fractional crystallization. A late magmatic brecciation phase is present at the summit of the layered zone. In the magmatic breccia zone, the matrix consists of magnetite-bearing pegmatites, plagioclases, chloritized pyroxenes and quartz and is also characterized by pseudospinifex textures in the giant (up to 1 m) pyroxenes.

Average grades in the layered zone reach 27.3% Fe, 39.04% Fe_2O_3, 6.55% TiO_2 and 0.42 % V_2O_5. Overall orientation is east-west with a subvertical dip to the north. The oxide zones are cut by thrust faults striking N130° with a variable dip to the north, interpreted as the products of the collision between the Abitibi and Opatica subprovinces, and by a network of conjugate dextral (NW-SE) and sinistral (northeast- southwest) strike-slip faults likely related to the Grenville orogeny. Chloritization of the pyroxenes indicates greenschist facies metamorphism.

Main oxide minerals are ilmenite and titanian magnetite. Ilmenite grains are homogeneous and have low V contents. Titanian magnetite grains are inhomogeneous, consisting of trelliswork of ilmenite lamellae in Ti-poor, V-rich magnetite (less than 2 wt. % TiO_2 and to 1.41 wt. % V_2O_5). Thus, magnetite is the principal ore mineral of vanadium. Vanadium is present in the crystalline structure of magnetite where V^{+3} ions replace Fe^{+3} ions. The origin of the oxide layers could be explained by fractional crystallization of an open to oxygen saturated Fe-Ti-V liquid. The pegmatites in the breccia zone display evidence of high abundance of volatils, heavy mineral density segregation during the multi-phase opening of the breccias and evidence of sudden cooling.

RECENT ADVANCES IN GEOPHYSICS AND GROUND PENETRATING RADAR

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From the macro (worldwide, hundreds of kilometres) to the micro (a few centimetres), the application of geophysics to forensic investigations has been growing steadily. At the large scale, forensic seismology has been particularly useful in the analysis of large explosions, be these terrorist-related, or accidents that require a legal investigation. Analysis of the shock waves recorded on the world seismology network allowed geophysicists to determine that the Russian nuclear submarine (the Kursk) suffered two explosions, one small, followed by one large, the latter being the reactor itself. Similar analysis showed the Nairobi and Dar-es-salam bombings to be coincidental in time, requiring the sort of exact planning only a highly proficient terrorist group (such as Al Qaeeda) could carry out. At the meso-scale of kilometres to hundreds of meters, geophysical techniques such as electrical resistance tomography, shallow seismics and

ground penetrating radar have been used to map large burials like mass graves (Bosnia, Iraq, Rwanda), animal slaughter burials (foot and mouth crises) and illegal toxic waste (Italy, Canada, Ireland). Conventional uses of magnetometry, resistivity and ground penetrating radar continue in searches for buried cadavers, weapons, explosives, contraband and drugs. What is new with these techniques is their application in unusual environments such as searching coastal locations, water bodies, and within buildings (such as child remains buried in walls), all of which will be reviewed.

RESERVOIR CHARACTERIZATION AND GEOPHYSICAL WIRELINE ANALYSIS OF THE EARLY JURASSIC GORDONDALE SHALE MEMBER OF THE LOWER FERNIE FORMATION, NORTHEAST BRITISH COLUMBIA

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As many geologists would agree, shale successions do not show great variability in hand sample, outcrop or drill core, and oftentimes their wireline log response is overlooked as any variation is considered insignificant. Shale gas reservoirs, however, are becoming increasingly important as energy demands increase worldwide, and oil becomes harder to extract. Hence, it is important to more fully understand mudstone and siltstone lithology and petrophysical character. Recent research has shown that shales are more heterogeneous than their hand specimen appearance. My study aims to prove that meaningful lithofacies and reservoir quality characteristics can be exposed through petrophysics and wireline analysis.

The organic rich early Jurassic Gordondale shale (GDN) of the Lower Fernie Formation located in north-eastern B.C., continuing through western Alberta, was used as a natural laboratory for this investigation. In particular, well 200D088H094A1300's full suite of wireline logs and drill core was examined and cross referenced with thin section microscopy, and SEM. The variety of scales used to investigate the lithology of the GDN was crucial to delineate proper petrofacies, and explained the great log variability it boasts. The analysis resulted in distinct three petrofacies, with minor sub-petrofacies, including carbonate inferring we can characterize wells without core with more accuracy and confidence.

Additionally, the study suggests by using the bulk density log, with some idea of lithology, we can calculate a 1:1 relationship between the bulk density and total organic carbon (TOC) with 86% accuracy for this well. Hence, the model could be used to estimate TOC throughout the formation. The more cored wells in the area where TOC can be calculated to more precise the model will become, of course.

In the future, quantitative x-ray diffraction modelling will be conducted to further validate how we can infer fine-grained lithology using wireline character examination.

REGIONAL CONTACT METAMORPHISM: A PRODUCT OF SLAB ROLL-BACK IN ACCRETIONARY OROGENS?

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The discovery that metamorphic zircons in a contact aureole of one of several regionally extensive NW-dipping intrusive granodioritic sheets in the Tananao complex, eastern Taiwan have the same ~86 Ma age as those intrusions (Wintsch *et al.*, 2011) suggests that virtually all of the "regional" high-grade metamorphism, here termed the Nanao Event, was caused by coalescing contact aureoles around these sheets. This interpretation contrasts with earlier interpretations than suppose that this metamorphism was caused by the still active collision of the Luzon arc with the continental margin of SE China, the "Taiwan orogeny" (e.g. Simose *et al*., 2007). We test the geodynamic plausibility of such a model using a 2D transient finite element thermal model which assumes that the granodioritic sheets were discoid with a diameter equivalent to their strike length and, as anatexis occurs in the contact aureoles, with initial temperature of 750°C. The model begins at 90 Ma with the present erosion level at 15 km, a depth consistent with biotite grade regional metamorphic conditions, with staurolite + kyanite (no andalusite) aureole assemblages, and with metamorphic pressure estimates of 4-5 kbar. We model emplacement both [1] as sills in sub-horizontal strata with NW subsequent tilting and [2] as NW dipping sheets in previously tilted strata. Case 1 produces a significant increase in metamorphic field gradient from west to east that is not observed, suggesting tilting of the entire section occurred during Early Cretaceous loading and pre-dates emplacement. Emplacement of tilted sheets raises initial temperatures along a 25 km transect from <420°C between the sheets to >490°C regionally, and to ~600°C near the contact aureoles. The model also produces uplift and cooling curves from 85 to 6 Ma consistent with Cenozoic thermo-chronologic data. Horizontal sections through the model space predict concave up PT gradients in the contact aureoles as opposed to the concave down gradients typical of burial metamorphism. Regional geological considerations suggest that this mid-Cretaceous magmatism was associated with roll-back of the Izanagi plate during regional mid-Mesozoic subduction along an active Chinese continental margin. Our interpretation of coalescing contact aureoles is consistent with similar metamorphic belts elsewhere in accretionary orogens.

NEW U-Pb AGES FOR GABBROIC MAGMATISM WITHIN THE RAMAH GROUP, NORTHERN LABRADOR: IMPLICATIONS FOR PALEOPROTEROZOIC EXTENSION IN NAIN CRATON, AND METALLOGENY

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Archean gneisses of the North Atlantic craton in northern Labrador are unconformably overlain by three principal Paleoproterozoic supracrustal remnants – the mostly clastic Snyder/Falls Brook Group, the dominantly volcanic Mugford Group, and, furthest north, the chiefly sedimentary Ramah Group.

Ramah Group is an ~1700m thick cover sequence of lowermost siliciclastic quartzite and sandstone, capped by a distinct supratidal dolomite horizon, together defining a west-facing shallow shelf sequence, overlain by euxinic, pyritic shales and mudstones and pyrite-chert associations (Nullataktok Formation). Upwards, this unit passes through a mixture of carbonate debris flow breccias, and then into voluminous turbiditic sandstones. Sills of diabase or gabbro intrude most sedimentary units, but are extensive within the upper formations. The sills typically exhibit chilled margins, and are transgressive to their host sediments. Sills reach up to ~100 m in thickness, though many are only a few meters thick, in many places with good igneous textures and primary layering features preserved. At least one thick gabbro sill is internally differentiated, with a central ultramafic portion. The entire sequence of sedimentary rocks and sills was deformed together and (locally) metamorphosed to amphibolite facies, as part of an east-verging fold-and thrust belt on the east margin of Torngat Orogen, reaching peak temperatures near 1.78 Ga. Deposition of Ramah Group has thus been bracketed only between its late Archean (ca. 2.5 Ga), Nain craton-derived detrital zircons, and Torngat deformation.

We have dated both gabbroic and ultramafic compositional variants of Ramah sills, from samples collected from thick sheets intruding the Nullataktok Formation. ID-TIMS U-Pb baddeleyite analyses yield identical ages of emplacement (within error) at 1888 ± 5 and 1887 ± 4 Ma. These represent the first precise U-Pb dates for extension-related mafic magmatism of this age in the North Atlantic craton in Labrador, and provide a new minimum age for the host Ramah Group sediments. Mafic magmatism of this age is unknown in the Greenland portion of the craton, but is well represented in the Circum-Superior belt, including the ca. 1883 Ma Molson dyke swarm and Fox River sill of Manitoba (Molson Igneous Events), the 1890-1870 Ma Raglan-Expo-Katiniq sills of the Cape Smith belt, Ungava, and the 1884-1874 Ma mafic-ultramafic magmatism of the Labrador Trough.

By analogy with contemporaneous Circum-Superior sediment-sill complexes (Thompson, Birchtree, Raglan-Expo), Ramah Group may have potential for magmatic Ni-Cu-PGE sulfide deposits.

GEOLOGICAL IMPLICATIONS OF GEOPHYSICAL SURVEYS IN THE FORTYMILE MINING DISTRICT, YUKON–TANANA UPLAND, EAST-CENTRAL ALASKA

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The Fortymile mining district, located in the eastern Yukon–Tanana Upland of east-central Alaska has a long history of mineral exploration, but its geologic history and mineral potential are still under active investigation. Much of the bedrock is obscured by Quaternary surficial deposits and vegetation. Geophysical data are crucial in interpreting the concealed geology and mineral resources in the district. Regional geophysical data compilations, as well as several detailed airborne geophysical surveys (magnetics and multi-frequency electromagnetics) and some surface measurements are available for portions of the district. The detailed surveys (400 m flight-line spacing, 30 m flight height) were collected by the State of Alaska, Division of Geological and Geophysical Surveys.

At regional scale (1:1,000,000), magnetic and gravity data indicate several crustal features. For example, a fundamental density and magnetic susceptibility break trends N-NE through Black Mountain, an area of gold prospects in the Goodpaster mining district, just west of the Fortymile district. Within the Fortymile district itself, the crust is significantly more dense and magnetic in a core region surrounding early Mesozoic intrusions including the Taylor Mountain batholith. The surrounding crust (including broad regions of late Mesozoic and Cenozoic intrusions) is lower density and largely devoid of magnetic minerals.

At more local scale (1:63,360) the magnetic anomaly data are particularly sensitive to intrusive, metamorphic, and structural geologic boundaries. Airborne electromagnetics can be inverted to estimate surficial and shallow (to about 100 m) electrical resistivity. This shallow resistivity is sensitive to the presence of water and to some conductive minerals. Depth inversion of the airborne electromagnetics provides guidance in the understanding of shallow structures including faults thought to be important to localization of mineral trends in the area.

Two different generations (both pre- and post- detailed geophysical surveys) of 1:63,360 geologic maps are available for the Eagle A1 and A2 quadrangles. The differences between the two maps are testament to the benefit of detailed geophysical data for geologic mapping.

New USGS mapping at 1:63,360 scale in the western Fortymile district has utilized the new detailed magnetic and electromagnetic surveys for the continuation of faults and other structures under cover. Especially important are revelations of complex structural details along the Kechumstuk fault that are reflected in both the magnetics and the shallow resistivity inversions and that are spatially associated with minimal prospects.

GEOCHEMISTRY OF THE 780 Ma GUNBARREL IGNEOUS EVENT OF NORTHWEST LAURENTIA

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The Gunbarrel igneous event of western North America consists of gabbroic sills, sheets, and dykes that have been shown, via U-Pb baddeleyite geochronology, to have crystallized at ca. 780 Ma. These occur as widely separated units that intrude Neoproterozoic strata in the Canadian Cordillera, Paleoproterozoic and Archean rocks in the Wopmay orogen/western Slave craton, and Archean rocks in the Wyoming craton. Gunbarrel rocks have well-defined paleomagnetic poles indicating crystallization in a near-equatorial position and are considered continental tholeiites derived from a mantle plume (centered southwest of Queen Charlotte Islands in present-day coordinates) associated with fragmentation of Laurentia. A modern and robust mineral chemical, lithogeochemical, and Sm-Nd dataset, from the Tsezotene sills in the northern Cordillera and the Hottah Sheets of Wopmay orogen, with additional data from the Christmas Lake dyke of the Wyoming craton are discussed.

Mineral chemical and petrographic data (plagioclase and clinopyroxene) from chill margins indicate repeated and turbulent mixing of geochemically and thermally similar primitive magmas in large chambers. Thick, large intrusions exhibit large major element variations, whereas thin dykes and sills have restricted compositions. The incompatible trace elements and the Sm-Nd isotopic data is remarkably homogeneous, particularly considering the samples were obtained from distinct geological terranes separated by up to 2500 km. Nevertheless, systematic petrochemical differences between units reveals that each is likely derived from a distinct, primitive magma having mildly differing but internally consistent trace element variations.

Trace element ratios demonstrate that the intrusions preserve evidence for contributions of varying proportions of depleted MORB (DMM) and enriched MORB (EMM) asthenospheric sources with smaller proportions of a LILE- and LREE-enriched lithospheric component. The nature of the lithospheric component is not constrained, but Sm-Nd isotopic data from the intrustions indicate that it may represent either Mesoproterozoic or older lower crust (T_{DM} = ~1600 Ma), or perhaps continental lithospheric mantle that was LILE- and LREE- metasomatized via subduction zone recycling of Mesoproterozoic or older continental material. The Gunbarrel event may record the interaction of a Neoproterozoic mantle plume with a Mesoproterozoic subduction-modified mantle on the west side of Laurentia.

THE STATE OF KNOWLEDGE FOR SOME NEWLY RE-COGNIZED AND REVITALIZED GOLD EXPLORATION TARGETS, NEWFOUNDLAND AND LABRADOR

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The primary objective of gold metallogenic research by the Mineral Deposits Section, Geological Survey Branch, since 2008 has been focused thematic investigations on a variety of new, or recently rejuvenated, gold exploration targets. Each of these studies represents a collaborative initiative involving government, industry and commonly university partners. Recently the Research and Development Corporation (RDC) of the Government of NL initiated "GeoEXPLORE 2011-2013" a scientific research program to enhance geosciences R&D capacity through academic, industry and government collaboration in support of mineral and petroleum exploration and development in NL. Our gold deposit research team was successful in receiving funding to aid continued research on these and other gold exploration targets, particularly in central Newfoundland.

To date the research team has initiated investigations into the origin and setting of five previously undocumented gold exploration targets in the province. These include: (1) the Aucoin Prospect of the Nain Province, Labrador; (2) the Jaclyn Deposit in the Victoria Lake Supergroup of the central Mobile belt; (3) the Mosquito Hill and adjacent (4) Brady deposits of the east central Mobile belt; and (5) the Viking Prospect of the Grenvillian Long Range Inlier. These gold targets now have a critical mass of geoscientific information that was previously lacking including: robust lithogeochemical data; paragenetic observations; sulphur isotopic data on sulphide minerals; fluid inclusion data for associated quartz veins; and radiogenic isotopic geochronology on host rocks and alteration. The research team is presently finalizing data collection and compilation for these deposits.

A number of other recently discovered, or older, gold prospects are also being examined in order to provide key information on their settings, character and age of mineralization. These include: the Staghorn Prospect of the southwesternmost Exploits subzone of the central Mobile belt; the Leprechaun deposit in the western Exploits subzone; and a number of precious metal targets with epithermal character hosted by rocks of the western Avalon Zone. This contribution briefly outlines the current knowledge base with respect to the lithotectonic setting and character of

mineralization at each of these gold targets and discusses avenues and methodologies for future research.

MICROBIAL ALTERATION OF IMPACT GLASS

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The initial catastrophic biological effects of hypervelocity impacts are well established. However, a growing body of evidence suggests that meteorite impact events also have beneficial effects particularly for microbial life. This has lead many to suggest that impact craters may have been important habitats for life on early Earth. Although impact craters are uncommon on present day Earth, (~50 000 km^2 globally), they are ubiquitous on rocky and icy bodies within the solar system often comprising the dominant geological features. Furthermore, impact flux was twice as high on the Archaean Earth during the Late Heavy Bombardment Period coinciding with the earliest evidence of life on Earth. Any hypervelocity impact into a water-rich target on a solid planetary body has the potential to generate hydrothermal system. Post-impact hydrothermal systems expand the potential environments for microbial colonization to environments without endogenous volcanic heat sources to drive hydrothermal activity. Our examination of impact glass from the Ries impact structure, Germany, has revealed the presence of putative microbial alteration. Given the probable ubiquity of impact glasses in post-impact environments throughout the Solar System, it is important to understand the biological components and potential of such systems. We have used a multi-analytical approach to assess the biogenicity of the tubular features in the Ries glasses. Their complex morphology (spiraling, bifurcation, avoidance, lack of intersection) has been studied extensively using both optical and scanning electron microscopy (SEM). Using SEM based Energy Dispersive Spectroscopy we have shown the presence of a depletion zone indicative of biological processing surrounding the tubules. Fourier Transform Infrared Spectroscopy has identified the presence of organic compounds spatially associated with the tubules and absent in crystallite regions. Synchrotron near edge fine structure (NEXAFS) spectroscopy at the C K-edge also indicates the presence of organically bound carbon in the glassy matrix surrounding the tubules, but absent in the matrix hosting only crystallites. NEXAFS spectroscopy at the Fe L2 and L3 –edges indicates distinct patterns of Fe speciation in the tubules not present in the Fe-rich abiotic quench crystallites. Impact cratering is a significant and ubiquitous geological process on terrestrial bodies in the Solar System as well as on the early Earth, as such the discovery of biogenic features in impact glass has profound implications for early life on Earth and the early evolution of life on Earth as well as for life on other terrestrial planets.

GRAIN SIZE FRACTION AND NUMBER OF GRAINS REPRESENTATIVE OF IRON OXIDE COMPOSITION IN TILL SAMPLES: THE SUE-DIANNE DEPOSIT AREA, NORTHWEST TERRITORIES, CANADA

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The magnetite to hematite-group Cu-Ag-(Au) Sue-Dianne IOCG deposit, located in the southern part of the Great Bear magmatic zone within the Bear Structural Province of the Canadian Shield, was chosen as a test site to optimize preparation methods for electron microprobe analysis of the ferromagnetic fraction of till samples. The objectives are to determine the optimum grain size fraction and number of grains to measure the composition of magnetite and hematite in the ferromagnetic fraction of till samples. Eight till samples were selected to provide a cross-section from up-ice, proximal to, and down-ice from the Sue-Dianne deposit. For each till sample, the ferromagnetic fraction was sieved in three size fractions: 1) <0.25 mm; 2) 0.25-1 mm; 3) 1-2 mm. The intermediate fraction (0.25-1 mm) was subdivided into sub-samples containing about 200, 100, 50, and 10 grains. The ferromagnetic fractions include magnetite, titano-magnetite, ilmenite, hematite, and other non-ferromagnetic oxides, silicates, and sulfides. At the deposit, hematite is the dominant oxide, whereas up-ice and down-ice of the deposit magnetite and titano-magnetite are the dominant oxides. The grains of the <0.25 mm size fractions are difficult to analyze with the microprobe because their size is too small to obtain accurate results. The 1-2 mm size fraction typically contains less than 110 grains such that analytical results are difficult to compare between samples. The 0.25-1 mm size fraction contains a large number of grains at all sample locations. The time and cost of analyzing 200 grains of the 0.25-1 mm size fraction limits the number of samples that can be routinely analyzed. Our results show that sub-samples from the 0.25-1 mm size fraction, containing circa 100 grains, yield a representative composition of magnetite contained in till samples. The mineral proportions in the sub-samples from the coarse and the intermediate fractions with 50 and 10 grains are variable and, generally, not consistent with the proportions determined for the 100 and 200 grains intermediate fractions. Sub-sample summary statistics of the composition of magnetite show that ca. 100 grains subsamples give the most reliable results. In the Ni/(Cr+Mn) vs. Ti+V and Ca+Al+Mn vs. Ti+V discriminant diagrams, the average magnetite composition of sub-samples from the coarse fraction, and from the 50 and 10 grains intermediate fraction show significant variations, supporting the use of the 100 grains intermediate fraction as the most appropriate sub-fraction to represent the average iron oxide composition of a sample.

3D LITHOFACIES MODELLING OF DEFORMED VOLCANOGENIC MASSIVE SULPHIDE (VMS) ORE SYSTEMS

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A 3D modelling study is presented for mapping the lithofacies architecture of the thrust-imbricated VMS-hosting mine horizon in Flin Flon, Canada using Wheeler's Time-Stratigraphy concept. The 3D modelling workflow of Paradigm's SKUATM software proceeds by modelling the volume of the faulted and folded mine horizon on a curvilinear grid. It then uses a coordinate transformation to remove the influence of geological structure on lithofacies interpolation. It subsequently applies the inverse of this coordinate transformation to map lithofacies on the curvi-linear grid to represent lithofacies in the finite deformed state.

The Flin Flon VMS deposits are hosted in rhyolite flow, rhyolite breccia and bedded tuff lithofacies of the Millrock member. The footwall of the ore system shows an abrupt lateral transition in lithofacies from intact pillowed basalt flows in the south to a thick volcaniclastic-dominated succession consisting of megabreccia, pillow fragment breccia and lapilli tuff towards the north across the margin of an intra-arc rift basin or cauldron. The regional structure is controlled by E-dipping D_3 thrust faults that broke-up D_1/D_2 N-trending fold structures and imbricated volcanic and volcaniclastic rocks of the Flin Flon arc assemblage and sedimentary rocks of the Missi Group. This thrust-imbricate structure was subsequently deformed by S-dipping ductile thrust faults (D_4) that re-imbricated the mine horizon and ore system in a northerly direction.

The first step in 3D modelling was to build a seamless fault network from mapped surface traces, structural field data, underground mine surveys and seismic data. Only the D_3 thrust fault segments in which D_4 thrust faults sole were included in this fault network, since their layer-parallel configuration does not provide constraints to model offsets of the mine horizon along them. Once the fault block model was generated, the faulted-curvilinear grid could be modelled from lithostratigraphic constraints that define its top and bottom. Categorical kriging of six lithofacies from generalized outcrop and drill core samples was applied to interpolate the lithofacies property on the 3D curvilinear grid.

The resultant 3D lithofacies model provides insight into the rifted volcanic arc setting in which the sulphide ore was deposited and elucidates how the ore-hosting horizon was deformed by thrust faulting. Furthermore, the lithofacies grid model serves as a stratified container for generating lithochemical property models that can be used for spatially characterizing ore forming processes, such as hydrothermal alteration. In addition, we demonstrate how the 3D lithofacies modelling approach can contribute to exploration targeting.

ANTHROPOGENIC (MAN-MADE) MATERIALS IN SOIL

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Soil is derived from a multitude of different materials from weathered bedrock including rock fragments and minerals, secondary material transported from other locations, namely colluvium an alluvium and organic matter from plants and animals. This presentation will focus on the characterization of manufactured materials commonly found in soil using polarizing light microscopy and scanning electron microscopy-energy dispersive spectroscopy. Many of the products discussed will include concrete, brick, wallboard, insulation, wood-plastic composites, combustion products, fibers, glass, asphalt and wood. Several case studies will be included to establish the investigative value in identifying the origin of man-made materials in soil.

VERTICAL VS HORIZTONAL ARCHEAN TECTONICS: A STUDY OF THE NORTH CARIBOU GREENSTONE BELT, NW ONTARIO

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The North Caribou Greenstone Belt (NCGB) is in the centre of the North Caribou Terrane (NCT), at the nucleus of the western Superior Province (WSP). A persistent problem plaguing the Archean field geologist is that regionally penetrative planar structures measured at the surface are typically subvertical; whereas, with seismic studies, only structures at shallow angles can be imaged. Our mapping along the NCGB confirms a dominant planar vertical fabric (foliation, upright fold axes), with gentle to moderate plunging lineations (fold axes, intersection lineations), a notable lack of strong L-tectonites, and occasional steep lineations in iron formations of the greenstone belt. This has implicated a primary horizontal tectonic regime responsible for the assembly and architecture of the NCT. Built on a >3.0 Ga basement, a dominant 2.87-2.85 Ga back arc-type volcano-plutonic tonalite sequence was formed near or on a thinned NCT margin. New LA-ICPMS in situ zircon U-Pb ages from St ± Al_2SiO_5 ± Bt-bearing metasediments are similarly 2.86 Ga, suggesting metamorphism synchronous with, if not a consequence of, elevated temperatures due to magmatism. This phase of crustal growth maybe the only vertical tectonic aspect in the NCT evolution as plutons and batholiths were assembled. Peak amalgamation within the WSP occurred c. 2.75-2.72 Ga in a series of discrete docking events with the NCT above a doubly-vergent subduction-type setting. Preservation of the pervasive 2.87-2.85 Ga ages suggest the NCT remained relatively cold and rigid during peak accretion and new 2.73 Ga U-Pb zircon rim and titanite ages record a metamorphic event coeval with volumetrically small re-melting episodes of more evolved granodioritic to granitic compositions. Continued accretion along the southern margin resulted in localized deformation and hydrothermal flow within the NCGB as inferred by c. 2.66-2.63 Ga Sm-Nd garnet and Pb-Pb accessory mineral ages within zones of intense strain. Ar-Ar ages of biotite and amphibole from central NCGB and new total-Pb *in situ* monazite ages from the North Caribou-Totogan Shear Zone yield c. 2.45 Ga ages, which likely correspond to an upper greenschist facies (400-500°C) tectonothermal pulse and structural reactivation nearly 200 m.y. after the latest stage of tectonism. Lithoprobe workers proposed the flat-lying geometry and inferred amphibolite composition of the imaged mafic slab beneath the WSP is consistent with Archean subduction models and can be used to explain the predominance of TTG suites in the Archean. The growing dataset of geochronology from the WSP is resolving a 400 m.y. long Andean- / Cordilleran-type margin, and the deformation pattern is consistent with that of horizontal tectonics.

EVIDENCE FOR NON-CYLINDRICAL IAPETUS SUBDUCTION FROM CONTRASTING ORDOVICIAN TECTONIC INTERPRETATIONS FROM SOUTHERN BRITAIN AND CENTRAL NEWFOUNDLAND

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In both southern Britain and central Newfoundland the Penobscottian Orogeny is thought to record horizontal translation of upper plate, back arc elements onto the peri-Gondwanan foreland in response to a shallow, advancing Iapetan subduction zone. On the island of Anglesey, NW Wales this is recorded by metamorphism and southeast-directed translation of a sedimentary succession comprising Gander-like sandstone-dominated units overlain by mudstones with tuffaceous units, thrust onto a Neoproterozoic granite-gneiss complex. The Anglesey accretionary complex preserves an overstepping Middle Ordovician foreland basin succession that records continued south-directed translation with a strong sinistral transcurrent component that persisted until at least Early Silurian times and was reactivated during probably Early Devonian, Acadian-age tectonism. This is interpreted to reflect persisting oblique shallow subduction in this segment of Iapetus with major basin subsidence and Late Ordovician volcanism on mainland Wales developed in a continental pull-apart setting.

Continued upper plate compression in Wales contrasts strongly with the central Newfoundland and other northern Appalachian successions. There, post-Penobscottian roll-back and upper plate extension led to development of a broad Exploits back arc that appears to only have become inverted during diachronous Silurian, Salinic tectonism.

We propose two possible mechanisms to explain these differences in post-Penobscottian tectonic styles. Firstly, subduction of low-density oceanic lithosphere in the southern British segment compared to central Newfoundland. This could have resulted from diachronous subduction of Iapetan spreading ridge. In this model early ridge subduction outboard of Anglesey would sustain shallow subduction and Iapetan transform faults could be reactivated as slab tears to accommodate roll-back in the nearby Newfoundland segment. This model is challenged by the apparent duration of shallow subduction in Wales as, intuitively, ridge subduction would be short-lived and roll-back would follow on afterward.

Alternatively, shallow subduction could result from higher relative plate velocity in southern Britain. This could reflect heterogeneous strain along a linear oceanic plate boundary. Southern Britain was however, proximal to a potential oceanic triple point and the strongly oblique, or transform, Tornquist –facing margin. Hence, aspects of more complex paleageographies incorporating strongly curvilinear margins such as in the Caribbean or Western Pacific are more likely.

THE PRIME MERIDIAN FOR MOLECULAR CLOCKS: WHEN DID LIFE BEGIN?

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Despite the fact that the fossil (including the molecular biomarker) record can provide evidence only of the first known occurrence of metabolic novelties or major evolutionary innovations — a necessarily minimum estimate of their actual time of origin — the benchmarks revealed by this record, the only direct evidence of the timing of such events, are pivotal in calibrating molecular phylogenies and inferred rates of evolutionary development. Foremost among such benchmarks is the beginning of life itself, evidence relating to the timing of which has been a subject of recent controversy that is now resolved.

Diverse, abundant, carbonaceous microscopic filaments described by Schopf in 1993 from the ~3,465-Ma-old Apex chert of Western Australia are recorded in many textbooks as the oldest fossils known. In 2002, however, the biogenicity of these sinuous microbe-like filaments was questioned by Brasier *et al.*, the existence of these filaments ascribed to graphite thought to be derived from organics produced by abiotic Fischer-Tropsch-type syntheses in a submarine hydrothermal setting. This nonbiologic interpretation is erroneous — recent studies establish that the filaments are authentic fossil microbes and that the Apex organic matter is assuredly biogenic.

Consistent with paleobiologic evidence from other geologic units 3,200 to 3,500 Ma in age — carbon isotopes, stromatolites, and microfossils (including those in other hydrothermal deposits) — Raman imagery and confocal laser scanning microscopy (CLSM) show that the

Apex fossils, like a great many other chert-permineralized filamentous Precambrian microbes, are three-dimensional, cylindrical, and composed of organic-walled cells that exhibit well defined cell lumina. Raman establishes that they are composed of biogenic kerogen, not abiotic graphite. CLSM data rule out their introduction by permeating organic fluids. And the CHONSP-composition and functional-group chemistry of the Apex organic matter documented in 2009 by De Gregorio *et al.* indicate "that the Apex microbe-like features represent authentic biogenic organic matter."

Other non-biological interpretations of the Apex fossils also fail. The solid mineral crystallites laboratory-synthesized in 2003 by García-Ruiz *et al.* lack the transverse cell walls and biological cellularity of the Apex microbes, and the clay mineral pseudofossils reported in 2009 by Pinti *et al.* as well as the hematite-infilled veinlets described in 2010 by Marshall *et al.* are not relevant to interpretation of the demonstrably carbonaceous Apex filaments.

This problem is solved. The Apex fossils are demonstrably biogenic. Microbial life was thriving on Earth 3,500 Ma ago, but its assuredly earlier actual time of origin has yet to be established.

HANS HOFMANN'S CONTRIBUTIONS TO PRECAMBRIAN PALEONTOLOGY

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One of the foremost Precambrian paleontologists in the history of science, Hans J. Hofmann (1936-2010) was a Fellow of the Royal Society of Canada and recipient of the Geological Association of Canada's Billings Medal (1980), the Royal Society's Willet G. Miller Medal (1995), and the U.S. National Academy of Science's Charles Doolittle Walcott Medal (2002). A pioneer in studies of Precambrian life, Hans filled in the evolutionary gap between the more recent fossil record and the oldest evidences of life and contributed more to the discovery and understanding of especially ancient, Archean, microbe-formed stromatolites than any one who has ever lived.

HRTEM AND XRD CHARACTERIZATION OF ILLITE/ SMECTITE (I/S) DIAGENESIS IN THE JEANNE D'ARC BASIN OFFSHORE NEWFOUNDLAND, CANADA

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An X-ray diffraction (XRD), high-resolution transmission electron microscopy (HRTEM) and conventional transmission electron microscopy (CTEM) study using octadecylammonium (nC=18) cation exchange has been applied to the clay-mineral separates (2.0-0.5, 0.5-0.1, and <0.1 µm fractions) of argillaceous rocks of increasing burial depth from the Jeanne d'Arc Basin, offshore Newfoundland, in order to study the smectite to illite (S→I) reaction during burial. Two wells were sampled: the North Ben Nevis (NBN) P-93 (2025 m, 2730 m) and Adolphus (AD) D-50 (2035 m, 3135 m). XRD patterns of the EG-solvated fine fractions resemble patterns of R0 randomly interstratified and R1-ordered I/S mixed-layer clay minerals. Lattice-fringe images of clay minerals in ultrathin sections treated with nC=18 cations document the multiphase nature of the clay mineral assemblages in all size fractions. The coarse and medium size fractions consist of low- and high-charge smectite-group minerals, expandable and non-expanded illite, vermiculite, mica, kaolinite, and chlorite. The <0.1 µm fractions of the shallow samples consist of low- and high-charge smectite-group minerals, a vermiculite-like phase and minor amounts of newly formed small packets of illite, which increases in abundance with depth of burial. Conventional TEM images of Pt-C replicas show a change in particle morphology with increasing depth of burial. Irregular, flake-like particles dominate in NBN P-93 at 2025 m and AD D-50 at 2035 m, while at greater depths (NBN P-93 at 2730 m and AD D-50 at 3135 m) a larger proportion of lath-like or equidimensional particles are observed. The HRTEM observations also reveal the absence of distinct R0 and R1 I/S mixed-layer phases which appear as an artefact of XRD analyses. Instead, three 2:1 layer silicate phases can form short rectorite-like (R1) sequences. Most common are smectite-group minerals that contain tetrahedral sheets with charge distributions that cause low-charge and higher-charge 2:1 silicate layers to alternate. Expandable illite and vermiculite are two other phases that may contain polar 2:1 silicate layers and therefore can form short rectorite-like sequences. The diagenetic evolution of smectite and illite in the depth interval of the Jeanne d'Arc Basin that was investigated should be considered as sequences of multiple discrete 2:1 clay-mineral phases that dissolve and recrystallize from solution in overlapping zones of burial depth and not as a single, continuous and progressive reaction series as traditionally assumed.

DIVERSE MESOSCOPIC MANIFESTATIONS OF LATE-OTTAWAN, MID- TO UPPER-CRUSTAL, OROGEN-PARALLEL SHEAR, GRENVILLE PROVINCE OF SOUTHEAST ONTARIO

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In the Central Gneiss Belt (CGB) and adjacent Composite Arc Belt (CAB), Grenville Province of Ontario, the regional dip of lithotectonic boundaries and the main foliation (S) is <35° toward the east or southeast. Associated elongation lineations (L) are typically down-dip. Assuming that S marks the XY plane of the strain ellipsoid (main ductile deformation) then its YZ plane dips steeply to the west or northwest. In the CAB boundary zone and adjacent domains, YZ-parallel sections through three kinds of mesoscopic structures attest to orogen-parallel components of ductile shear and, by implication, triaxial regional strains. The structures are: (1) naked or winged ovoidal porphyroclasts that are discordant to S, (2) quasi-cylindrical segments of gentle or open, asymmetric buckle folds in which S is the folded surface and hinge lines are parallel to L, and (3) discordant brittle-ductile dislocations such as m-scale faults, sheared contacts of weakly deformed pegmatite dikes or narrow high-strain zones. These structures appear to have developed consecutively, and represent post-peak-metamorphic stages of Ottawan deformation.

With respect to ovoidal porphyroclasts (1), the obliquity between the foliation trace and the major diameter of ovoids in the YZ plane seems to be due to shear-induced rotation about the lineation direction. However, the shear sense is commonly equivocal, especially where feldspar porphyroclasts are naked or have σ-wings at one end and δ-wings at the other. Concerning the buckle folds (2), the vast majority have S-asymmetry and therefore attest to an orogen-parallel regional component of sinistral ductile shear. Discordant brittle-ductile dislocations (3) are particularly common in the Bancroft and Barry's Bay regions. In YZ sections through dislocation walls, the offset or deflection of prominent folia attests to orogen-parallel shear components, but the regional-shear sense remains to be determined.

In summary, results of our recent work suggest that orogen-parallel shear components contributed significantly to the later stages of regional Ottawan deformation in southeastern Ontario. This supports our contention that regional strains were triaxial, at these stages, both in the exhumed mid crust and the upper crust, and thus that it is problematic to investigate late phases of the Ottawan orogenic evolution through use of two-dimensional, plane-strain models.

GEOCHEMISTRY OF THE PROTEROZOIC NUELTIN-MCRAE SUITES, WESTERN CHURCHILL PROVINCE

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Shallow granitic intrusions commonly generate mineralized, hydro-thermally altered zones in porous roof rocks. Typically the alteration involves potassic metasomatism, which can be revealed as enhanced K/Th and K/U ratios in airborne gamma ray maps. 1.75 Ga Nueltin granite plutons in the Dubawnt-Baker-Aberdeen lakes area are subvolcanic, intruding co-magmatic rhyolitic carapaces of the Pitz Formation. A north-

opening triangle of enhanced K/Th extends from the Pamiutuq intrusion at Tulemalu Lake (65O) toward Mallery Lake, and a corridor of enhanced K/Th extends north from Dubawnt Lake (65N). These domains coalesce south of Abderdeen Lake (66B,C) at an east-west high-K domain. Although large exposures of Pitz Formation and Nueltin granite constitute portions of these domains, broad tracts with high K/Th have no obvious relation to silicic intrusions.

The Geomapping for Energy and Minerals Program has demonstrated that the 65O triangle contains previously known basaltic intrusions (McRae Lake Dyke and an unnamed intrusion east of it) and newly recognized hi-Ti basalt flows within the Pitz Formation (SE of Tebesjuak Lake, in 650, on Thelon River south of Beverly Lake, and at Mallery Lake), all correlated with the mafic trigger that generated silicic Nueltin/Pitz magmas. Two sets of dykes correlated with the Pitz basalts (~015° parallel to the McRae Lake dyke, and ~075° parallel to the Thelon Fault) are prominent in the high K/Th domain in 66B. We postulate that regional potassic metasomatism is a result of alteration driven by the basaltic phase of the Nueltin event, which is unusually prominent in these domains, with local enhancement by Nueltin granites.

Geochronological tests of this hypothesis are in progress at the University of Manitoba. Fluorite from the Au-Ag deposit at Mallery Lake, located above the roof of a Nueltin pluton near its contact with Pitz Formation basalt, has been dated by Nd-Sm isochron at 1434 ± 60 Ma. Uraninite at Kiggavik, which has a close spatial association with hypabyssal Nueltin bodies, has been dated by a U-Pb method at. 1.4 Ga; this age is also represented in Athabasca Basin uranium deposits. The driver for the 1.4 Ga event is uncertain, but it must reflect a crustal scale disturbance which has no known relation to igneous activity in these areas. We speculate that at Kiggavik, this age represents low T resetting of an original higher-grade metasomatic event in wall rocks of the Nueltin Suite which is proposed as an exploration guide to U-Au-Ag deposits.

FRACTURES, VEINS AND HYDROCARBON EVOLUTION OF THE UTICA FORMATION, MOHAWK VALLEY, NEW YORK

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The Upper Ordovician Utica Shale is a widespread hydrocarbon source rock in the Appalachian Basin. Analysis of field exposures in the Mohawk Valley of New York State demonstrate that the lower interval of the Utica (high TOC Flat Creek Member) is characterized by E-W Mode 2 (strike-slip) fractures, bed-parallel thrusts and N-S Mode 1 (tensile) fractures. Dilational jogs in Mode 2 fractures host calcite veins with hydrocarbon stains, and methane-dominated and low-salinity aqueous fluid inclusions. Mode 1 fractures host calcite veins, and sand injectite dikes sourced from volcanic ash within the Utica, and sand and dolomite sourced from underlying Paleozoic strata and faulted Proterozoic basement. Horizontal calcite veins in the Flat Creek Member document high fluid pressures and/or relatively low confining pressure during vein formation. These features indicate active seismic pumping of fluid and sediment slurry during fracturing, and are linked to the diagenetic fluid systems that gave rise to hydrothermal dolomite and quartz/bitumen mineralization in units that underlie the Utica. Fluid inclusion (Th ≈105-185°C, TMice = -0.5 to -4.5 C) and stable isotope ($\delta^{13}C_{calcite}$ =+1 to +15 PDB; $\delta^{18}O_{calcite}$ = -9 to -11 PDB) data indicate that vein generation occurred during hydrocarbon maturation and that vein-forming fluids were mainly derived from within the Flat Creek Member. A mixture of Utica Shale-derived fluids and more saline brines sourced from basement fracture systems formed the hydrothermal waters that drove development of hydrothermal dolomite reservoirs in the Trenton-Black River interval that immediately underlies the Utica. Vertical flux and mixing of fluids was driven by active seismic pumping in fault systems during evolution of the Taconic foreland basin.

The types and orientations of fractures in the upper Utica and overlying units are markedly different from the Flat Creek Member, suggesting that fracturing and fluid expulsion in the Flat Creek Member were relatively early burial phenomena. Hydrocarbon maturation during early burial may have been facilitated by basement-derived hydrothermal fluids. Aromatic hydrocarbons are common in early stage veins associated with sand injectite dikes. Later burial and regional fracturing of the Utica occurred after deposition of overlying Silurian strata and permitted up-migration of dry gas into Silurian sandstone reservoir.

THE LABRADOR TROUGH: PERSPECTIVES ON THE VARIATIONS IN IRON FORMATION ACROSS THE BASIN

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The Labrador Trough is an 1100 kilometer geosyncline that extends from Ungava Bay in the north, through western Labrador and back into southeastern Quebec. The Labrador Trough stratigraphy comprises Lower Proterozoic sedimentary and volcanic rocks of the Kaniapiskau Supergroup that were deposited within an early Proterozoic rift basin along the eastern edge of the Superior Craton. The Kaniapiskau Supergroup is subdivided into a lower sedimentary dominated sequence known as the Knob Lake Group and an upper mafic volcanic dominated succession known as the Doublet Group. The Sokoman Formation of the Knob Lake Group hosts all of the iron deposits and occurrences within the belt.

Within the Labrador Trough there are hundreds of iron occurrences, dozens of defined iron ore deposits and several iron ore mines, some of which have been operating in the region for over 50 years. Variations in iron mineralization occurring throughout the Labrador Trough are associated with changes in stratigraphy and varying degrees of deformation, metamorphism and weathering. There are three iron ore deposit-types that are recognized within the Labrador Trough: direct shipping ore (DSO), taconite and meta-taconite. However, there are many subtle differences within these ore types that have important implications for mining and exploration. This presentation will provide a synopsis of our empirical research and understanding of the variations in the Sokoman Formation through the Labrador segment of the Labrador Trough and also pose questions that remain to be answered.

CHARACTERIZATION OF MINERALIZING FLUIDS ASSOCIATED WITH THE HINGE ZONE GOLD DEPOSIT, BISSETT, MANITOBA

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The Rice Lake Mine and associated deposits including the Hinge Zone are located 150 km northeast of Winnipeg, Manitoba within the Archean Rice Lake Greenstone Belt (RLGB) of the Uchi Subprovince. In the vicinity of the deposits, the RLGB is composed of intermediate and felsic volcaniclastic and epiclastic rocks, local mafic volcanic flows and volcaniclastic units, and subvolcanic intrusions. The deposits lie northwest of the Ross River pluton. Lithologies in the belt are affected by lower greenschist facies metamorphism and contain several syn-metamorphic to retrograde foliations.

The Hinge Zone was discovered in 2008 and is entirely hosted by the intermediate volcanic rocks of the Townsite unit. It contains a measured and indicated mineral resource of 197,700 ounces of gold and an inferred mineral resource of 538,700 ounces of gold. The main objective of this study is to characterize the fluids associated with gold mineralization.

Petrography of samples from the Hinge Zone shows that there are three generations of quartz. Stage 1 quartz (Q1) occurs as massive grains associated with albite and fine-grained (<1-5mm) primary pyrite (Py 1). Stage 2 quartz (Q2) forms as small subhedreal grains that are coeval with tourmaline, sericite fluorite, chlorite, and stage 2 coarse grain euhedral pyrite (Py 2). Stage 2 Py contains small blebs (<1mm) of gold. Stage 3 (Q3) quartz post-dates gold mineralization and forms as large (5-10mm) euhedral (druesy) grains that grow in vugs. Calcite is late and occurs as massive aggregates (10-20mm) and small, blocky grains (1-5mm).

Oxygen and sulfur isotopic compositions of quartz and pyrite were analyzed by Secondary Ion Mass Spectroscopy (SIMS). The $\delta^{18}O$ values for quartz range from 5.8‰ to 13.5‰ for generations Q1, Q2 and Q3. The $\delta^{34}S$ values for both generations of pyrite range from -0.4‰ to 4.9‰, which suggest that the source of sulfur is magmatic.

A preliminary fluid inclusion study indicates that the Hinge Zone deposit has had a complex fluid history. Several generations of fluid inclusion were observed. Primary fluid inclusions in Q1 are aqueous and have constant vapor/liquid ratios, whereas secondary fluid inclusions in Q1, which are associated with Q2 are aqueous inclusions with variable liquid/vapor ratios. The variable liquid/vapor ratios of these secondary fluid inclusions suggest boiling is the most likely mechanism for gold precipitation.

THE GEOCHEMISTRY AND GEOCHRONOLOGY OF THE BONG URANIUM DEPOSIT, THELON BASIN, NUNAVUT, CANADA

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The Thelon Basin has been an exploration target for decades because its geologic history suggests that it could host high-grade unconformity-related deposits similar to those of the Athabasca Basin. The Kiggavik project area is located near the northeastern terminus of the Thelon basin and comprises multiple uranium deposits. The Bong deposit is located at the intersection of two camp-scale faults and lies southwest of the Kiggavik deposits. The Thelon Formation has been eroded and the uranium deposits are hosted exclusively in basement rocks: highly deformed metavolcanic and volcaniclastic strata of the Neoarchean Woodburn Lake group, ~2.6 Ga mylonitized rhyolite (quartz eye quartzite), and parts of the undeformed yet mixed 1.83 Ga + 1.75 Ga Lone Gull granite.

Within the Bong deposit two stages of uraninite have been identified, both of which show alteration to coffinite. Uranium mineralization occurs in veins parallel to foliation, botryoidal grains and in mini roll-fronts. Stage 1 uraninite is associated with coarse-grained illite that formed at ~235°C. The veins of massive uraninite are highly fractured and altered. The uraninite is characterized by variable PbO (3.4-13.1 wt.%), SiO_2 up to 6.2 wt.%, and CaO <1.6 wt.%. Stage 2 uraninite mainly occurs within mini roll-fronts and is characterized by low PbO (<2.1 wt.%) with variable SiO_2 and CaO (1.4-6.8 wt.%). The ThO_2 content of both stages of uraninite is low (< 0.1 wt.%), which suggests that these minerals formed from hydrothermal fluids. Coffinite alteration of uraninite occurs along grain boundaries and in areas of increased sulphide content. It is characterized by variable SiO_2 (9.8-19.2 wt.%), low PbO (<1.3 wt.%), and moderate CaO (1.0-3.6 wt.%). Coffinite is associated with paragenetically late fine-grained illite that formed at ~160°C.

Chemical lead ages for least altered stage 1 uraninite range from 838 Ma to 1192 Ma (average age 1031 Ma), whereas altered portions of stage 1 uraninite consistently give much younger ages between 575 Ma and 668 Ma (average age 591). Stage 2 uraninite has a wide range of ages from 10 Ma to 113 Ma (average age 70 Ma), whereas coffinite gives an average chemical-Pb age of 19 Ma. The ages of unaltered stage 1 uraninite correlate with the Grenville Orogeny (1140-980 Ma) whereas the alteration of stage 1 uraninite may be related to the breakup of Rodinia (750-600 Ma). Chemical-Pb ages from the Bong deposit are similar to those that have been observed in deposits from the Athabasca Basin.

CELEBRATING WORLD HERITAGE GEOLOGY IN GROS MORNE NATIONAL PARK

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Gros Morne National Park is one of 43 national parks in Canada and was designated a UNESCO World Heritage Site in 1987. It is an area of spectacular natural beauty with a rich variety of scenery, wildlife, and recreational activities. The rocks of Gros Morne National Park and adjacent parts of western Newfoundland are world-renowned for the stories they tell of the formation of ancient mountains and ancient seas. The geology of Gros Morne illustrates the theory of plate tectonics, one of the most important ideas in modern science, and every year we share this story with thousands of visitors from all over the world. From the Global Stratotype Section and Point marking the Cambrian-Ordovician Boundary at Green Point, to the exposed Ophiolite suite of the Tablelands, to the Precambrian gneiss of Western Brook Pond Fjord, to the graptolites, trilobites and conodonts who reveal their fossilized fortune, our geology ROCKS! This session will highlight how we use technology, interpretive theatre, Artists in Residence, and new and old media to connect with audiences, both real and virtual, to expose the wonders found in the rocks, fossils and layers of Gros Morne. Making personal connections and sharing stories about the geology beneath our feet, helps us preserve and celebrate our spectacular geological heritage in Gros Morne National Park.

SEISMIC STRATIGRAPHIC INFERENCES REGARDING LATE-PHASE VOLCANISM AND SUBSIDENCE HISTORY ALONG SOUTHERN ALPHA RIDGE

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The Alpha-Mendeleev ridge complex is a submarine mountain system extending in an arcuate trend across the Arctic Ocean Basin from the Canadian margin, northwest of Ellesmere Island, to the Siberian margin north of Wrangel Island. Ranging in elevation from about 3500 to 250 m below sea level, and covering an area of 7.5E5 sq km, the ridge complex exhibits highly variable morphologies. It is generally interpreted to be a large igneous province that possibly includes domains of continental crust. However, the nature and origin of the Alpha-Mendeleev complex are actively debated because of the sparseness of geological and geophysical data and the complexity of the tectonic framework.

Modern 16-channel seismic reflection data collected from icebreakers over the southernmost flanks of the ridge complex reveal a distinctive unit deposited immediately on top of presumed igneous crust (inferred from acoustic basement). The unit comprises high amplitude, continuous, parallel to sub-parallel internal reflections. Its base forms a angular unconformity that extends southward into Canada Basin until it is eventually obscured by deep burial. The top of the unit is an onlap surface that also exhibits pronounced truncation along regions of Nautilus Spur. Modelling of wide-angle reflection and refraction sonobuoy data demonstrates a range of seismic velocities within the unit. For burial depths of less than 1.0 km, velocities range from 2.0 to 3.3 km/s. At deeper burial depths velocities are between 4.1 and 4.6 km/s. High impedance contrasts indicate the presence of indurated lithologies such as calcareous or siliceous sediments, or possibly volcanics.

Ranging up to about 600 m in thickness, the unit appears to be concordant with basement topography. Faulting is generally minor, but normal offsets at several locations indicate that deposition of the unit predates the most recent phase of significant extension in Canada Basin. The distinct onlap of the overlying sedimentary succession indicates that the extension was associated with rapid subsidence followed by tectonic quiescence. Throughout the northern reaches of Canada Basin, the unit onlaps the flanks of several large basement structures interpreted to be volcanic edifices, suggesting a temporal and possibly genetic linkage to late-phase volcanism. Samples have not yet been obtained, but a working hypothesis is that the unit consists of high-velocity siliceous oozes interbedded with hemipelagic and pelagic sedimentation.

PENNSYLVANIAN TO EARLY PERMIAN SHELF MARGIN TO TRANSECT, BORUP FIORD, NORTH WEST ELLESMERE ISLAND, ARCTIC CANADA

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The Sverdrup Basin, Arctic Canada, contains one of the worlds largest Pennsylvanian to Early Permian shelf margins at a thickness of up to 2.0km and a length of 400km. This is due to the prolific carbonate factory

created along Northwest Pangea by an influx of warm waters from the Tethys. The Nansen and Hare Fiord formations form a correlative shelf to basin sequence. The Nansen Formation is characterized by a variety of shallow water, carbonate-dominated lithologies while the Hare Fiord Formation is characterized by mixed carbonate-clastic slope to basin deposits. The Nansen formation is unconformably underlain with the Borup Fiord Formation and unconformably overlain by the Raanes formation. High frequency cycles are commonly observed in the Nansen formation and have been attributed to variations in sea level during Gondwana land Glaciation. The Hare Fiord Formation is underlain conformably by subaqueous evaporites of the Otto Fiord Formation and overlain unconformably by the Van Hauen Formation.

Eight stratigraphic sections were measured in an East (proximal environments) to West (Basinward environments) orientation along Borup Fiord at four different localities; Mount Burril, Borup Fiord Pass, Oobloyah Bay and Ricker Glacier, resulting in a transect though a carbonate margin and its adjacent slopes. Petrographic analysis was used to determine biota, mineralogy and rock fabric relating to depositional energy and ultimately classification of microfacies. Microfacies are linked to determine stratigraphic relationships and cyclicity of intervals. Preliminary petrographical analysis and field observations have reveled a laminated dolomitic back reef, phylloid algae and Palaeoaplysina rich reef mounds, cyclical shelf sediments and well preserved slope deposits. More than 2 900m of true stratigraphic thickness were measured and 723 samples collected.

UNDERSTANDING COMPLEX GEOPRESSURE PATTERNS IN THE JEANNE D'ARC BASIN, INTEGRATING TECTONISM AND SEDIMENTATION

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A critical component of exploring for hydrocarbons anywhere is gaining a location-specific understanding of mechanisms of geopressure generation and preservation. These are key inputs which allow for appropriate planning of new exploration and development wells.

The Jeanne d'Arc Basin has a complex history of polyphase tectonism with episodic rotation of stress regimes, as well as multiple diagenetic processes including long term maturation of prolific source rocks. We will illustrate past expressions of over-pressure encountered in the Jeanne d'Arc Basin along with conclusions regarding the dominant mechanisms of generation based on a new regional study of this highly productive basin.

Subsidence rates provide a primary control on one dominant mechanism, disequilibrium compaction. Local subsidence rates in the Jeanne d'Arc Basin are a function of tectonically-induced extension of the crust, block faulting of overlying sediments and subsequent regional subsidence following break-up of the upper crust and eventual generation of new oceanic crust. Consequently, variable patterns of incomplete de-watering in low permeability shales have been observed in multiple shale-dominated intervals moving into progressively deeper buried portions of the basin. Analyses of wireline logs, including resistivity, velocity and density, show that it is possible to quantify the intra-shale pore pressures.

The resultant patterns of pore pressure distribution measured by wireline pressure measurements, however, are complicated by variable degrees of lateral communication within porous and permeable strata buried within over-pressured shales. It is critical to understand the difference between the inherently long-term geopressures preserved within under-compacted shales and the expression, or non-expression, of that pressure when drilling into permeable beds.

We will review examples of apparently abrupt transition zones to high pressure marked by substantial jumps in drilling mud weight and contrast these with examples of long transition zones where mud weight was raised in a relatively progressive manner. In many existing wells, sharp transitions in mud-weight are often observed to be coincident with kick data, suggesting that drilling had been under-balanced for some interval. Finally, examples where measured pressure regimes return to hydrostatic below over-pressured zones will be illustrated. Controls inherent in the tectonic and stratigraphic isolation of specific sandstones within zones of shale disequilibrium compaction will be presented.

GEOLOGY, GEOCHEMISTRY AND TECTONIC IMPORTANCE OF THE HORSE COVE COMPLEX: A LATE NEOPRO-TEROZOIC IGNEOUS COMPLEX IN THE EASTERN AVALON ZONE, NEWFOUNDLAND

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The Horse Cove Complex is a recently recognized late Ediacaran swarm of mafic-to-felsic dykes that coincides with the extrapolated trace of the Topsail Fault along the east coast of Conception Bay and is hosted by mafic submarine volcanic rocks, diorite and, locally, granodiorite. The Horse Cove Complex has been divided into the following ten rock units: feldspar porphyry, gabbro and diorite, which are the host rocks to the dyke swarm, and eight rock units that represent dykes of mafic-to-felsic composition. The age of magmatism in the Horse Cove Complex has been bracketed by CA-TIMS U/Pb zircon ages of feldspar porphyry (581 ± 2.0 Ma) and an andesitic dyke (578 ± 2.3 Ma). Since field relationships indicate that these rock units represent the oldest and youngest datable rocks in the Complex, magmatism occurred over a period of 6.5 Ma or less, at maximum age limits. This age of magmatism overlaps, within uncertainties, with several magmatic events on the NE Avalon Peninsula, including felsic volcanic and fine-grained intrusive rocks along the eastern margin of the Holyrood Horst and near Cape St. Francis. Based on lithogeochemistry, feldspar porphyry and rhyolitic dykes in the Horse Cove Complex represent volcanic arc magmatism and may be co-magmatic. The mafic-to-intermediate dykes and host rocks in the Horse Cove Complex are comprised of calc-alkaline and tholeiitic rocks that exhibit a range of compositions, from rocks with E-MORB-like geochemistry to rocks that show LREE-enrichment and negative Nb anomalies, comparable to subduction-related calc-alkaline basalts and andesites. There is an overall progression from E-MORB-like magmatism to rocks with arc signatures. A rhyolitic dyke and several mafic-to-intermediate rocks of the Complex have ε_{Nd} values (at 580 Ma) of +4.1 to +6.4. Thus, these rocks are interpreted to have depleted mantle sources that have undergone various degrees of mixing or assimilation with older, LREE-enriched sources, such as continental crust and/or sediments in a subduction zone. The interpreted paleo-tectonic setting of the Horse Cove Complex is a back-arc basin environment, in which rocks with LREE-enriched mantle sources and subduction-contaminated sources were emplaced side-by-side and closely in time. The Complex may represent the last phase of subduction-related magmatism in the eastern Avalon Zone in Newfoundland prior to deep marine, deltaic and alluvial fan sedimentation during the late Ediacaran.

SUBDUCTION TO SLAB BREAK-OFF TRANSITION RECORDED IN THE TIMING, COMPOSITION AND SETTING OF EARLY SILURIAN VOLCANO-PLUTONIC COMPLEXES, BAIE VERTE PENINSULA, NEWFOUNDLAND

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Early 445 Ma tonalite-granodiorite in the Burlington Plutonic Complex (BPC) on Baie Verte Peninsula (NL) represents a late, post-Taconic phase of the Notre Dame continental arc that coincided with the emergence (likely <457 > 445 Ma) of the Laurentian continental margin during the Salinic Orogeny. These plutons are unconformably overlain by conglom-erate and 442 Ma subaerial, calc-alkaline ignimbrites of the lower Micmac

Lake Group (MLG). Synvolcanic, 441 Ma quartz diorite- tonalite plutons in the eastern BPC are intruded by 433 Ma tonalite-granodiorite. Epsilon Nd values (+2 to 0) in the BPC reflect limited crustal assimilation. A deeply incised erosional unconformity separates both the lower MLG and 433 Ma BPC from overlying alkaline basalt, hawaiite, mugearite and 430 Ma tuffs and comenditic ignimbrite. The ignimbrites likely originated from the nearby ca. 427 Ma King's Point Volcanic complex, where ring dykes, comenditic ash flow tuffs and breccia record caldera collapse. To the northeast, the Cape St. John Group (CSJG) unconformably overlies Ordovician ophiolite-cover, and contains continental clastic sediments, tholeiitic to alkaline basalts, 428 Ma welded felsic lapilli tuff, volcanic breccia, alkaline basalt, and a thick upper sequence of silica-saturated ignimbrite, felsic air-fall tuffs and 426 Ma flow-banded rhyodacite. Synvolcanic plutonic rocks are ferroan and include the ca. 429 Ma Cape Brule porphyritic monzogranite and crosscutting QFP ring dyke, 427 Ma Dunamagon monzogranite, tholeiitic to alkaline Redditts Cove gabbro and 426 Ma Seal Island Bight monzogranite. Epsilon Nd values in post 433 Ma plutons are +1 to -4 and reflect assimilation of continental crust. Direct evidence for contamination is shown by 428 Ma S-type granite and migmatite with low epsilon Nd (-4 to -8) that intrude underlying Neoproterozoic Humber margin metasediments and paragneiss (ε_{Nd} -12 to -16). Tholeiitic to alkaline, 430-426 Ma magmatism was broadly syntectonic with penetrative regional D_2 deformation and amphibolite grade metamorphism that yield hornblende $^{40}Ar/^{39}Ar$ ages in the range 439-418 Ma. Crosscutting K-feldspar megacrystic granodiorite contains 423 Ma titanite and provides a minimum age for D_2, whereas 430 Ma MLG and 426 Ma CSJG are overprinted by D_2 and younger fabrics. These results support a model (modified from Whalen *et al.* 2008) in which oblique collision of Ganderia with the accretionary Laurentain margin (Salinic Orogeny) led to cessation of arc magmatism (after 433 Ma in Baie Verte), and subsequent slab-breakoff and asthenospheric melting triggered renewed uplift, tholeiitic to alkaline magmatism (430-426 Ma) and crustal melting.

WESTERN BAIE VERTE PENINSULA REVISITED: FROM OPHIOLITE OBDUCTION ONTO LAURENTIA, THE NOTRE DAME CONTINENTAL ARC, TO POST-ARC CONTINENTAL VOLCANISM AND THE SALINIC OROGENY

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The Laurentian continental margin, including the 557 Ma Birchy Complex along the Baie Verte Line (BVL), underlies the western part of Baie Verte Peninsula where it represents an east-facing prism beneath obducted ophiolite. The overlying Advocate Complex contains dismembered ophiolite including mantle, boninitic cumulates, gabbro and sheeted dykes. Its volcanic section was faulted or eroded and is preserved as tectonic slivers of island arc tholeiitic (IAT) basalt in the BVL. Basinward, the Point Rousse Complex (PRC) contains thrust slices of boninitic cumulates, 488 Ma gabbro, sheeted dykes and IAT basalts, whereas the ophiolite section in the Pacquet Complex only exposes boninite and 487 Ma VMS-bearing rhyolite. All three complexes contain vestiges of syn-obduction, submarine cover (Snooks Arm Group). Proximal to the BVL, the basal cover contains megabreccia with ophiolitic blocks overlain by conglomerate and iron formation; basinward, the disconformity is marked by iron formation. Conglomerates contain ophiolitic- and platformal-derived detritus including 2550-550 Ma zircons and 479 Ma granitoid clasts providing a maximum age on obduction. Overlying 476 Ma felsic volcanic rocks and age data from the east constrain the cover sequence to 476-467 Ma. Emergence of the margin followed deposition of 457 Ma tuffs, quartzite and pillow basalt. Notre Dame Arc magmatism was associated with a number of unconformity-bound, volcano-plutonic sequences. The earliest phase of the Burlington Plutonic Complex (BPC; 445 Ma) is unconformably overlain by lower Micmac Lake Group conglomerate and 441 Ma subaerial ignimbrite coeval with 442 Ma BPC granodiorite. The upper Micmac Lake Group contains post-arc, comenditic- and 430 Ma mafic tuffs and high Ti basalts separated by an angular unconformity from lower Micmac Lake Group and a 432 Ma late BPC granite.

Western Baie Verte Peninsula has been affected by four phases of deformation. Preserved D_1 tectonometamorphism (468-459 Ma) in the Birchy Complex is related to Taconic ophiolite obduction. D_2 is the main tectonometamorphic event in the western map area, where the SSW-trending S_2 fabric (427-417 Ma) is associated with ESE-directed shear zones. To the east, the D_2 structural grain is rotated into E-W orientation and associated with L-tectonites and S-directed shear zones (ca. 430-420 Ma; Scrape fault). D_3 SW-NE-plunging sinistral folds and SE-directed shear zones are believed penecontemporaneous with D_2 and resulting from Salinic transpression. Major SSW-trending D4 fault zones and extensional reactivation of D_2 faults in the PRC reflect Devonian-Carboniferous dextral transtension between the Baie Verte Road and Green Bay faults.

LATE DEVONIAN-MISSISSIPPIAN(?) Zn-Pb-Ag-Au-Ba-F SEDEX DEPOSITS AND RELATED ALUMINOUS ALTERATION ZONES IN THE NOME COMPLEX, SEWARD PENINSULA, ALASKA

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Stratabound Zn-Pb-Ag-Au-Ba-F deposits and related aluminous alteration zones occur in siliciclastic and minor carbonate metasedimentary rocks of the Nome Complex on south-central Seward Peninsula. Stratiform lenses of disseminated to semi-massive sulfide (Aurora Creek, Wheeler North deposits), within strata of Late Devonian-Mississippian(?) age, typically are 0.5-2 m thick and extend along strike for up to 2 km. Deformed veins (Quarry and Galena deposits) are in a structurally lower unit of Ordovician-Devonian age. Both deposit types are mineralogically similar, consisting of sphalerite and/or galena with subordinate pyrite, tetrahedrite, arsenopyrite, chalcopyrite, and local gold in a gangue of quartz and carbonate (siderite, ankerite, dolomite); fluorite, barite, and magnetite are abundant in places. Layered and laminated exhalites at the Aurora Creek deposit are siliceous or baritic.

Sulfur isotope values for sulfides, exclusive of pyrite, are 1.8 to 17.3 per mil, suggesting a major component of sedimentary sulfur and/or seawater sulfate. Values for barite in the exhalite at Aurora Creek (25.5-26.3 per mil) are consistent with Late Devonian-Mississippian seawater being the predominant sulfur source. New Pb isotope analyses of galena (and other sulfides) from the stratiform lenses and deformed veins are heterogeneous in $^{206}Pb/^{204}Pb$ and plot as steep arrays with a restricted range of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. Pb isotopic compositions of galena from both deposit types indicate different isotopic sources, reflecting interaction of hydrothermal fluids with varying proportions of Paleozoic metasedimentary and mafic metaigneous rocks, and Proterozoic basement rocks.

Most deposits (both stratiform and vein) have spatially associated aluminous alteration zones, as much as 10 m thick and up to 3 km long, composed of muscovite + quartz + chloritoid + Fe-carbonate ± chlorite ± tourmaline ± barite ± hyalophane ± pyrite ± sphalerite ± galena ± chalcopyrite. Whole-rock analyses show generally lower SiO_2/Al_2O_3 ratios and higher $Fe_2O_3^T/MgO$ ratios, compared to those of unaltered clastic metasedimentary rocks of the Nome Complex and of average shale and graywacke. Aluminous rocks from deposit-proximal settings also have anomalously high Zn, Pb, Sb, and Hg, relative to the unaltered metasediments. Whole-rock oxygen isotope data suggest that metasomatic processes involved in forming the aluminous alteration zones had relatively minor effects on $\delta^{18}O$ values.

Our field and laboratory data indicate that the stratiform lenses and deformed veins represent different levels of sedimentary-exhalative (SEDEX) hydrothermal systems, in which the former type (e.g., Aurora Creek, Wheeler North) formed on the seafloor and/or in the shallow subsurface, whereas the latter (Quarry, Galena) formed deep in the subsurface. Potential may exist for significant polymetallic SEDEX deposits within Late Devonian-Mississippian(?) metasedimentary strata of the Nome Complex.

PROVENANCE OF NEOPROTEROZOIC TO CRETACEOUS SEDIMENTARY ROCKS FROM EASTERN GREENLAND AND THEIR CONTRIBUTION TO THE SEDIMENTS IN THE NORWEGIAN SEA

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We report new detrital zircon isotope (U-Pb, Lu-Hf) data from Neoproterozoic to Cretaceous sandstones of eastern Greenland, in order to characterize and evaluate the provenance from Greenland during Mesozoic and Cenozoic sedimentation in North Atlantic region. Middle Devonian to Lower Cretaceous samples show more or less uniform detrital zircon age distributions with variable Archean populations, abundant Proterozoic populations ranging from ca. 2000 to 900 Ma and a Caledonian population with mode at ca. 440 Ma. Neoproterozoic sediments of the Eleonore Bay Supergroup are characterized by a dominant age peak at 1100 to 1000 Ma, a secondary peak at 1700 – 1400 Ma, and rare Archean to Paleoproterozoic ages. We propose that the Neoproterozoic metasediments (Krummedal and Smallefjord sequences and the Eleonore Bay Supergroup) together with Caledonian rocks of age ca. 440 Ma and variable volumes of Paleoproterozoic basement were the main sources for the analyzed Middle Devonian to Lower Cretaceous sandstones. The small number of Archean zircons indicates limited role of the Archean basement rocks of the eastern Greenland Caledonian orogenic belt as a source for most of the analyzed younger sedimentary rocks.

The average detrital zircon age pattern from the Phanerozoic eastern Greenland samples (minor Archean to Paleoproterozoic component, abundant Paleoproterozoic to Neoproterozoic ages, significant Lower Silurian signal) resembles zircon age distributions of Upper Cretaceous turbidite sandstones from large parts of the Norwegian Sea as well as the three Oligocene sandstone samples from east of Jan Mayen Island. Upper Cretaceous to Paleocene Norwegian Sea sandstones, known to be derived from Norway, differ from this eastern Greenland age pattern by a near total lack of Archean zircons and a less pronounced Caledonian component. Wide detrital zircon age spectra with a distinct Silurian group and a population of Neoarchean zircons is thus suggested as indicative of sediments sourced from the studied area of eastern Greenland.

The Hf isotopic compositions of detrital zircons suggest that Eoarchean crust derived from a source with chondritic Lu/Hf ratios at ca. 3900 - 3700 Ma contributed to zircon-forming processes in the source area for the eastern Greenland sandstones until ca. 2300 Ma. The Caledonian orogeny in this area was probably a crust reworking event with a limited contribution from depleted mantle.

DEVELOPMENT AND PRESERVATION OF MICROFABRICS AND POROSITY IN UNCONVENTIONAL RESOURCE SHALES

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Petrographic and scanning electron microscope analysis reveals at least seven pore types that are present in unconventional resource shales: porous floccules, organopores, porous fecal pellets, porous fossil fragments, intragrain pores, microchannels, and microfractures. Possible primary transport, depositional, and reworking processes for these shales include: hemipelagic rain, hyperpycnal flows, turbidity current flows, storm reworking, and/or contour currents. Some of the microfabric and porosity features are a direct result of physical sedimentary processes whereas others are a result of biogenic processes (or a combination of both types of processes). Burial processes also modify some of the primary features.

Physical processes: The abundance of micro-sedimentary structures and micro–stratification suggest hyperpycnal and turbidity current flows predominate in transporting significant volumes of mud into a shale basin. To transport mud by these currents requires clay particles to be in the form of floccules, which perhaps surprisingly, are preserved in many shales upon burial, thus providing a significant volume of the rock's total porosity. Microchannels, which often cross-cut bedding, are the expression of erosion and deposition surfaces by bottom currents. Some intragrain pores, such as those within pyrite framboids, are the result of early diagenesis.

Biogenic (and combined) processes: Some shales contain alternating laminae of biogenic-rich and biogenic-poor (clay rich) particles. Most likely, the biogenic-rich laminae are related to periodic algal blooms (i.e. marine snow), during which relatively large volumes of organisms such as radiolarian, coccolithospores, sponges and Tasmanites are fed by upwelling of nutrient-rich marine waters. The organisms die and fall to the sea floor, perhaps as hemipelagic rain, or possibly as biosediment aggregates held together by algal 'mucus'. Pores are present on and in the shells or carapaces of these organisms, as well as within fecal pellets that the organisms produce during the bloom.

Burial processes: Micro- to nano-meter size pores within 'organic matter' have been well-documented. These pores are believed to have formed during burial by hydrocarbon generation from the primary organic matter. Mineral cements also are deposited and grains are recrystallized during burial, giving rise to microfractures within lithified shale.

These processes and their products give rise to a variety of shale types, some of which are organic-rich, hydrocarbon sources, and some of which are 'fracable' reservoir rocks. These strata can form 'brittle-ductile' couplets at a variety of stratigraphic scales.

COMPLEX DEFORMATIONAL HISTORY OF SUPRACRUSTAL ROCKS OF THE CORONATION SUPERGROUP, SOUTHERN WOPMAY OROGEN: THRUSTING, SHORTENING AND THICKENING OF A PROTEROZOIC WEDGE AGAINST A COLD ARCHEAN CRATON

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In the southern Wopmay orogen, sedimentary rocks of the Coronation Supergroup were deposited on the western margin of the Archean Slave craton. This highly strained Paleoproterozoic sequence has experienced a long history of thrusting, shortening and thickening as a result of the ca. 1885 Ma Calderian orogeny. Post-Calderian cross-folding has been linked to the occurrence of basement culminations which occur throughout the study area.

Initial structural analysis around the Brownwater Lake area has revealed two domains of ductile deformation: (1) On the south side of the lake metapelitic schists preserve a prominent E-W striking subvertical biotite foliation locally overprinted by a shallow north dipping fabric. Garnet porphyroblasts preserve evidence of two earlier foliations that pre-date the matrix fabrics; the cores contain steep/vertical inclusion trails (defined by quartz and elongate ilmenite) and the rims have texturally distinct shallower inclusions trails defined by coarser grained quartz and ilmenite. The axis of inclusion trail curvature/intersection in garnet porphyroblasts are oriented ~northwest-southeast with a later overprinting northeast-southwest striking crenulation, which represents an overall change in orientation of bulk shortening. (2) On the eastern to northeastern side of Brownwater Lake in a 4-6 km wide high strain belt abutting the Slave craton, metapelitic schists preserve evidence for northwest-southeast shortening. Rocks in this area have a very well developed ~northeast-southwest striking subvertical foliation that is overprinted by a very shallow, variably dipping crenulation.

Metamorphism occurred under low pressure - high temperature conditions, which peaked during the development of the latest overprinting subhorizontal crenulations in the rock (manifest as curved inclusion trails and late stage rims on andalusite porphyroblasts). The rocks grade from greenschist to upper amphibolite partial melts westward from the Slave craton, with abundant migmatite enveloping the ca. 1850 Ma Rodrigues granite west of the study area. Zircon ages in the locally occurring basement culminations have been reset by this pluton, and we propose it may be the heat source for the metamorphic mineral growth.

Targeted U-Pb in-situ monazite age dating and ongoing structural analysis will aid in unravelling the timing and relationship of deformation and metamorphism in the southern Wopmay orogen.

WAVEFORM TOMOGRAPHY IN 2.5-D TO ACCOUNT FOR 3-D GEOMETRY: APPLICATION TO REFLECTION DATA IN CENTRAL BRITISH COLUMBIA

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In order to improve the tractability of waveform tomography when applied to seismic field data acquired along a crooked line, we implement 2.5-D forward modeling and inversion. Waveform tomography combines conventional velocity-model building (i.e. tomography) with full-waveform inversion to reconstruct an image of subsurface acoustic velocity. For reasons of computational efficiency, it is desirable to use 2-D full-waveform inversion when processing data acquired with 2-D seismic survey geometry. However, crooked-line acquisition results in a cross-line component of the source-receiver offset that cannot be accounted for by 2-D forward modeling. If the cross-line geometry components are significant, full-waveform inversion may be intractable with a normal 2-D approach.

Our data set consists of refracted arrivals from a vibroseis multichannel seismic survey along crooked roads in the Nechako Basin, south-central BC. We carry out traveltime tomography in 3-D followed by full-waveform inversion in 2.5-D to build a detailed velocity model for the upper 2–3 km of the crust. The initial traveltime tomography step is used to produce a best-fit 2-D model that represents the earth model along the profile (averaged in the cross-line direction). The data waveforms contain significant information that is not utilized by traveltime inversion. By applying full-waveform inversion in 2.5-D (i.e. extending the 2-D model in the cross-line direction), we invert these data to produce an updated model with significantly improved detail. Computing the model updates in 2.5-D accounts for 3-D geometric spreading and point sources. The 2.5-D result is generated by combining the series of 2-D wavefields through a Fourier transform. This represents a solution to the 3-D viscoacoustic wave equation, which avoids many of the limitations of a purely 2-D method. The increased computational cost is modest: the 2.5-D method requires ~40× the computation time used by our 2-D method. A case study using Nechako Basin data is presented 1) to contrast the 2.5-D method with an earlier approach that used a static correction for geometry followed by the more usual 2-D full-waveform inversion and 2) to illustrate geological interpretation based on the near-surface velocity model. The interpretation indicates possible sub-basins in the Nechako Basin and delineates the Eocene volcanic rocks of the study area. When 3-D geometry is present on the seismic acquisition line, this newly developed 2.5-D method yields improved results over 2-D full-waveform inversion. In addition, the 2.5-D method is substantially less expensive computationally than full 3-D full-waveform inversion applied to 2-D crooked-line acquisition.

FRACTURE STUDIES IN THE HORTON GROUP, WINDSOR-KENNETCOOK SUB-BASIN, NOVA SCOTIA

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The Horton Bluff Formation is a unit of Mississippian age consisting dominantly of sandstone and shale, commonly interpreted to have been deposited in a lacustrine environment. The formation occurs in both the hanging wall and the footwall of the Kennetcook thrust system, a transpressional structure associated with dextral motion on the Cobequid-Chedabucto Fault Zone. Rocks in the footwall of the Kennetcook Thrust are possible targets for hydrocarbon exploration. Fracture studies permit a better understanding of deformation history of footwall rocks exposed on the east and west sides of the Avon River, Nova Scotia; the type locality of the Horton Bluff Formation was the primary field of study. The area between Horton Bluff and Blue Beach shows two kilometres of continuous cliff and wave-cut platform outcrop that show fractures in a variety of orientations. Fracture studies were performed on ten horizons on large areas of exposed sandstone. Circular scan-lines were measured using two measurement techniques to avoid directional sampling bias. In most results, two orthogonal fracture sets are predominant, with mean strikes of 165° and 075°. This indicates that there was a common stress regime throughout the area. In other locations, dominant fractures are interpreted as conjugate sets, with dominant strike directions of 165° and 090°. In rose diagrams with two dominant orthogonal strikes, in most cases, a third peak is observed with a roughly E-W strike. These results indicate two stages of fracturing. In the first, an extensional regime existed, forming the orthogonal fractures. This phase was probably associated with basin formation. In the second, strike-slip movement on the predominantly dextral Cobequid-Chedabucto Fault Zone to the north reactivated the 165° fractures, and formed the conjugate 090° fractures. It is likely that these fracture systems extend eastward in the footwall of the Kennetcook thrust system, where their orientations may affect fluid migration pathways.

THERMAL REDUCTION OF MOLYBDITE AND HEMATITE IN WATER AND H_2O_2-H_2O SOLUTIONS AS A TOOL TO DETERMINE OXYGEN FUGACITY IN HYDROTHERMAL DIAMOND ANVIL CELL (HDAC) EXPERIMENTS

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The HDAC is an excellent tool to study volatile bearing melts and solute-rich fluids at conditions of the crust and shallow upper mantle (100-1500 MPa). Despite the fact that oxygen fugacity is among the key parameters to be constrained in studies of speciation of elements in melt and aqueous fluid systems, it is very difficult to assess its value for HDAC experiments due to decomposition of water and interaction of fluid with gasket materials.

In this study the temperatures at which MoO_3 is thermally reduced to MoO_2 and those at which hematite transformed into magnetite in water and hydrogen peroxide-water solutions were measured in order to constrain the f_{O2} in HDAC experiments. The sample was contained within either a rhenium gasket between two diamond anvils or within a laser-milled recess in the culet face of the lower diamond (i.e. no gasket). In most experiments MoO_2 precipitated directly from solution once the temperature of thermal reduction was attained, whereas magnetite formed on the surface of hematite. MicroRaman spectroscopy was used to characterize run products. The temperature at which tugarinovite appeared varied depending on the experimental setup, and was 315 ± 2 °C in experiments where a gasket was used and 344 ± 2.5 °C without gasket. This implies that the presences of a Re gasket resulted in more reducing conditions of $\log(f_{O2})$ = -20.6 ± 0.5, compared to $\log(f_{O2})$ = -19.5 ± 0.2 for the series without gasket. Experiments with hematite and deoxygenated water (no gasket) gave an estimated log(fO2) of -19.6 ± 0.1. Introduction of hydrogen peroxide into water, in various molarities, allowed to prepare an equation relating oxygen fugacity in the charge and H_2O_2 molarity of the fluid: Log (f_{O2}) = (a * b^M) + c, where Log (f_{O2}) is expressed in bars, a = 0.25, b = $5.93*10^5$, c = -19.61 and the exponent M is hydrogen peroxide molarity.

These set of results indicate that a Re gasket has a significant reducing effect on the f_{O2} at relatively low temperatures (200-400 °C) and that the f_{O2} conditions appear to be imposed (mainly) by the fluid and not by the noble metal gasket. At the same time we proved that hydrogen peroxide could be efficiently used to impose a desired f_{O2} in HDAC runs, without using solid buffers or liquid compounds containing atomic species other than Hydrogen and Oxygen.

APPLICATION OF THE THERMO SCIENTIFIC NITON PORTABLE XRF ANALYZER IN GEOCHEMICAL EXPLORATION: AN EXAMPLE FROM THE FRANCISCO I. MADERO Zn–Pb–Cu–(Ag) DEPOSIT, ZACATECAS, MEXICO

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Francisco I. Madero is a Zn–Cu–Pb–(Ag) deposit owned by Peñoles and operated as an underground mine in Zacatecas, central Mexico. Historical production up to 2011 is 23.1 Mt of ore containing 12.8 MOz Ag, 92.09 kt of Pb, and 623.9 kt of Zn. The deposit consists of several mineralized zones located around a dome-type structure (laccolith) probably generated by forceful emplacement of an intrusive body at depth which shows a wide magnetic and gravimetric anomaly; however, the only intrusive rocks

found in the mineralized area are a few Tertiary, post-Laramide dikes. The mineralized area is ~10 km^2 with several ore bodies located in the same stratigraphic unit from 30 to 690 m in depth. The stratabound ore bodies are hosted by the Mesozoic back-arc marine sedimentary rocks, suggesting a syngenetic submarine exhalative genesis as sedimentary exhalative (SEDEX) or volcanogenic (VMS). However, calc-silicate mineralogy and replacement textures within calcareous units, and the absence of exhalites or identifiable feeder zones favors distal skarn model.

There are two types of sulfide ore assemblages in the ore body: 1) Pb-Zn sulfides as NW trending 6-65 m thick masses composed of bands and laminations of sphalerite and galena cut by quartz, clay-pyrite and chlorite-epidote veins at the base of the ore body in an area of 6 km^2, and 2) Cu-Ag sulfide assemblage consists of chalcopyrite, pyrite, cubanite, enargite, and tetrahedrite as laminations and bands in 3-40 m thick ore masses cut by quartz-pyrite-chalcopyrite veinlets.

To compare assay results from different analytical methods and investigate application and efficiency of portable x-ray fluorescence (XRF), three types of analyses were carried out on drill core samples. These methods include in-house Madero atomic absorption (AA), ALS inductively coupled plasma emission spectroscopy (ICP-ES), and Thermo Scientific Niton portable XRF (Niton® XL3t and Niton FXL on pulp samples). The study shows high correlation between data from portable XRF and lab methods. Cu correlation between XRF-Niton XL3t and ICP method is 0.92 whereas this correlation between XRF-Niton FXL and AA method is 0.96. Similar correlation for Zn assayed by the same instruments yield 0.983 and 0.982 for the core samples of this ore deposit. This correlation drops to 0.87 for Ag. Lead shows the highest correlation (0.99) among the elements that were analyzed by portable XRF and AA or ICP methods. Systematic analyses of core samples by these three methods and comparative studies indicate that geochemical anomalies for metals of interest in this deposit (Zn-Pb-Cu-Ag) can be identified readily in real time using portable XRF in the field.

HOLOCENE WATER LEVELS, PALEOSHORELINES AND UNDERWATER PREHISTORIC ARCHAEOLOGICAL POTENTIAL OF RICE LAKE (ONTARIO, CANADA)

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Rice Lake, located in the eastern Great Lakes of North America, has a high density of prehistoric terrestrial archaeological sites. It has been speculated that a large number of submerged sites are present on the lakebed, as lake levels have risen about 9 m since the arrival of Early Paleoindian peoples (ca. 11 ka BP). In order to better understand the submerged landscape and its archaeological potential, a detailed bathymetric survey and sediment coring was conducted across a 30-km^2 area of northeastern Rice Lake. Changes in Holocene water levels and shoreline positions were reconstructed by integrating core data with a digital elevation and bathymetric model (DEBM) that accounted for differential isostatic uplift and basin sedimentation. The DEBM was used to generate a series of paleogeographic maps showing paleoshoreline positions, water depths and areas of prehistoric archaeological potential.

The basin stratigraphy consists of a 3-5 m thick Holocene mud, marl and gyttja overlying glacial Lake Iroquois (ca. 12.5 ka BP) sand and clay deposits. Erosional hiatuses at the base of the Holocene sequence and at the mid-Holocene (ca. 6.5-4 ka) marl-gyttja boundary provide a low water level datum for construction of a water level curve. Isostatic uplift of the eastern basin outlet (> 30 m) had a dramatic influence on water levels and shoreline positions since the inception of Rice Lake (ca. 12 ka BP). During the Early Paleoindian occupation phase (ca. 11-10.5 ka BP) water levels were at a maximum lowstand (10 m bpl) and much of the present lakebed was an exposed lake plain with extensive wetlands. At the time of the Late Paleoindian/Early Archaic occupation of the McIntyre lagoon (9.5-8.7 ka BP) the lake was about half its modern extent and the lagoon was separate from the open lake. During a second lowstand phase after 6.5 ka BP, water levels dropped to > 4 m bpl and the lake was hydrologically closed. After 4 ka BP water levels recovered and the lake approached its modern extent. Sedimentation rates remained relatively constant (0.01-0.03 $cmyr^{-1}$) during the Early to Mid-Holocene and increased dramatically during the last 170 years due to post-European land use change. An archaeological potential map based on the reconstructed paleoshorelines identified four areas of archaeological potential: drowned river mouths, submerged wetlands and an area of uplifted Early Holocene lakebed in northeast Rice Lake.

STRUCTURAL HISTORY AND KINEMATICS OF THE TAUREAU SHEAR ZONE, LANAUDIÈRE-MAURICIE AREA, GRENVILLE PROVINCE - PRELIMINARY RESULTS

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The Mekinac-Taureau domain of the Lanaudière-Mauricie area (Quebec) extends for more than 80 km from the Saint-Maurice River to the Taureau Reservoir. It is mostly composed of granulite facies, felsic to intermediate orthogneiss and forms an elongated dome plunging to the south under the overlying Morin Terrane, which is composed of upper amphibolite orthogneiss and paragneiss. The contact between the Mekinac-Taureau domain and the Morin Terrane is named the Taureau shear zone on the western side and appears to be continuous with the unnamed tectonic discontinuity mapped on the eastern side. The kinematics and tectonometamorphic history of this shear zone are still poorly understood. Whereas structural studies conducted on the western flank of the Mekinac-Taureau domain suggested it is an oblique thrust, the decrease in metamorphic grade observed across the tectonic discontinuity on the eastern flank of the domain points to a normal sense of shear. However, the metamorphic contrasts between the Mekinac-Taureau domain and the Morin Terrane are still poorly defined due to the lack of precise quantitative P-T-t studies. The few U-Pb ages in the Lanaudière-Mauricie area mainly constrain the timing of thrusting along the western boundary of the Mekinac-Taureau domain. No conclusive geochronologic studies have been performed to constrain the movement along its eastern boundary.

This M.Sc. study aims at characterizing the tectonometamorphic evolution of the Taureau shear zone. Kinematic, metamorphic conditions and age of the shear zone will be respectively determined by detailed structural field studies, geothermobarometric analysis and combined U-Pb and $^{40}Ar/^{39}Ar$ geochronology.

Outcrops mapped during the 2011 summer field season show a strong deformation gradient towards the eastern boundary of the Mekinac-Taureau domain. Deformation peaks within a shear zone located on the contact with the Morin Terrane. The occurrence of down-to-the-south-east structures observed on key outcrops supports a model in which normal motion occurred along the eastern Mekinac-Taureau boundary. This is contradictory with the dextral-reverse sense of shear proposed previously for the western side and presents an interesting problem. Geothermobarometric studies are needed to confirm the kinematics of the Taureau shear zone and get a precise idea of the amount of displacement. Geochronology will be useful to establish the timing of shearing and understand how those two opposite kinematics can be reconciled into a coherent tectonic scenario.

NEW TECHNIQUES FOR SAND PROVENANCE – COMBINED ISOTOPIC TRACING OF DETRITAL ZIRCON AND TOURMALINE

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Sandstone units hosting oil and gas reservoirs in sedimentary basins are often difficult to trace in the subsurface, particularly where drilling and seismic data are limited. Heavy minerals present in the sandstones can provide distinctive fingerprints of the clastic sources of the sandstones, which may be used to reconstruct paleo drainage pathways into the basins and correlate sandstone formations. Traditional approaches in clastic heavy mineral studies have emphasized ratios of particular minerals with similar hydrodynamic properties, and in situ uranium-lead geochronology of

zircon. More recent studies of sand provenance have investigated *in situ* uranium-lead geochronology of detrital monazite and in situ lead isotope geochemistry of detrital feldspar. Here we explore the potential of hafnium isotope geochemistry of detrital zircon and lead isotope geochemistry of detrital tourmaline for sandstone source tracing.

Heavy minerals are pre-concentrated using bromoform (specific gravity = 2.85 g/cm^3) in order to separate the heavy mineral fraction from matrix light minerals such as quartz and feldspar. An epoxy grain mount is made directly from the 63 µm – 177 µm heavy mineral concentrate to avoid any potential bias produced by magnetic separation and hand picking of mineral populations. An integrated scanning electron microscope/Mineral Liberation Analyzer (SEM/MLA) allows for automated identification and chemical analysis of all heavy mineral grains within the grain mount. The MLA identifies the position, chemical and physical characteristics, and relative abundances of all heavy mineral phases of interest present in the concentrated subsample. *In-situ* isotopic analyses of identified detrital zircon and detrital tourmaline grains are made by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS). The Hf isotope characteristics of analyzed detrital zircon grains can be combined with in-situ U-Pb LA-ICPMS analyses from the same zircon grain. This information, integrated with the Pb isotope geochemistry of detrital tourmaline from the same sample can be used to even further refine the provenance for a particular sandstone unit. Example data from petroleum reservoir sandstones of the offshore Newfoundland Grand Banks and potential source rocks from on land Newfoundland stream and till deposits will be presented.

EFFECT OF IMPACT-RELATED PROCESSES ON THE LEAD ISOTOPE SYSTEMATICS OF ANORTHOSITES: A LUNAR ANALOGUE STUDY AT MISTASTIN LAKE CRATER, LABRADOR

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The Pb in lunar samples is a complex, multi-component mixture of initial Pb, initial radiogenic Pb and primary radiogenic Pb. An excess of radiogenic Pb, unsupported by radioactive decay of U and Th, is common in most lunar samples, including some of the oldest Ferroan Anorthosites (FAN). Models to explain excess radiogenic Pb in FAN have included early (> 4.36 Ga) development of a high-µ, KREEP-rich reservoir within the lunar upper mantle/lower crust, and volatile mobilization of radiogenic Pb from KREEP sources during 3.9 Ga basin-forming impacts. The Mistastin Lake impact structure, Labrador, Canada is an unique lunar analogue site, being the only known terrestrial crater to produce impact melt largely from an anorthositic source, while still preserving simple field relationships. To assess the effect of impact processes on Pb isotope systematics, five different materials from Mistastin were analyzed by LA-(MC)-ICPMS: (1) Plagioclase from shocked anorthosite on Horseshoe Island, the central uplift of Mistastin. (2) Maskelynite found in association with plagioclase crystals in the Horseshoe Island anorthosites. (3) A clast-bearing glassy vein, adjacent to plagioclase crystals. (4) Unshocked plagioclase laths from anorthosite located on the east side of the lake. (5) Well-preserved areas of plagioclase megacrysts from mangerite on the north side of the lake, considered a proxy for radiogenic, incompatible element enriched KREEP-like compositions identified in lunar rocks.

Shocked and unshocked anorthosite plagioclase and maskelynite have similar Pb concentrations (avg. ~3.5 ppm), Na/Ca (avg. ~0.6), $[La/Sm]_n$ (avg. ~10) and $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ isotopic compositions, suggesting the impact at Mistastin did not result in modification of $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ in the studied anorthosite plagioclase. Mangerite plagioclase has distinctly higher Na/Ca (avg. ~1.4), Pb concentration (~25 ppm) and $[La/Sm]_n$ (avg. ~60), with $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ isotopic compositions overlapping shocked and unshocked anorthosite plagioclase and maskelynite. The glassy vein has similar Pb and [La/Sm]n as shocked and unshocked anorthosite plagioclase and maskelynite but distinctly lower Na/Ca (avg. ~0.35) and higher 208Pb/206Pb with generally over-lapping $^{207}Pb/^{206}Pb$. If the unsupported radiogenic Pb found in lunar FAN is the result of volatilization and mobilization of Pb related to ~3.9 Ga impact events, the Mistastin results suggest that infilitration of Pb from external sources was much more pervasive in lunar anorthosites than in the anorthosites of Horseshoe Island. This may reflect more intense impacting on the Moon and/or a more intimate spatial relationship between lunar FAN and KREEP than Mistastin anorthosite and mangerite-granodiorite.

GEOCHEMICAL SURVEY OF BOTTOM SEDIMENTS OF THE CAPIBARIBE MIRIM RIVER, PERNAMBUCO, BRAZIL: SOURCES OF REE ANOMALIES

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The Capibaribe-Mirim river belongs to the Goiana river basin in north of the Pernambuco State. Its surrounding areas present agricultural and industrial activities lacking sewage systems, which are potential sources for contamination of water and sediments of this river. The aim of this study was to evaluate the concentration of major and trace elements, organic matter and total carbonates in bottom sediments as well as the physical-chemical parameters of water. Concerning the geochemical survey carried out, bottom sediments were sampled in four stations that were located 5km far each other to along the Capibaribe Mirim river, strategically situated upstream and downstream in relation to Timbaúba town. In these sampling stations, the physic-chemical parameters of the superficial water were measured, and shown the following values: pH (8 to 8,6), Eh (108 to 132 mV), electric conductivity (331 to 385 µS/cm), resistivity (2.58 to 3.02 kΩ×cm), and dissolved total solids (233 and 274 ppm). The concentration of organic matter ranged from 2.06 to 3.46 wt.%, whereas the total carbonates from 2.99 to 4.23 wt.%. The concentrations of 48 chemical elements were obtained by multi-acid digestion of the samples and measurements were carried out by ICP-AES / MS. Only eight chemical elements shown anomalous concentrations when compared to the values established in the Brazilian norms for sediments and to the global shale composition. These last eight chemical elements are (minimum and maximum concentrations, in mg×kg^{-1}): Ba (1,460 to 2,620), Ce (119 to 480), Cr (31 to 55), Ni (14 to 20), P (560 to 890), Pb (44 to 49), Sr (323 to 495), and Zr (314 to >500). It is noted that the anomalous concentrations of Ce, Sr, and Zr, can be justified by the relative high amounts of epidote, allanite and clinozoisite, mainly in the amphibolitic rocks of the metavolcanosedimetary complex, and granodioritic to granitic gneisses composing the substrate of area. Alternatively, the high Ce, Sr, and Zr values could also be related to the constant addition of lime to correct the soil pH since the material comprising the lime is usually rich in ETR. The relative high concentration of Ba and Pb could come from a Pb-Ba mineralization located north of the area (Camutanga town). But, in principle, the mineralization wouldn't have connection to the drainage system of the present study area. Thus there is also the possibility to discover other Pb-Ba mineralization upstream from the area investigated.

THE CENTRAL MINERAL BELT OF LABRADOR: AN ESTABLISHED URANIUM DISTRICT WITH DIVERSE METALLOGENY

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The Central Mineral Belt (CMB) of Labrador was first defined as a uranium province 50 years ago, and recent exploration since the mid-2000s has lead to the significant expansion of known resources within the region. Uranium mineralization in the CMB is very diverse and often obscured by post-mineral deformation, but the known deposits can be broadly subdivided into three main formational environments namely, magmatic, metamorphic-metasomatic and sedimentary.

Syngenetic magmatic mineralization is represented by uraniferous pegmatites and aplites, and by some locally stratiform mineralization in felsic volcanic rocks. The metamorphic-metasomatic style of mineralization covers a broad group of occurrences, which generally have an overriding structural control. The most significant deposits of this type

are hosted within strongly deformed felsic metavolcanic rocks, and pelitic metasedimentary rocks. The Michelin deposit (~100 million lbs of U_3O_8) remains the largest example of the metamorphic-metasomatic style of mineralization, although the Jacques Lake deposit (currently ~20 million lbs) also contains a significant resource. The higher-grade Kitts deposit also falls under this style of mineralization, but is now thought to represent an earlier mineralization event within the region. Mineralization in sedimentary rocks within the CMB is largely confined to terrestrial facies, where uranium concentration is linked to localized reduction of oxidized sequences, but there is no clear association with regional unconformities. The links between such mineralization and that of magmatic or metamorphic-metasomatic origins remain unclear, but at least some of the sandstone-hosted mineralization must be significantly younger in age.

On a regional scale, geochronological data from the CMB suggest that it records several discrete metallogenic events. The most significant deposits appear to be of Paleoproterozoic age (~1.9 to 1.8 Ma) but were not necessarily formed as part of a single event. Ongoing investigations are aimed at further constraining the ages of mineralization within the CMB, in attempts to better understand the nature and genesis of the uranium mineralization contained within.

A BASIN REDOX TRANSECT AT THE DAWN OF ANIMAL LIFE

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Molecular clock studies using different genes, taxa, calibration points and models of sequence evolution all suggest that crown-group animals diversified between ~750-850 Ma. Animals require oxygen to fuel their metabolism, and low oxygen levels have been hypothesized to account for the temporal lag between animal origins and the Cambrian radiation of large, ecologically diverse animals. Here, paleoredox conditions were investigated in the Fifteenmile Group, Ogilvie Mountains, Yukon Territory, Canada, which hosts an 811 Ma ash horizon and spans the origin and early evolution of animals. Iron-based redox proxies and carbon and sulfur isotopes were analyzed in seven stratigraphic sections along two parallel basin transects. These data suggest that for this basin, shallow oxygenated waters overlay anoxic and generally ferruginous deeper waters. Comparison with the ecology of modern oxygen-deficient settings suggests that the inferred oxygen levels would not be prohibitive to the presence of sponges, eumetazoans or bilaterians. Thus the evolution of the earliest animals was probably not limited by the low oxygen levels that characterized the Neoproterozoic. These inferred levels, though, would limit animals to very small sizes and low metabolic rates, and likely prohibit predatory behavior capable of driving predator-prey arms races.

WHAT GOES DOWN MUST COME UP: SCANDIAN METAMORPHISM AND EXHUMATION OF THE SUBDUCTED BALTICAN MARGIN, NORDØYANE UHP DOMAIN, WESTERN GNEISS REGION, NORWAY

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The recent discovery of coesite-eclogite in Nordøyane, western Norway, has prompted further investigation of the metamorphic and tectonic history of Baltican margin units in the northern part of the (ultra-)high-pressure ((U)HP) Western Gneiss Region. We report geochronological data (CA-TIMS, Ar-Ar, EPMA monazite) from basement and supracrustal rocks from the island of Harøy, and integrate these results with P-T and field data to construct P-T-t-d paths for both units.

Southern Harøy is underlain by migmatitic orthogneisses containing abundant eclogite pods, interpreted to represent Proterozoic Baltican basement. Coesite-eclogite records peak P-T conditions of ca. 3 GPa and 760°C. Northern Harøy is underlain by pelitic migmatites and garnet amphibolites, interpreted as Baltican margin rocks of the Blåhø nappe. Mineral assemblages record peak T conditions of ca. 850°C at ≥1.5 GPa; peak P has not yet been determined quantitatively but was likely <2 GPa. Peak metamorphic assemblages in both units were overprinted by granulite- to amphibolite-facies metamorphism at ca. 1.0 GPa and 750-800°C. The contact between them is marked by an amphibolite-facies shear zone, cut by scapolite-bearing pegmatites, that represents the northwestern known limit of the Nordøyane UHP domain. Zircon and rutile in southern domain orthogneisses and eclogites were dated by CA-TIMS. All analysed zircons show evidence of inheritance; the best results suggest eclogite facies metamorphism at ca. 410 Ma, with concordant rutile yielding ages of 378 ± 1.6 Ma. In contrast, EPMA monazite data from northern domain pelitic migmatites suggest protracted melt crystallisation at ca. 425-405 Ma. Ar-Ar analysis of hornblende, muscovite, and biotite samples from both units yielded plateau ages of 398 ± 5 Ma, 366-368 ± 4 Ma, and 380 ± 4 Ma, respectively.

The data suggest that the two units initially followed different P-T-t-d paths, with basement gneisses buried to depths of ca. 100 km during west-directed subduction of Baltican continental crust. In contrast, supracrustal rocks of the Blåhø nappe experienced burial and high-P partial melting at depths ca. 50 km; no evidence of UHP metamorphism has yet been found. The two units were juxtaposed along an amphibolite-facies ductile shear zone during exhumation, and cooled together through 500-350°C between ca. 400 Ma and 365 Ma. The results of this study will help constrain numerical models for UHP metamorphism and exhumation in the northern Western Gneiss Region.

RECUMBENT FOLDING AND ROTATION OF STRUCTURES DURING EXHUMATION IN A TRANSPRESSIVE TECTONIC REGIME, EASTERN SEGMENT, SVECONORWEGIAN OROGEN, SWEDEN

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North of lake Vänern, Sweden, the Eastern Segment in the Sveconorwegian orogen consists of 1.7 Ga and 1.8 Ga plutonic rocks, and 1.6 Ga dolerites. In the easternmost areas and further east outside the orogen, 0.98-0.95 Ga dolerites are also present. An east-west traverse provides a section through a crust affected, to variable extent, by Sveconorwegian tectonic reworking. In the east, an upper unit was affected by non-penetrative, ductile strain as shear zones operative under greenschist-facies conditions. The middle unit was affected by a penetrative gneissosity under amphibolites-facies conditions with local modification of 1.6 Ga dolerite to garnet amphibolite. The lower unit, to the west and south, was affected by penetrative ductile strain and migmatization; all the basic rocks in this unit are amphibolitic. Kinematic data in the upper unit and, less commonly, the middle unit indicate consistent, top-to-the-east shear. A prominent, ductile shear belt that forms the western boundary of the Eastern Segment shows sinistral transpressive strain along segments that strike NW-SE and predominantly reverse, top-to-the-east followed by normal, top-to-the-west shear along segments that strike N-S.

The generally flat-lying, gneissic structure in the lower and middle units was deformed in major recumbent folds with axial surfaces that dip to the north and fold axes that plunge gently in a predominantly ENE direction, sub- parallel to a mineral lineation. Locally, the strain is extreme along some of the fold limbs. However, in higher crustal units and even locally in the lower unit, the same folds show an eastward vergence with fold axes plunging to the north, consistent with the kinematic data. Rotation of these folds into orogen-transverse structures sub-parallel to the stretching direction is inferred. It is suggested that the structures formed and were modified at deeper crustal levels in a bulk transpressive tectonic regime, in connection with ductile exhumation of the crust during the Falkenberg phase (0.98-0.97 Ga) of the Sveconorwegian orogeny. This process resulted in a "squirt-like" pattern and tectonic rollover in the Eastern Segment, which, around 1.0 Ga, was tectonically sandwiched against a more rigid block to the west with older Sveconorwegian reworking. Ongoing U-Pb (zircon) SIMS dating work from the migmatities and a garnet amphibolite provide some support to this conceptual understanding.

TERTIARY MAGMATIC EVENTS IN THE FISH CREEK MOUNTAINS, GREAT BASIN, NORTH-CENTRAL NEVADA

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The Great Basin of Western United States is a region of Cenozoic lithospheric extension and volcanism that includes the state of Nevada and parts of southeastern California and western Utah. The Fish Creek Mountains (FCM), located in north-central Nevada, is a site of multiple igneous events ranging from 35Ma to 1Ma, covering most of the igneous history of the Great Basin. 29 samples of Late Tertiary volcanic rocks of unknown age and chemistry were collected from regions in the west, south and eastern parts of the FCM. The samples range from felsic rhyolites to mafic basaltic andesites and have been subsequently divided into these 3 regions (west, south, east) based on location within the FCM. The West flows are typically non-vesicular and are columnar jointed in outcrop indicative of thick lava flows. The East flows are mostly andesites and are accompanied by xenocrists of plagioclase and hornblende, and the South flows are typically glassy basaltic andesites with flow texture of plagioclase laths. All 3 groups have glassy aphanitic groundmasses and commonly contain pyroxene and zoned plagioclase phenocrysts. Ar-Ar ages from three flows yielded ages of 34.34 Ma (rhyolite dome), 33.8 ± 0.14 (dacite) and 33.3 ± 0.3 (andesite), and young in a westerly direction possibly related to the shift of volcanism from the eastern Colorado plateau back towards the west as a result of an increased angle of the subducting Farallon plate. Whole rock chemical analyses show some scatter, especially in mobile elements as a result of alteration but the data suggest a subalkaline affinity and subduction-like trace element signatures (HFSE-depletion, LILE-enrichment) with highly radiogenic $^{87}Sr/^{86}Sr$, consistent with an old, metasomatized mantle source ± some crustal input. Initial Sr isotope ratios for the basaltic andesites range from 0.706358 to 0.707755. The exceptional exposure of volcanic rocks in this area, including these late Tertiary lavas, 24.7 Ma FCM Tuff and late Pliocene to Quaternary alkali lava flows and cinder cones allows for the reconstruction of magma sources through time, which reflect the interplay of lithospheric extension and magma generation in the mantle (asthenosphere and lithosphere) and crustal interaction.

ALLEGHANIAN DEFORMATION AND FABRIC DEVELOPMENT IN AMPHIBOLITES OF THE BRONSON HILL TERRANE, CONNECTICUT

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Amphibolites in the Bronson Hill terrane of north central Connecticut lie near the southern boundary of the Acadian metamorphic high and the northern boundary of the Alleghanian metamorphic high in southern New England. Some rocks in the metabasaltic Middletown complex studied here preserve a coarse-grained granofelsic texture of randomly oriented amphibole and plagioclase grains consistent with a phaneritic equigranular gabbroic texture. However, most rocks are well foliated and lineated. Amphibole needles define a penetrative NNW plunging lineation and a foliation with a moderate WNW dip. Kinematic indicators (S-C fabrics, sigma porphyroblasts, asymmetric boudins, and sheath folds) all record a top-to-the-SE sense of motion. We report preliminary results of electron microprobe analysis in order to constrain the metamorphic conditions and the P-T-time deformation path followed during this fabric-forming event.

Amphibole and plagioclase dominate the mineralogy of all rocks, but some also contain epidote, titanite, ilmenite, and garnet. Most amphiboles are tschermakitic with 6.1 to 6.3 Si cations p.f.u. They are zoned parallel to the lineation with Si, Mg and Na decreasing from core to rim, and Al, Ti, and K increasing from core to rim. This zoning pattern is suggestive of prograde growth, an inference confirmed by Holland and Blundy (1994) edenite-richerite thermometry. Calculated temperatures for these samples range from ~650 °C to ~690 °C from core to rim with a maximum variation of 30° in a single grain. Other samples contain garnet, quartz, plagioclase, cummingtonite and pargasite. These two amphibole populations occur in discrete bands. The cummingtonite bands contain well aligned smaller (<200 μm) amphibole grains and are garnet-free. Pargasitic bands contain poorly aligned large (>200 μm) amphibole grains and euhedral to subhedral garnets sheathed in well aligned pargasite folia. These garnets are zoned, with Mg increasing from core to rim and Mn and Ca decreasing from core to rim. This is consistent with prograde growth after peak pressure but before peak temperature along a clockwise P-T-t path. Using the amphibole-garnet-plagioclase-quartz thermobarometer (Berman, 1991), we calculated pressures and temperatures to be ~6.0 Kbars and ~630°C. In combination with previous results of one-dimensional thermal modeling (Wintsch *et al.*, 2003, Wintsch *et al.*, 2005), these results allow us to conclude that these fabrics developed during decompression caused by SE thrusting in an out-of-sequence stack of thrust nappes ~275 million years ago.

SULFIDE-SILICATE IMMISCIBILITY AND EUTECTIC TEXTURES IN THE DUKE ISLAND COMPLEX, SOUTH-EASTERN ALASKA

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The Duke Island Complex (DIC), located in southeastern Alaska's Alexander Terrane, is well-known for its exquisite examples of igneous layering. The complex is generally regarded as an Ural-Alaskan intrusion, but the concentric zoning that characterizes most Ural-Alaskan intrusions is poorly developed in the DIC. The intrusion exhibits attributes that are more in line with an origin as a layered body that has crystallized via fractional crystallization of a high-Mg basaltic to ankaramitic liquid. Detailed evaluation of the crystallization of the ultramafic rocks is hampered by the absence of preserved interstitial liquid. Rarely, euhedral olivine is enclosed in larger clinopyroxenes; however, adjacent crystals in olivine clinoproxenites and dunites commonly meet at 120° triple junctions. Post-cumulus processes are clearly indicated with an absence of preserved interstitial liquid. "Trapped liquid" is only obviously present as net-textured, interstitial sulfide. Pyrrhotite and chalcopyrite are observed in amoeboid textures with olivine and clinopyroxene, with highly lobate sulfide-silicate interfaces. Sulfide inclusions in both olivine and clinopyroxene vary in morphology and abundance, but sulfide inclusions constitute up to 50 volume % of optically continuous silicate phenocrysts. Textures found in sulfide-bearing clinopyroxenites are strongly suggestive of coexisting immiscible sulfide and silicate liquids, representing apparent eutectic conditions. The presence of these sulfide minerals indicates that a dense immiscible sulfide liquid was retained and silicate liquid was expelled as clinopyroxene and olivine accumulated. In sulfide-bearing clinopyroxenites dihedral angles are commonly between 0° and 60°, suggesting that conduits for silicate liquid expulsion existed, and that sulfide liquid was wetting. Sulfide-silicate textures found in the Duke Island Complex are extremely uncommon in magmatic Ni-Cu deposits associated with ultramafic intrusions. Possible interpretations of Duke Island Complex sulfide-silicate textures include sulfide inhibition of silicate growth and dissolution of silicate minerals by reaction with sulfide-saturated interstitial liquid. Sulfide wetting of olivine is consistent with relatively high f_{O2} conditions (Rose and Brenan, 2001), as often proposed for sub-arc magmas. We suggest that sulfide wetting of silicate surfaces promoted the inhibition of silicate mineral growth, and the development of strongly lobate grain boundaries.

CAMBRIAN–ORDOVICIAN DEVELOPMENT OF SVALBARD, THE NORTHEASTERNMOST MARGIN OF LAURENTIA

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The Lower Paleozoic stratigraphy of Spitsbergen and Nordaustlandet, Svalbard archipelago is described based on new field observations in the region. The investigated sedimentary successions are referred to respectively the Oslobreen Group on Spitsbergen composed of

Tokammane, Kirtonryggen and Valhallfonna formations and the Kap Sparre Formation on Nordaustlandet. The succession unconformably overlies the Late Precambrian (Neoproterozoic) sedimentary deposits and initiates with siliciclastic sediments and continues with Middle Cambrian to Early Ordovician shallow water, platformal carbonates. This development, together with the micro- and macrofaunal development, is comparable to coeval deposits in the west (North-East Greenland) and southwards (i.e. Scotland and western Newfoundland). The Floian Stage is characterized by deeper water deposits yielding graptolites and pelagic trilobites. The microfauna (conodonts and radiolarians) confirm the deep-water to oceanic setting. In this period the faunal succession also compares with that known from the slope deposits of the Cow Head Group, western Newfoundland. In the Middle Ordovician the succession is composed of open marine carbonates and the youngest strata are Darriwilian in age. This interval, previously named the Valhallan Stage, is now referred to the Middle Ordovician. The macrofauna is largely of Laurentian affinity but the conodont fauna is a mixture of North Atlantic Province affinity and of unknown provincial affinity.

The classic interpretation of the palaeogeography of the region is that northeastern Svalbard belonged to North Greenland and North-East Greenland but this interpretation may have to be revised in the Middle Ordovician as the fauna includes taxa, which are foreign to Laurentia and rather suggest communication with another paleocontinent (or terrane).

DIVERSE VASE-SHAPED MICROFOSSILS IN THE NEOPROTEROZOIC CALLISON LAKE DOLOSTONE, COAL CREEK INLIER, YUKON TERRITORY, CANADA

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Vase-shaped microfossils (VSMs) occur in Neoproterozoic sedimentary successions from around the world. Yet, despite the spectacular exposures of Neoproterozoic strata in northwest Canada, they have not been described from this region. Here we report exceptionally preserved new populations of VSMs from the Callison Lake dolostone of the Coal Creek inlier, west-central Yukon. The Callison Lake dolostone was previously mapped with the Fifteenmile Group (unit PF1) due to its stratigraphic position between the Pinguicula and Rapitan Groups in the Hart River inlier; however, a significant exposure surface and low-angle unconformity separates the Callison Lake dolostone from the underlying Fifteenmile Group in both inliers and indicates that the Callison Lake dolostone is tectono-stratigraphically related to the overlying Mount Harper Group. Recent U-Pb ID-TIMS zircon ages from a tuff interbedded with the Fifteenmile Group and a rhyolite in the upper Mount Harper volcanics bracket the depositional age of the Callison Lake dolostone between 811.51±0.25 Ma and 716.47±0.24 Ma. Multiple stratigraphic sections through the Callison Lake dolostone reveal two distinct horizons rich in VSMs. A basal 4–75 m thick mudstone and minor sandstone interval is interbedded with laterally discontinuous stromatolitic bioherms that host VSMs suspended in organic-rich patches that escaped pervasive early diagenetic recrystallization. Medium- to massive-bedded shallow-water platformal dolostone up to 400 m thick overlie the lower clastic interval and gradationally transition into laminated organic-rich black shale and silicified organic-rich mats that host another VSM horizon. This deposit yields abundant and exceptionally preserved specimens of diverse morphologies, sharing multiple species with well-characterized VSM assemblages from the >742±7 Ma uppermost Chuar Group, Arizona. The discovery of VSMs in the Callison Lake dolostone adds to a rapidly expanding Neoproterozoic microfossil record in northwestern Canada, which includes diverse and abundant organic walled microfossils in the Wynniatt Formation of Victoria Island, a similar, though less diverse, assemblage in the Rusty Shale Formation of the Little Dal Group in the Mackenzie Mountains, and phosphatic scale microfossils in the Fifteenmile Group of the Ogilvie Mountains.

THE CALLISON LAKE DOLOSTONE: IMPLICATIONS FOR LATE NEOPROTEROZOIC RIFTING IN NORTHWEST CANADA

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Neoproterozoic carbonate and siliciclastic strata of the Fifteenmile and Mount Harper Groups are exposed in the Coal Creek and Hart River inliers of Yukon, Canada. The Callison Lake dolostone was originally recognized in the Hart River inlier and correlated with the upper Fifteenmile Group of the Coal Creek inlier, which underlies rift-related deposits of the Mount Harper Group. However, the recognition in both inliers of a significant exposure surface and/or low-angle unconformity separating the Callison Lake dolostone from the underlying Fifteenmile Group suggests that the Callison Lake dolostone could be more closely related to the Mount Harper Group. Stratigraphic sections measured through this unit reveal significant thickness and facies variation throughout the Coal Creek and Hart River inliers and evidence for a conformable contact with the overlying Lower Mount Harper Group. The basal 4–75 m generally consists of finely laminated sandstone, siltstone, and shale interbedded with laterally discontinuous stromatolitic bioherms that host vase-shaped microfossils. These mudstones and sandstones are capped by a sharp transition into medium-bedded dolostone up to 400 m thick, which is characterized by abundant domal stromatolites, cryptalgal laminites, evaporite pseudomorphs, sedimentary talc horizons, and other shallow-water sedimentary structures indicative of a marginal marine (or lacustrine?) depositional setting. Provisionally, we refer to the entire shale-carbonate sequence as the Callison Lake dolostone because it represents a coherent stratigraphic expression of rift-related subsidence preceding the deposition of Lower Mount Harper Group continental rift deposits and the Mount Harper volcanics. The Callison Lake dolostone likely correlates with the Coates Lake Group of the Mackenzie Mountains, Canada. The recognition of a Coates Lake equivalent in the Coal Creek and Hart River inliers supports a model of multiple unconformity-bound tectonostratigraphic units within the basal Windermere Supergroup. Additional detailed stratigraphic sections of the Callison Lake dolostone will provide better constraints on the depositional environment of this unit, its relationship with the metalliferous Coates Lake Group, and a greater understanding of Late Neoproterozoic protracted rifting on the northwest margin of Laurentia.

IMPROVED SEISMIC TIME-LAPSE QUALITY – CONTROL WHAT YOU CAN, AND MEASURE WHAT YOU CAN'T

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Seismic reservoir monitoring is a well established technology. However, it still has many, yet unrealized potentials which will open for wider use if higher repeatability can be obtained. Wider applications could be more quantitative interpretations, monitoring over shorter time intervals and application of the technology to smaller, tighter and more complex reservoirs. Turnaround time to acquire and process seismic monitoring data and to interpret the results has traditionally been several months. To maximize the added value of seismic monitoring in reservoir management, turnaround should preferably be reduced to a few weeks.

The key for high-precision seismic monitoring is repeatability. The data processing immediately becomes more complicated when things change from survey to survey, as these changes introduce data perturbations that must be compensated. The compensation processes often rely on measurements made from the seismic data itself, and it can be a difficult and time-consuming process.

The flexibility and cost-effectiveness of towed streamer acquisition make it often the technology of choice for the marine environment. WesternGeco has worked to control the variability of marine acquisition and data processing; firstly by introducing a steerable streamer with individually calibrated hydrophones, and then by deploying integrated systems that monitors the environment and automatically steer the vessel, sources and streamers to planned shot and receiver locations.

Regarding the acquisition environment-changes within and between surveys like sea-surface, water velocity and tidal variations, the philosophy is to measure these and enable deterministic compensation rather than work-flows based on the seismic data itself. The data processing job is confined to removing noise and multiples in a robust manner, and regularizing and imaging the time-lapse reservoir differences.

We will discuss how this latest acquisition and carefully designed DP flows can be utilized to provide the most optimal time-lapse image and turnaround time.

INDIGENOUS AND REWORKED PALYNOMORPHS APPLIED TO THE PROVENANCE AND STRATIGRAPHY OF CRETACEOUS/PALEOCENE STRATA, BYLOT ISLAND, NU

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In a palynological study of the North Bylot and Eclipse troughs, we have recovered rich spore, pollen and dinoflagellate assemblages from Upper Cretaceous and Paleocene strata. We have also found reworked organic-walled Proterozoic and Paleozoic "algal" cysts in these sequences. These fossils indicate the sediment sources for the two basins were at times different. Substantiating our findings is a complementary study of single grain detrital zircon U-Pb age distributions and rutile geochemistry. The results have implications for the sedimentological fabric of the troughs' infill and have motivated us to determine the properties of the reworked organic material derived from much older source sediments.

Specifically, Upper Maastrichtian and Lower Paleocene strata of North Bylot Trough contain conspicuous reworked populations of "algal" cysts possibly from the Proterozoic Bylot Supergroup. These include Leiosphaeridia crassa and L. tenuissima, which are rare in the Campanian part of the section but sometimes abundant in the uppermost Cretaceous in association with persistent occurrences of the angiosperm Porosipollis porosus. A vestibulate form of P. porosus is restricted to the lower Upper Maastrichtian of the Western Interior Basin, Yukon Territory and Northwest Territories. Its presence with the dinoflagellate Cerodinium diebelii in the North Bylot and Eclipse troughs allows the correlation of interbasinal sequences. From this we have determined that Leiosphaeridia is abundant in the North Bylot Trough but rare in coeval Eclipse Trough strata. This indicates to us that sediment provenance for the two troughs was separate by the Maastrichtian.

Rare to scarce reworked Late Paleozoic spores and Early Cretaceous pollen and spores are also present in Bylot and Eclipse trough fill. Some Early Cretaceous palynomorphs have an enhanced thermal maturity and others a thermal maturity similar to the indigenous palynomorphs. The latter may be locally derived from Albian or contiguous sediments whereas more thermally mature reworked specimens must have come from strata uplifted subsequent to substantial burial. A mid Paleocene marine episode, marked by a dinoflagellate influx, in the North Bylot and Eclipse troughs indicates re-establishment of a marine connection during the Paleocene.

LITHOGEOCHEMISTRY OF THE LOFDAL CARBONATITE COMPLEX, NORTH-CENTRAL NAMIBIA: UNUSUAL LATE STAGE HYDROTHERMAL HREE ENRICHMENT

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The Pan-African (ca 760 Ma) Lofdal carbonatite complex in northern Namibia is hosted by Paleoproterozoic metamorphic rocks at the southern edge of the Congo Craton. The sequence of events, suggested by geological mapping and lithogeochemical studies is: 1) intrusion of syenite and nepheline syenite plugs, and emplacement of related dykes into NE-trending basement structures; 2) explosive brecciation of the syenite and nearby country rocks, probably as a result of overpressuring of carbonatite magmas; 3) intrusion of calcite carbonatite plugs and related calcitic to dolomitic carbonatite dykes; 4) extensive hydrothermal alteration along major structures characterized by development of calcite, albite, phlogopite and chlorite (may be partly coeval with carbonatite intrusion); and 5) late hydrothermal, remarkably HREE-enriched, mineralization.

The REE in the nepheline syenite and calcic carbonatite intrusive phases are dominantly LREE-rich but late hydrothermal phases are HREE-rich with HREE comprising 75 to 95% of the total REE. This mineralization is dominated by xenotime and is the principal exploration target in the complex.

Systematic lithogeochemical sampling of carbonatite dykes between 2008 and 2010 over an area of more than 200 km_2 (+4000 samples) demonstrates REE mineralization on a district scale. However, only certain structures were subject to the late-stage hydrothermal event. The lithogeochemistry identified structures that host the late-stage hydrothermal alteration and pinpointed specific drill targets. Subsequent diamond drilling has revealed the three dimensional character of the HREE-mineralized structures. They are typically characterized by: 1) a visible, intense alteration zone that is generally broader than the mineralization itself dominated by albitite and coloured by red iron oxide and/or brown carbonatite; 2) a positive radiometric anomaly that reflects the presence of Th; 3) a geochemical anomaly characterized by elevated concentrations of the HREE and Y, Th, P_2O_5, and variable enrichments in other HFSE and granophile elements including Nb, Zr, Hf, Ta, and Mo; and 4) late veins and fracture fills that can carry abundant HREE. At shallow depths, the alteration zones are strongly oxidized, but in deeper zones, there is a close association of HREE and sulphide minerals (<2%).

The Lofdal complex appears to record an unusual (for carbonatites) fractionation of the REE, in which early crystallization of LREE-rich phases produced a residual fluid enriched in the HREE. This fluid was concentrated during carbonatite magma crystallization, and escaped into selected structures late in the history of the complex. The source and controls leading to the selective channeling of these fluids along certain structures remains unclear.

BIOGEOCHEMICAL ANALYSIS OF ULTRA-BASIC REDUCING SPRINGS IN THE TABLELANDS OPHIOLITE, IN GROS MORNE NATIONAL PARK, NEWFOUNDLAND

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Serpentinization reactions- the hydration of olivine in ultramafic rocks- is suggested to have occurred on the Archaean Earth during the early evolution of life, and recently hypothesized to have occurred on other planetary bodies such as Mars, contributing to the production of hydrocarbon gases such as methane. Locations on Earth where serpentinization is occurring can be considered early Earth and Mars analogues. The Tablelands Ophiolite, in Gros Morne National Park, Newfoundland is a continental site of present-day serpentinization as evidenced by springs found near serpentinized peridotites that are ultra-basic ($pH \geq 10$), calcium rich, and highly reducing, associated with the production of hydrogen gas. Serpentinization can produce conditions favorable for both abiogenic synthesis of methane and other hydrocarbons while also producing conditions amenable for chemosynthetic microbial metabolisms. This study examines the biogeochemistry of the ultra-basic reducing springs discharging from the ultramafic rocks of the Tablelands Ophiolite to determine the source of CH_4 and the microbial community present in this extreme environment.

Both isotopic and compositional analyses of dissolved gases sampled from the ultra-basic reducing springs have been used to identify the hydrocarbon source and thus subsequent reaction pathways responsible for

hydrocarbon synthesis. Geochemical analyses of hydrocarbon gases from the ultra-basic reducing springs suggest that the source of methane is not microbial. However, preliminary data shows the presence of a microbial community in the ultra-basic springs of Tablelands. Concurrent phospholipid fatty acid (PLFA) composition and ^{13}C isotopic analyses identify microbial communities that are present and their possible metabolized carbon source(s). Identifying possible carbon source(s) used by the microbial community in the springs will help in better understanding how they harness their energy for growth.

Determining how methane is formed at serpentinization springs in addition to understanding the microbial community that exists in these present-day extreme environments could help in our interpretation of past or present life on Earth and potentially on other planets.

TAPHONOMIC VARIABILITY OF THE EDIACARAN FORM GENUS ASPIDELLA (EDIACARA MEMBER, SOUTH AUSTRALIA)

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Aspidella, the disk-like Ediacaran form genus, is a common and globally-distributed member of the Ediacaran Fauna. In South Australia, it occurs prolifically (n > 1000) in locally dense assemblages on the bases of siliciclastic beds in the Ediacara Member of the Rawnsley Quartzite. Due to unequivocal association of certain specimens with stalks and fronds and preservation as a variety of taphonomic morphotypes, Aspidella is interpreted as the holdfast of a frondose, Charniodiscus-like organism, living with its holdfast secured in or under a microbial mat and its stalk and front protruding into the water column.

Excavation and sequential reassembly of 20 fossiliferous beds (>300 m^2) and bed-scale community analysis at Nilpena Station has revealed considerable variability in the composition of fossil assemblages. As the dominant component of three fossiliferous beds and a minor component of all others, Aspidella exemplifies this heterogeneity. Aspidella is also characterized by highly variable morphology. However, the distribution of morphological characters is unrelated to either specimen size or bed assemblage. This morphological diversity is therefore interpreted to be a function of taphonomic variability.

The morphological variability of Aspidella at Nilpena can be explained by four taphonomic pathways: 1) Internal mold: upon current-mediated severance of the stalk and frond, the hypomat holdfast may become filled in with sand. Following burial, compaction and lithification, this internal mold of the pedal surface is preserved as a convex disk adhering to the base of the overlying bed. When viewed in cross-section, internal slumping and infill by sandy laminae are commonly visible. 2) Cast of external mold: in cases where the holdfast is enveloped in a thicker microbial mat, the pedal surface may be captured as an external mold, subsequently cast, following burial, by the overlying veneer of sand. This preservational morph is especially prominent where Aspidella is preserved in association with Funisia; as viewed in hyporelief, Aspidella is always superimposed upon Funisia. 3) Composite cast: rapid burial (smothering) of holdfasts immersed in a thin microbial film may result in casting of the composite collapsed structure on the epimat surface, at times including portions of the stalk. 4) Mop: Dragging or plucking of the holdfast from the substrate may, in cases in which the substrate is characterized by a thin microbial film, result in casting of this perturbed epimat surface.

PRECISE U-Pb AGES FOR MESOPROTEROZOIC TANDILIA MAFIC DYKES IN THE SOUTHERN RIO DE LA PLATA CRATON: CORRELATIONS AND TECTONIC IMPLICATIONS

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The Tandilia System in eastern Argentina is a Paleoproterozoic igneous and metamorphic basement complex which crops out in the southernmost edge of the Rio de la Plata ('Plata') craton. It hosts a major shear belt in which many of the mylonitic rocks are derived from granitoids; major accretion took place during a juvenile event (2.25–2.12 Ga) along an active continental margin, followed by continental collision (2.10–2.08 Ga). Two distinct mafic dyke swarms crosscut the Tandilia System. In a previous study dykes trending E-W were characterized as calc-alkaline and gave Ar-Ar ages of 2007±24 Ma to 2020±24 Ma, whereas N-NW trending dykes are tholeiitic and a NW-trending subset yielded a U-Pb baddeleyite age of 1588±11 Ma. An expanded program of dating of both N- and NW-trending dykes from the tholeiitic swarm yield two precise U-Pb (ID-TIMS) baddeleyite ages of 1589±5 Ma, 1588±3 Ma, and a third, provisional age of ca. 1588 Ma. The tholeiitic dykes define low- and high-Ti trends and have geochemical and Nd signatures which are consistent with the presence of two compositionally different magmas. As yet, only the low-Ti suite of dykes is firmly dated.

The distribution of four matching U-Pb ages throughout the tholeiitic swarm over a distance of 70-80 km and with dyke thicknesses up to 80 meters confirms a high volume, but short duration for this magmatism. From a comparison with the global record of Large Igneous Provinces (LIPs), ca. 1590 Ma intraplate magmatism has few recognized correlatives. One includes an episode of bimodal AMCG magmatism (including Breven-Hallefors and Åland-Åboland diabase dykes) in Baltica, with possible connection to the 1.57±0.02 Ga Capivarita anorthosite, northern Plata craton. Other examples include precisely coeval activity in both the Gawler craton and NW Laurentia, with these two crustal blocks recently proposed to have been connected at this time. The global distinctiveness of this Mesoproterozoic event invites speculation that Plata craton - as part of Columbia (Nuna) supercontinent - was also a nearest neighbour to a reconstructed Gawler craton + NW Laurentia landmass at that time. Associated ca. 1590 Ma IOCG (iron oxide copper gold) mineralization is present in the Gawler craton (e.g. Olympic Dam deposits) and in NW Laurentia (large-scale IOCG breccias of the Wernecke and Ogilvie Mountains, Yukon Territory). However, ca. 1590 Ma IOCG mineralization has yet to be recognized in the Rio de la Plata craton.

UPPER AGE CONSTRAINT, PARAGENESIS AND GEOCHEMISTRY OF THE TIGER ZONE, RAU PROPERTY, CENTRAL YUKON

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The Tiger zone, central Yukon is a carbonate replacement gold-rich oxide and sulphide mineralized showing that occurs in a regional Jurassic-Cretaceous fold and thrust belt comprising rocks of the Selwyn basin and the Mackenzie Platform. Silurian-Devonian carbonate rocks of the Bouvette Formation host the Tiger zone and are locally bounded to the south by the Dawson thrust and to the north by the Kathleen Lakes fault. The Tiger zone stratigraphy consists of bedded limestones intercalated with locally extensive volcanic flows and volcaniclastic units all of which dip gently to the northeast. Two suites of intrusive rocks occur within 50 km of the Tiger zone, including the 92 ± 2 Ma Tombstone intrusions known for their mineral and gold occurrences and the 64.0-66.8 Ma McQuesten intrusions that have very few associated mineral occurrences. A U-Pb zircon age of 62.9 ± 0.5 Ma (2σ) was determined for a small intrusive stock, the Rackla pluton, that intrudes the stratigraphy ~3 km east-southeast of the Tiger zone. Additionally, small aplitic and pegmatitic dykes ~1km east of the Tiger zone yielded $^{40}Ar/^{39}Ar$ muscovite ages of 62.3 ± 0.7 Ma, 62.4 ± 1.8 Ma and 59.1 ± 2 Ma.

A paragenetic study has revealed an early mineralization event characterized by hydrothermal dolomites, arsenopyrite, gold and two phases of pyrite, and a late mineralization event that hosts silicate minerals, pyrite, bismuthinite, gold, pyrrhotite and minor base metals and importantly late-stage monazite growth. The two stages of gold mineralization manifest as 1) early arsenopyrite-bearing gold with no anomalous elemental signatures, and 2) a late-stage gold event which is

associated with bismuthinite, pyrrhotite, minor base metals and anomalous antimony and arsenic concentrations.

A U-Pb age of 58.37 ± 0.93 Ma (2σ) has been obtained by laser ablation inductively coupled plasma mass spectrometry from monazites that post-date both gold-bearing phases. The Tiger zone is interpreted to have formed by complex multistage fluid-flow where the later phases are directly associated with the emplacement and cooling of the 62.9 ± 0.5 Ma Rackla Pluton. Importantly, while the late stage gold-bearing event is the first significant Paleocene intrusion-related gold system identified in Yukon, the age and origin of the earlier gold-bearing event remains unconstrained. Ongoing fluid inclusion work, as well as a carbon, oxygen, sulphur and strontium isotope study will further constrain the fluid sources and character of these two mineralizing events.

A NEW MODEL FOR THE CALEDONIDES OF ENGLAND & WALES

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Many interpretations show the Welsh and English Caledonides arcing around the apex of the triangular Midlands Microcraton. However, this view is based on the arcuate strike of the Acadian (mid-Devonian) cleavage. The continuity of major NE-SW striking Palaeozoic fault systems in Wales is not proven through northern England. Similarly, the NW-SE trending Anglo-Brabant Deformation Belt (ABDB) is commonly shown extending northwestwards through eastern England, but not into northern England. Thus the relationship of the northern English Caledonides with those in Wales and in the ABDB is uncertain and differing interpretations have contrasting implications for the Early Palaeozoic tectonics of the region.

We use a previous review of UK airborne potential field data and a new regional analysis of mainly Variscan fault patterns as a guide to likely underlying Caledonide structure. From this evidence, we propose a new tectonic model in which the Caledonides of N and E England are separated from those of Wales by a NW-SE trending Lake District - Charnwood Lineament of Ordovician age or older. To the NE lie Tornquist-facing arc rocks of Ordovician age, formed in a transpressional regime above an oblique subduction zone. The Welsh Caledonides to the SW have a different volcanic and sedimentary history through at least the late Cambrian and Ordovician, and a markedly different structural grain. The contrasting Ordovician fault patterns provided the template for Silurian and early Devonian sedimentation and for the Devonian deformation that now defines the apparently continuous structural arc.

We suggest that the NE-SW trending, broadly orogen-parallel, structural grain in the Welsh Caledonides reflects late Neoproterozoic through Ordovician accretion tectonics. In contrast, the NW-SE trending Lake District-Charnwood Lineament possibly represents a Gondwanan margin-normal structure, developed when Avalonian elements rifted away from Gondwana in Early Cambrian times. The Ordovician arc, located on the NE side of Eastern Avalonia developed as the Tornquist Sea closed during the oblique docking of Avalonia with Baltica.

The new model accommodates marked differences in the volcanic history of Wales and the English Lake District, rotation of Wales with respect to the Lake District in the mid- to late Ordovician and provides for a new strike-slip extension model for the generation of the Lake District volcanic edifice itself.

MISTAKEN POINT ECOLOGICAL RESERVE - A WORLD HERITAGE SITE IN THE MAKING?

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Renowned as "the place where life first got big", Mistaken Point Ecological Reserve (MPER) is a provincially-managed protected area located on the southeast coast of Newfoundland's Avalon Peninsula. Deep water Ediacaran fossils were first discovered at Mistaken Point in 1967; establishment of the original Reserve occurred in 1987. MPER's expansion in March 2009 saw the introduction of new regulations designed to enhance the protection of its fossils. Recently, there has been a dramatic increase in MPER's public profile due to media events such as the "E" Surface casting project (filmed by the Discovery Channel), a visit by Sir David Attenborough (filming for his TV series "First Life") and the Reserve's inclusion in the 2012 edition of NL Tourism's award-winning "Find Yourself" advertising campaign.

MPER is a globally significant fossil site because (among other attributes) its rocks contain: 1) fossils of the world's oldest (579 Ma), architecturally-complex, multi-cellular organisms; 2) the largest Ediacaran fossils on Earth; and, 3) the earliest macroscopic evidence for locomotion in the fossil record. To date, at least 20 taxa have been recorded in the Reserve.

In 2004 MPER was added to Canada's official Tentative List of WH properties (no other Ediacaran sites are included on their respective nations' Tentative Lists). Being inscribed on the World Heritage (WH) List is the most prestigious formal international recognition a fossil site can attain. Of the present List of 936 WH Sites just 12 are 'primary' Fossil Sites. There are **no** Precambrian fossil sites on the WH List. Applying for WH Site status is a lengthy, complicated, demanding and rigorous process. Work is underway on the Reserve's nomination package which should be submitted to the WH Centre by Feb. 1st, 2014. There are no guarantees but the Reserve's chances of success are considered good.

Management concerns of relevance to the WH application include: mitigating natural and anthropogenic erosion; forestalling fossil theft and vandalism; private land boundary issues; the degree of community involvement in and public support for the bid; assuring adequate funding and staffing levels, and pressures from increased tourism.

Should MPER's WH application be successful it would obviously confer a number of socio-economic and other benefits upon the Southern Shore region. It is intended that the Interpretive Centre in Portugal Cove South be greatly expanded to house the repatriated, 900 ft^2, "E" Surface master cast which will become the centerpiece of a WH Site-dedicated exhibit.

REFINED STRATIGRAPHY AND SEDIMENTOLOGY OF THE WYNNIATT FORMATION, NEOPROTEROZOIC SHALER SUPERGROUP, AMUNDSEN BASIN, NW CANADA

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Previous stratigraphic studies of the Neoproterozoic (late Tonian-Cryogenian) Shaler Supergroup of the Amundsen Basin, Northwest Territories, focused mainly on its upper and lower formations, leaving a conspicuous gap in our understanding of the evolution of the Amundsen Basin. Middle Shaler Supergroup records a transition from restricted basin deposits of the Minto Inlet Formation to open-marine deposits of the Wynniatt Formation. This study addresses the litho- and sequence stratigraphy of the Wynniatt Formation, a >900m-thick succession deposited on a distally steepened, storm-dominated, carbonate ramp in a shallow intracontinental sea. The Wynniatt Formation is divisible into: 1) lower-carbonate member, an upward-deepening succession of supra- to sub-tidal carbonates; 2) black-shale member, a recessive interval of dark-grey siltstone and silty shale deposited on a pro-delta; 3) stromatolitic-carbonate member, comprising stacked upward-shallowing cycles of sub- to supratidal carbonates and, 4) upper-carbonate member, an upward-shallowing succession from sub-tidal black calcareous shale to resistant benches of peritidal cross-bedded intraclast grainstone and stromatolitic limestone. Four facies assemblages, composed of approximately 25 facies, define depositional environments that range from outer-ramp, deep-subtidal, sub storm-weather wave base, to heterolithic, inner-ramp, peritidal to supra-tidal mudflat.

Facies-stacking patterns during deposition of the Wynniatt Formation are generally cyclical, with classical upward-shallowing parasequences that define at least six third-order sequences. Harmonious sets of third-order base-level rise and fall define three, second-order sequences

(supersequences). Supersequence 1 (SS1) comprises lower-carbonate member, black-shale member, and base of the stromatolitic-carbonate member. The black-shale member records a major transgression within SS1. Base-level fall resulted in a subaerial unconformity that defines the upper boundary of SS1. SS2 comprises the stromatolitic-carbonate member, which is characterized by amalgamated packages of mid- to inner-ramp carbonates. A thin lowstand deposit is overlain by a major flooding surface that marks the sequence boundary, followed by deposition of SS3. SS3, comprising the upper-carbonate member, represents a second major transgression, which was followed by sustained highstand deposition, culminating in a second-order sequence boundary at the contact between the Wynniatt and overlying Kilian Formation. This boundary is defined by a flooding surface followed by rapid transition to restricted-basin conditions that accompanied a change in the subsidence regime of the Amundsen Basin. Our work in the Amundsen Basin suggests relatively stable tectonics during Wynniatt time, despite strata southwest of the study area that record northwest-facing rift basins over an equivalent time period. These data support multi-stage, non-correlative breakup of Rodinia along northwestern Laurentia during Neoproterozoic time.

GOLD METALLOGENY OF THE CAMBRO-ORDOVICIAN VOLCANO-SEDIMENTARY ROCKS IN THE ANNIDALE AREA, SOUTH-CENTRAL NEW BRUNSWICK, CANADA

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A 50 km long, northeast-trending belt of Cambro-Ordovician volcanic, sedimentary and intrusive rocks of the Annidale Terrane in south-central New Brunswick is appreciably enriched in gold, antimony, base-metals, and silver. These rocks comprise remnants of the Penobscot volcanic arc-back arc system associated with marginal basin closure between the Cambro-Ordovician Annidale and Neoproterozoic New River terranes through southeastward-directed subduction during the Early Ordovician. The suture zone between these terranes is now marked by the Taylor Brook Fault.

Gold occurrences are prolific throughout the Annidale Terrane and the majority are concentrated along structural features. These include regional northwest-directed thrusts related to telescoping of the stratigraphic succession, subsequent strike-slip faulting (and associated shear zones), and later, north- to northwest-trending normal faults with relatively minor displacements along the northeast-trending structures. A few gold occurrences show a spatial association with rhyolite dome complexes, primarily in the western part of the terrane.

The characteristics of the auriferous zones vary, depending on hosting lithologies, structural setting, and proximity to felsic intrusions. They occur mainly within shear zone-hosted quartz (±carbonate) veins and/or as disseminations within altered wall rocks. Pyrite and arsenopyrite are ubiquitous in the mineralized zones, but base-metal sulphides, stibnite and silver-bearing minerals may be present as well. Alteration assemblages broadly consist of variable proportions of quartz, carbonate, sericite, fuchsite and/or leucoxene.

Using oxygen isotope analyses of vein quartz (n=8) and an estimated temperature range of 300-400°C, the calculated $\delta^{18}O$ of the mineralizing fluid fell between 4.0 and 11.9‰, which overlaps the accepted values for magmatic and metamorphic fluids. Contrasting common lead isotope signatures from five Pb-bearing occurrences (n=6) suggest compositionally distinctive fluids for each, which is likely a reflection of the heterogeneity amongst the hosting lithologies. Two groups were broadly defined by the results of $\delta^{34}S_{sulfide}$ analyses (n=12) with signatures between -3.90‰ and +12.00‰. A magmatic S source is interpreted for those that clustered around 0‰ (i.e., intrusion-related deposits), and a sedimentary S source for those that were more enriched in $\delta^{34}S$. The latter was likely derived from leaching of country rocks by metamorphic fluids (i.e., mesothermal orogenic deposits).

Episodic tectonic and magmatic activity throughout the Annidale Terrane was instrumental in focussing gold-enriched fluids into a number of favourable depositional environments. Timing of these mineralizing events has been constrained to Late Cambrian to Middle Ordovician time, with possible overprinting by younger intrusion-related systems or subsequent remobilization of pre-existing mineralization into the later north- to northwest-trending structures.

PROVENANCE STUDY OF SEDIMENTS FROM THE DAVIS STRAIT AND THE LABRADOR SEA, BASED ON U-Pb DATING OF DETRITAL ZIRCONS

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Zircon U-Pb provenance is proving to be an important tool in deciphering source areas and dispersal patterns in sandstone units as well as changes in sediment source through time. In this study, we analysed 78 samples from Cretaceous and Palaeocene sandstones from drill cores and cutting samples from the Davis Strait and the Labrador Shelf. To help characterize sediment flow patterns, we also analysed stream sediment and till samples collected onshore West Greenland resulting in a relatively-unbiased age map of this potential source region. In total, we carried out 102 U-Pb zircon ages determinations. The analyses were done *in situ* using a ThermoScientific Element2 Sector Field Inductively Coupled Plasma Mass Spectrometer (SF-ICP-MS) coupled to a New Wave Research®/ Merchantek® UP213 laser ablation unit that is equipped with a frequency quintupled ND-YAG laser (wavelength of 213 nm).

Attempts to characterize the diversity and complexity of sediment source regions using zircon age spectra requires assumptions regarding zircon distribution in the source regions as well as efficiency of transport and preservation. In granitoid terrains that represent the most common prospective source regions in the North Atlantic region, we presume that zircons reflecting the dominant igneous and metamorphic events are widely available and that they will be transported and preserved with comparable efficiencies. As such, we interpret the zircon age spectra derived for young sediments to be indicative of the simplicity or diversity of source regions. The likelihood of successfully identifying an individual age component in a sample is a function of its relative abundance in the zircon population and the number of zircons analyzed. The more zircon grains that are analysed in any given sample, the more likely that all present age components will be successfully identified. We have been aiming for 120 grains from each sample, but some samples yielded considerably fewer grains.

ARCHEAN SEDIMENTS: RECORD OF A DIFFERENT WORLD

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Archean sediments on >2.7 Ga blocks consist of: 1) fluvial to deltaic coarse clastics with TTG provenance then transgression with sediment starvation yielding carbonates, cherts, and banded iron formation (BIF) (e.g. Marmion terrane); 2) continental rupture sequences consist of quartz-rich clastics progressing through stromatolitic carbonates to shale, BIF and komatiite/tholeiites all deposited unconformably on granitoids and/or greenstones, (N. Caribou terrane, Slave Prov.); 3) wackes, silts, and BIF forming a continental margin sequence e.g. the S. margin of older terranes in the Superior & Yilgarn. Sedimentary rocks in Neoarchean terranes consist of: 4) sedimentary interface zones in greenstone belts dominated by chemical sedimentary units with low contamination by continental material; 5) syn-orogenic flysch on the margins of older cratonic blocks (e.g. the English River), and 6) intracratonic basins developed post-cratonization such as the Witwatersrand, and their Paleoproterozoic cousins e.g. the Huronian and the Hurwitz.

Archean sedimentary styles differ from younger orogens i.e. local vs. distal provenance (zircon ages) and low vs. higher contamination measured by Th/U: basins on Mesoarchean substrate have transgression-related sequences with carbonates, cherts, and BIF (e.g. Winnipeg R.), the deeper parts have sulfide BIF (e.g. Zimbabwe); regression-associated sequences consist of BIF above cratonized crust (Superior and Yilgarn). Continental rupture sequences show transgression-related sequences and rift-related volcanism on block margins (Superior, Slave). Continental margin sequences consist of wacke, silt and BIF (Marmion terrane)and only when deeper water is available do we see laterally extensive medium - fine grained clastic sequences e.g. the English River, Quetico etc. During

lateral accretion in regions with multiple disparate blocks we see microcontinental margin-related quartz-rich clastics e.g. blocks in the N. Caribou terrane. In Neoarchean belts (e.g. Abitibi), pre-orogenic sedimentation consists of chemical and minor clastic sediments. The chemical sediments are BIF typified by very low contamination levels.

During cratonization, several shields see widespread initial fine clastics with abundant evidence of continental provenance (older zircons) followed by younger laterally restricted alluvial-fluvial coarse clastics and associated calc-alkaline to alkaline volcanics again with continental provenance.

Provenance of types 1-3, 5 & 6 show evidence of older detritus whereas type 4 shows little evidence of older detritus. In summary, Archean sediments are characterized by a low mud content, very restricted shelves variable levels of contamination and provenance. Thus, most Archean terranes represent sedimentation on continental crust with ample access to older terranes whereas greenstone belts seem to represent restricted provenance consistent with volcanism and sedimentation on oceanic plateaux.

UNIQUE AND DIAGNOSTIC ISOTOPIC FINGERPRINTS OF PALEOZOIC SHALE GAS IN THE APPALACHIANS

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Isotopically reversed gases have recently become of particular interest as they have been found to be common in mature, highly productive shale gases. Significant isotope data sets that include isotopically reversed gases of thermogenic origin have been reported for fractured reservoirs in the Appalachians (Burruss and Laughrey, 2010) and the WCSB (Tilley *et al.*, 2011) and for the Barnett shale, Texas and the Fayetteville shale, Arkansas (Zumberge *et al.*, *in press*). These data sets provide a framework within which mature shale gases can be evaluated and better understood in terms of their general evolution. Re-evaluation of isotope data from the Barnett and Fayetteville shales, the Appalachian Utica and Marcellus Shales, and new data from the WCSB Montney/Doig Phosphate and Horn River Shales show that shale gases can be classified into three distinct maturation stages that have unique and distinctive carbon and hydrogen isotopic relationships and trends. Identifying the maturation stage of a gas can lead to a better understanding of the processes that have occurred and may help predict the productivity of a shale gas play.

The three maturation stages are defined here as pre-rollover, rollover and post-rollover stages. Gases in the pre-rollover stage are isotopically normal ($\delta^{13}C_1 < \delta^{13}C_2 < \delta^{13}C_3$) unless mixing of gases from different sources has occurred. In the rollover stage, $\delta^{13}C$ ethane and $\delta^{13}C_3$ propane become progressively more negative as $\delta^{13}C$ methane becomes less negative, but ethane and methane are reversed ($\delta^{13}C_2 < \delta^{13}C_1$) only towards the most mature portion of the rollover stage. In the Appalachians, where Marcellus shale gases are generally at the transition between the rollover and post-rollover stages, isotope ratios must be compared to a background range of Marcellus shale gas maturities in order to assign a maturity stage. Correct assignment of maturity stage could be of importance because the rollover stage may represent the peak of high productivity shale gas whereas the post-rollover stage may represent a decline in productivity (Burruss and Laughrey, 2011). At the beginning of the post rollover stage, $\delta^{13}C1 > \delta^{13}C_2 > \delta^{13}C_3$, but as $\delta^{13}C$ ethane and $\delta^{13}C$ propane become increasingly less negative at varying rates, ethane and propane may or may not be reversed with respect to each other at the highest maturities. δD of methane in gases of the post-rollover stage generally stays constant or becomes more negative with increasing maturity. Utica shale gas represents the post rollover stage both in Quebec and Pennsylvania.

A GEOCHEMICAL STUDY OF TERTIARY VOLCANISM IN WEST-CENTRAL GREAT BASIN, WESTERN NEVADA

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The Great Basin (GB), located within the Basin and Range Province (BRP), western USA, has 200 Ma of magmatic and tectonic history. About 40 to 15 Ma, a complex surge of primarily intermediate to felsic magmatism swept southwestward across the GB concurrent with subduction of the Farallon plate beneath the North American plate. Previous petrological and geochemical work has focused on young (<15Ma) silicic and/or mafic volcanism around the margins of the GB. We will use petrology and geochronology as well as isotopic and major and trace element geochemistry on lavas from the west-central GB to test hypotheses surrounding the Eocene to Mid-Miocene southwestward "sweep" of volcanic activity, including its relationship to the convergence rate of the Farallon and North American plates as well as shallowing and eventual rollback of the Farallon slab beneath North America.

We have collected samples along an east-west transect through the west-central GB, including the Stillwater, Clan Alpine and Desatoya mountain ranges, to add to existing datasets from the Ancestral Cascades Arc (ACA) and western Great Basin (WGB). Preliminary results show that samples range from basalts and trachybasalts to dacites and trachytes. Most samples east of the Stillwater Range have a strong calc-alkalic signature with elevated K_2O, and high primitive mantle normalized La/Sm and Ba/Zr. All samples display negative Ta and Nb anomalies and depletion in Ti, and most rocks have elevated Ba and Sr, consistent with a subduction zone signature. These data, along with high initial $^{87}Sr/^{86}Sr$ (0.704 to 0.707) and low $^{143}Nd/^{144}Nd$ (0.5123 to 0.5128), suggest that Tertiary magmatism tapped metasomatized lithospheric mantle rather than the mantle wedge, resulting in mafic through intermediate volcanic rocks. Metasomatism of the lithospheric mantle by dehydration of the underlying Farallon slab would also have resulted in the late Mesozoic regional uplift and low-velocity upper mantle. Tertiary magmatism was enhanced due to slab roll-back exposing the base of the metasomatized lithosphere to hot asthenosphere.

This study will provide information on mantle sources and magma evolution of the west-central GB. Additional impacts of this project include: contributions to geochemistry and geochronology for regional Tertiary volcanism, evaluation of magma-lithosphere interaction in continental volcanism, utilization of continental magmas as "probes" for lower lithospheric composition, assessment of the interaction between magmatism and tectonism, and evaluation of models for igneous activity in the GB and surrounding tectonomagmatic provinces.

GEOLOGY, MINERALOGY, AND S-ISOTOPE GEOCHEMISTRY OF THE LITTLE DEER VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, LUSHS BIGHT GROUP, SPRINGDALE, NEWFOUNDLAND

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The Little Deer Cyprus-type VMS deposit is hosted within the Cambrian Lushs Bight Group of the Central Mobile Belt, Newfoundland and has been the focus of extensive exploration in recent years. The deposit is situated in a chlorite-schist zone hosted within island arc tholeiitic pillow lavas. The basaltic host rocks for Little Deer have undergone varying degrees of chlorite, quartz and sericite alteration and have been metamorphosed to greenschist facies. Mineralization in the deposit consists of a stockwork that is comprised primarily of disseminated and stringer-style mineralization with occasional semi-massive to massive sulfide horizons containing chalcopyrite, pyrrhotite and pyrite, with minor sphalerite and cobaltite. Native tellurium; (bismuth/mercury/silver/nickel and lead) tellurides; electrum; galena; selenium-bearing galena; arsenic and monazite are present as trace phases. The sulfide mineralization has been variably deformed and metamorphosed with many of the above trace phases located within cracks and at sulfide grain boundaries, suggesting a potentially remobilized origin. Some phases, however, - including BiTe, AgTe, HgTe, NiTe, and electrum - are enclosed within the main sulfide ore phases, indicating that they are potentially primary. This latter observation may suggest a magmatic fluid component to sulfide mineralization at Little Deer.

δ^{34}S-values for chalcopyrite, pyrrhotite, pyrite and one crystal of cobaltian pyrite range between +1.0‰ and +7.2‰. These data suggest that the sulfur for sulfides within Little Deer is likely to have been derived from the thermochemical reduction of seawater sulfur, with or without a magmatic input. Overall, the δ^{34}S-values obtained are within the per mil (‰) range observed for Cambrian VMS deposits globally.

WIDESPREAD CRATER-RELATED PITTED MATERIALS ON MARS: FURTHER EVIDENCE FOR THE ROLE OF TARGET VOLATILES DURING THE IMPACT PROCESS

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Recently acquired high-resolution images of Martian impact craters are providing further evidence for the interaction between subsurface volatiles and the impact cratering process. A densely pitted crater-related morphologic unit has been identified in Mars Reconnaissance Orbiter (MRO) images of 198 craters. This population of craters are nearly equally distributed between the two hemispheres spanning from 53°S to 62°N latitude. They range in diameter from ~1 to 150 km, and are found at elevations between -5.5 to +5.2 km relative to the Martian datum. The pits are polygonal to quasi-circular depressions that often occur in dense overlapping clusters and range in size from ~10 m to as large as 3 km. Pit size is shown here to correlate with the host crater's diameter. They have subtle raised rims and lack ejecta, unlike primary and secondary impact craters, but they also lack any sign of any preferential alignment expected of volcanic or tectonic collapse features. The results of a morphologic, morphometric and stratigraphic analysis of the crater-related pitted materials support an impact origin. This includes the observation that pitted materials primarily occur as ponded and flow-like deposits on crater floors, behind terraces, and infilling the lowest local topographic depressions atop the ejecta blanket – similar to the distribution of impact melt-bearing bodies on the Moon. We conclude, based on our observations and interpretations with respect to terrestrial and lunar analogs, that the pit-bearing materials represent Martian impactite deposits. The presence of these deposits in older craters, where preserved, suggests that they have formed on Mars throughout most of its geologic history; thus, they may represent an important lithologic unit with respect to understanding the history of water and past climates on Mars.

TECTONIC EVOLUTION OF THE QUEBEC-NEW ENGLAND APPALACHIANS: A LAURENTIAN PERSPECTIVE AND ACTUALISM CONSIDERATIONS

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Understanding tectonic settings and processes in old orogens such as the Appalachians is challenging, mainly due to the paucity of rock exposure, the occurrence of major syn- and postcollisional unconformities, and the surimpression of multiple deformational/metamorphic cycles. The Québec-New England Appalachians, the result of three principal Paleozoic orogenic pulses, are no exception. The Ordovician Taconian orogeny mainly affects the Cambrian-Ordovician rocks of Laurentia. Penetrative deformation is restricted to the Laurentia marfin and is mainly attributed to ophiolite obduction and accretion. The Devonian Acadian orogeny is predominant in peri-Laurentian Ordovician oceanic rocks and in Silurian-Devonian rocks, whereas the Permian Alleghanian is restricted to southern New England. Viewed from Laurentia, the Taconian and Acadian orogens show similar structures along their strike but the metamorphic conditions and the intensity/timing of deformation vary significantly. Tectonic models currently proposed are thus frequently conflicting and comparison with younger mountain belts provides valuable insights into the «genetics» of these orogenic events.

Taconian ophiolites, much well-preserved in Québec than in New England, are pieces of oceanic lithosphere obducted onto Laurentia in Early-Middle Ordovician times. Existing geochronological data (U-Pb and Ar/Ar) indicate that ophiolites obduction onto Laurentia lasted for ca. 15 m.y. and was completed by ca. 460 Ma. Regional deformation then transferred into foreland-directed thrust propagation and associated exhumation of the obduction-related collisional wedge. The Quebec ophiolites are overlain by sedimentary ± volcanic rocks representing a syncollisionnal forearc basin developed over an exhumed basement of continental and oceanic rocks; a tectonic setting similar to the Central Range of Papua-New Guinea where subducted continental crust is being exhumed 13 Myr in a delaminating plate boundary zone. In Québec, the Taconian~since orogeny is envisioned as a typical Oman-type obduction that evolves into an arc-continent collision (ACC) in New England, sharing similarities with the current ACC between the Luzon arc and the Asian margin in Taïwan. Both the Oman- and Taïwan-type settings can account for Taconian metamorphism and west-directed piggyback folding/thrusting of the Laurentian margin. The margin has been affected however by «late Taconian» hinterland-directed deformation, a phenomenon also observed in Oman and Taïwan, that we attribute to a thin-skin - thick-skin diachronic transition during obduction and/or ACC. Following a period of crustal extension of debatable origin, plate convergence during the Acadian orogeny led to diachronic crustal thickening within an overall coaxial lithospheric deformational regime.

FAULT ANALYSIS AND FRAMEWORK MODELING OF THE SCHULTZ LAKE IGNEOUS SUITE, BASEMENT TO THE NORTHEAST THELON BASIN, NUNAVUT

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The northeast Thelon Basin in the Kivalliq region of Nunavut is prospective for unconformity associated uranium deposits. Integral to the exploration of unconformity-associated uranium deposits are the locations, geometries and histories of motion and alteration along reactivated faults that transported uranium-rich fluids from sources and helped to focus ore deposition. New basement hosted prospects reported by Cameco Corporation east of Kiggavik are hosted by highly metamorphosed psammitic enclaves within the extensively fractured Schultz Lake plutonic suite comprising 1830 Ma Hudson granite and Martell syenite. Voluminous enveloping hematite and clay alteration zones were reported to affect both granitoid and metasedimentary rocks. Further localization is by steeply north-dipping, dextral-dip-slip, 080° faults intersecting with steeply dipping 015° and/or 165° cross-faults. Some steep faults have long been identified by visual interpretation of linear topographic and potential field data, integrated with variably exposed geological features such as intensely silicified breccia zones, abrupt lithologic changes, and fabric elements such as en echelon quartz veinlets, slickensides and other mineral lineations.

Potential field data clearly delineate these faults as belonging to arrays of criss-crossing magnetic and resistivity lows ranging from a few to more than 20 km across. The magnetic anomaly pattern is interpreted as oxidized and clay altered components of the otherwise highly magnetic granitoid suite. Oxidation of magnetite to hematite causes a significant drop in magnetic anomaly amplitude and is commonly associated with increased fluid migration. Geologically important subhorizontal discontinuities are unlikely to produce mappable magnetic anomalies, but may constrain the thickness of the granitoid pluton into tabular components that could be modeled using high-resolution gravity transects.

This work aims to define the framework of the Shultz Lake plutonic complex through quantitative analysis of detailed aeromagnetic and gravity data. The magnetic anomaly associated with a non-fractured granite body is approximated by a convex hull geometric model. Peak separation techniques show the alteration along faults and fractures transecting such a body as a deviation in the observed signal from the generalized geometry, resulting in concavities within the overall convex hull shape. A combination of inversions on the aeromagnetic data is helping to resolve the structure of the faults at various depths and scales of

resolution, as well as the framework of the complex as a whole. Detailed gravity transects provide constraints on the depth extent and geometry of the plutonic complex. This knowledge package should help identify fluid flow pathways and foci for ongoing uranium exploration.

STRUCTURE AND METAMORPHISM OF AN ECLOGITE-BEARING DEFORMATION ZONE WITHIN THE SVECONORWEGIAN OROGEN, SWEDEN

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In the southern Eastern Segment, which is considered to be the counterpart to the Parautochthonous Belt in Grenville, relics of eclogite occur as lenses in high-grade gneisses. The eclogite metamorphism constitutes evidence of a high-pressure event followed by regional deformation and metamorphism in the granulite and upper amphibolite facies at ~1 Ga.

We combine structural and petrological data with airborne magnetic anomalies to characterize the polyphase tectonic evolution. The southern boundary of the eclogite domain constitutes a deformation zone, the Ullared Zone, in which three deformation phases (D_1-D_3) have been identified and related to microstructures and metamorphic assemblages. A D_1 event is locally preserved as early folds. These structures are overprinted by the main deformation stage (D_2), which affected heterogeneously the entire southern Eastern Segment. D_2 is characterized by asymmetric cm- to m- scale tight to isoclinal folds, which commonly present a well-developed axial planar fabric. The folds are often associated with shearing sub-parallel to their axial planes, particularly in areas where the deformation was intense. This deformation took place under high-pressure granulite and upper amphibolite conditions and resulted in strong E-W to WNW-ESE stretching, in places associated with top-the-east or dextral sense of shear. Late open upright folding (D_3) with predominant NNE-SSW axes superimposed D_2.

Ongoing and planned studies aim at constraining the P-T path of the eclogite-bearing unit and surrounding units by multiequilibrium thermobarometry and pseudosections. Metamorphic evolution will be linked to the structural model to allow interpretation of the tectonic buildup.

THE RACKLA GOLD BELT – A YUKON RELATIVE TO CARLIN-TYPE SYSTEMS

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The Rackla Gold Belt is a recently discovered mineralized trend on the northern margin of Selwyn Basin in east-central Yukon Territory. The regional geological framework and style of mineralization are both analogous to the Carlin trend in Nevada. Potential mineralized targets identified by arsenic stream sediment geochemical anomalies led to the recognition of numerous mineralized zones. Some of these were drill tested in 2010, with the best mineralized interval at the Conrad Zone returning 62.48 m at 8.03 g/t Au. Drilling in 2011 returned an exceptional intersection of 114.93 m at 3.15 g/t Au.

Current research is focused on the Conrad and Osiris Zones as they are the most significant discoveries to date. They are bound structurally to the south by the regional scale Dawson Thrust and the Kathleen Lakes Fault to the north. This structural setting lies at the interface between the dominantly Neoproterozoic to Paleozoic rocks of the Selwyn Basin and Mackenzie Platform. Rocks in the area are dominated by slope and basin facies carbonates, clastics and siltstones. Mineralization is typically shear- and breccia-hosted, reflecting a strong structural control on the development of mineralization that is exerted by the Nadaleen Fault Zone. The principal host rock to mineralization is variably decarbonatized silty limestone, although where permeability has been enhanced by shearing, siliclastic rocks may also contain significant mineralization. Visible mineralization includes decarbonatization with black sooty pyrite and is associated with variable realgar. However, significant disseminated gold mineralization often extends beyond the limits of visible alteration and structural domains.

Geochemical enrichments associated with gold at the Conrad and Osiris Zones are typical of Carlin-type deposits, with strong correlations between arsenic, mercury, antimony, thallium and gold. Arsenic is found primarily as widespread and locally abundant realgar and orpiment. Arsenic-rich pyrite rims around pyritic cores are also present as indicated by use of the SEM. Carbon and oxygen isotopic signatures of mineralized carbonate veins and altered host rocks indicate a significant shift from background values and indicate their value in identifying cryptic alteration as an exploration vectoring tool. Further research to characterize the structure, alteration and mineralization, as well as utilizing stable isotopic analysis and electron microprobe analysis of mineralized zones will constrain the genesis and nature of the key mineralized systems in the Rackla Gold Belt. Insight from this work and comparison to Carlin-type systems in Nevada will build and refine exploration models for these systems.

SYNDEPOSITIONALLY BRECCIATED DEEP-WATER LAMINITE, NANISIVIK FORMATION, BORDEN BASIN (NU): DEEP-WATER EQUIVALENT OF MOLAR-TOOTH STRUCTURE?

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Deep-water dololaminite of the Mesoproterozoic Nanisivik Formation, Borden Basin, Nunavut, consists almost entirely (hundreds of metres) of millimetric laminite that was deposited below storm wave-base and below the photic zone, and represents incremental deposition of carbonate from an anoxic water column. Rhythmic lamination is marked by slightly pressure-solved micro-laminae of windblown terrigenous dust. In rare locations adjacent to synsedimentarily active normal faults, detrital material, including terrigenous clasts, is interbedded with the laminite.

Brecciation includes crackle (veinlets only), mosaic (fitted, in situ clasts) and rubble (chaotic) breccias. Cracks are parallel-sided, and breccia clasts are angular. Cracks and breccia masses rarely terminate at a distinct bedding surface, instead forming a network of vertical to inclined crack networks or breccia bodies linked along slightly dilated laminae. Breccia masses are seldom layer-parallel. Some cracks and breccia are concentrated in the noses of synsedimentary folds. Margins of breccia bodies are abrupt, with planar surfaces separating chaotic rubble breccia from comparatively unaffected laminite, or gradational, with rubble breccia passing laterally to mosaic breccia, then crackle breccia, then undeformed host rock. Multiple cross-cutting generations of cracks are ubiquitous.

Breccia interstices are occluded by an early generation of isopachous dolomite euhedra that is generally overlain by blocky dolospar. In rare locations where terrigenous material is interlayered with brecciated laminite, some breccia cracks contain particulate material from the overlying bed, and breccia masses forming slight depressions at dolostone bedding planes are draped by these layers. Brecciation intensity varies with geographic and stratigraphic position, but is generally abundant wherever the laminite facies is present. Where laminite interfingers with shallower-water facies, brecciation is limited to the laminite lithofacies.

The above evidence demonstrates that: (A) laminite was lithified on the sea floor; (B) brecciation was synsedimentary and affected both strata near or at the sediment-water interface, and more deeply buried material; (C) laminite lithification was more rapid than lithification of allochthonous interlayers; (D) some breccia bodies were exposed at the sea floor; (E) brecciation took place when laminite was lithified but when allochthonous interlayers were in any state from unlithified to fully lithified; and (F) precipitation of the isopachous dolospar lining breccia interstices was penecontemporaneous with laminite deposition.

The above evidence refutes all previous interpretations of the breccia (evaporite solution collapse; MVT solution collapse; meteoric karstification). The formation of breccia probably involved local, explosive evasion of intrastratally generated gas. This sedimentary structure may, therefore, be a basinal equivalent of molar-tooth structure.

THE OCCURRENCE AND ORIGIN OF RING SCHLIEREN IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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The South Mountain Batholith (SMB) of Nova Scotia is a Late Devonian, peraluminous, discordant, granitoid complex, consisting of many plutons that intrude mainly metasedimentary rocks of the Meguma Supergroup. The Halifax Pluton (HP) outcrops prominently along a coastal section of Halifax County. The Peggys Cove lithological unit within the HP, a biotite monzogranite, is host to a variety of schlieren structures, including more than 150 decimetre- to decametre-scale ring schlieren. Ring schlieren are alternating melanocratic and leucocratic bands in granites forming open to closed, nested, circular to elliptical, concentric to eccentric, prolate to oblate structures with cross-cutting relationships indicating a younging direction toward the centre. The purpose of this investigation is to develop a field-based model for ring schlieren formation in the SMB.

Geographically, ring schlieren occur in clusters, with significant groups occurring near Aspotogan Point (n=7), near Peggys Cove (n=61), near West Dover (n=14), near Pennant Point (n=41), and near Prospect (n=8). Dominantly isolated ring structures occur between these areas. Geometrically, the number of rings in a single structure and their shapes define three groups: 16 structures have one ring, 79 structures have two or more rings, and 58 structures have complex shapes including ladder dykes, snail-shaped rings, ladle-shaped rings, and convoluted rings. The local disruption of regional flow foliation in the granitoid host rocks around the rings suggests that the rings are late magmatic structures, created when the degree of crystallinity of the magma was 55-75%, a condition permitting both deformation of the mush and retention of the deformed state. Rare three-dimensional outcrop exposures reveal that the ring schlieren are vertical cylinders. As such, they appear to represent vertical fossil pathways, either of solids descending from the roof of the pluton, or of bubbles ascending from late-stage degassing of magma at greater depth. Shear flow at the margins of descending xenoliths or ascending bubble trains can produce flowage differentiation between silicate melt and solids of various sizes by the Bagnold effect, and may thus explain the particle-sorting textures in ring schlieren structures. A miarolitic cavity in one multi-ring structure suggests that a rising bubble train may have produced the rings. Natural analogues (bubbling mudpits, volcano vapour rings) and synthetic analogues (concrete, petroleum gel) provide qualitative support for this model.

GEOLOGICALLY CONSTRAINED INVERSION OF AIRBORNE GRAVITY GRADIOMETER DATA USING UNSTRUCTURED TETRAHEDRAL MESHES

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Minimum-structure inversion is often used in the interpretation of gravity data to gain knowledge of the three-dimensional subsurface density distribution. Improvement in gravity instrumentation since the 1980s allows airborne gravity surveys to be undertaken routinely and with a high degree of accuracy. Two advantages of airborne surveying include the ability to access remote regions and the ability to quickly cover large areas. Technological advancements mean that both airborne gravimeter and gravity gradiometer measurements are possible. Gravity gradiometer measurements provide two advantages over conventional gravimeter measurements. Gradiometers can measure five of the nine terms in the gravity gradient tensor providing a complete description of the anomalous gravity field gradient. Additionally, gradiometers are less susceptible to large accelerations which negatively affect gravimeters in dynamic environments. However, only a limited number of inversion programs exist for gravity gradiometer data and these programs rely on the use of a rectilinear mesh. A minimum-structure inversion program for multi-component gravity gradiometer data that recovers the three-dimensional distribution of the subsurface density contrast using unstructured tetrahedral meshes subject to various geological constraints has been developed. Results will be presented for the inversion of synthetic airborne gravity gradiometer data for a simplified three-dimensional model of the Voisey's Bay deposits. The model discretizes the subsurface into a set of tetrahedral cells with each cell having a constant density contrast. The forward modelling is based on the closed-form expression for a tetrahedron. The inversions are performed using a standard minimum-structure algorithm. Minimum-structure inversion seeks a model that has minimal spatial variation while still reproducing the observed data. The advantage is that the model constructed contains few spurious features while the disadvantage is that the results are typically smeared out and bear little resemblance to the true geology. In order to improve the solution, geological information is incorporated into a reference density model. Several reference models were constructed with varying amounts of geological information incorporated. It will be demonstrated how much information can be obtained by inversion of airborne gravity gradient data and how unstructured tetrahedral meshes can be used for prescribing geological constraints.

SEDIMENT DISPERSAL TO MESOZOIC BASINS ALONG THE NE ATLANTIC MARGIN: INSIGHTS FROM Pb ISOTOPES IN DETRITAL FELDSPAR

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Provenance studies aim to place fundamental constraints on the scale, routing and evolution of ancient drainage systems with consequent implications for the nature and distribution of reservoir sandstones. However, many of the commonly applied provenance tools can produce equivocal results due to inadequate characterization of potential source areas, post-depositional modification and/or averaging due to recycling and mixing. A technique that uses the Pb isotopic composition of detrital K-feldspar grains can overcome some of these shortcomings. K-feldspar is a common and likely first-cycle framework grain in sandstones, hence, in contrast to approaches which utilize robust mineral grains such as zircon, constraining its source can provide direct information on the palaeo-transport system. Rapid, in situ Pb isotopic analysis of single sand grains of K-feldspar by laser-ablation multiple-collector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) provides a provenance signal that has been shown to survive weathering, transport and diagenesis. Moreover, broad regional-scale variations in Pb isotopic composition in basement terranes mean that potential source areas can be readily characterized.

This approach has been applied to a broad range of sandstones in Mesozoic sedimentary basins on the NW European margin, including the Slyne, Porcupine and Rockall basins offshore western Ireland, and the Faroe-Shetland Basin offshore NW Scotland. Sharing tectono-stratigraphic similarities with basins on the Canadian conjugate margin, they record a complex history of rifting, thermal subsidence and, locally, inversion, prior to and during the opening of the North Atlantic. Although they contain a number of proven hydrocarbon accumulations in sandstone reservoirs, the basins are relatively underexplored.

Pb isotopic analysis of K-feldspars from Triassic, Jurassic and Cretaceous sandstones in these basins highlight the important role played by Archean and Proterozoic offshore basement blocks (e.g. the Porcupine High, the Rockall Bank) in both supplying and controlling dispersal of sediment during the Mesozoic. On a regional scale, the data reveal periods of major drainage reorganization, likely associated with the rifting that eventually culminated in the break-up of Pangea and the opening of the North Atlantic. On the scale of individual basins and sub-basins, results show stratigraphic variations in the relative contributions of different sources. These changes could be caused by the periodic rejuvenation of specific tributary systems, possibly linked to varying uplift rates in the hinterland, or are a result of subtle climatic factors affecting the delivery of sand to the basin.

Keynote THE 1.2–1.0 Ga GRENVILLIAN SUPEREVENT: AN OROGENIC CLIMAX OF EARTH ACROSS EARTH'S EVOLVING SUPERCONTINENT CYCLE

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Plate tectonics both creates and recycles crust, but the rate of continental growth over Earth history remains contentious: some believe it formed fast and early, others more gradually and, perhaps, episodically, through the supercontinent cycle. Time constrained analysis of both oxygen and hafnium isotopes in zircon grains and incompatible elements (Zr, Th) from magmatic rocks confirms the importance of Earth's supercontinent cycle not only on the degree of crustal recycling rates that arises from the aggregation and dispersal of supercontinents, but also on mantle temperatures, crustal growth rates, and climatic conditions.

These changes are used to infer a conditioned duality of the Earth system between alternating periods of hot and cold mantle that arise in response to the supercontinent cycle. Hot mantle periods that accompany supercontinent aggregation are characterised by mantle superplume events, increased crustal recycling, and warm, reducing climatic conditions. Cool mantle periods during supercontinent rifting result from core insulation by slab graveyards and are characterised by low rates of crust production and cool, more oxidizing conditions.

Changes in the intensity of the orogenic cycle through time since its inception at c. 3.2 Ga are ascribed to self-reorganisation of progressively larger tectonic plates (tessellation of a sphere) that accommodate the secular decrease in planetary heat. Bursts of crust extraction during Neoarchean and Mesoproterozoic supercontinent assembly led to overstep periods of large plates on subduction-cooled, melt-depleted mantle, accompanied by global ice ages.

Optimal packing (pentagonal dodecahedron) of the plates was attained on dispersal of Nuna at 1.4 Ga, leading to an orogenic climax during the 1.2–1.0 Ga amalgamation of supercontinent Rodinia across a global chain of Grenvillian supermountains. When combined with geological and geophysical observations, the peak in geochemical and isotopic datasets at this time are interpreted to reflect an unprecedented level of sequential juvenile crust formation, crustal recycling, and sediment subduction arising from a "Goldilocks" combination of large plates and more rapid continental drift on a warmer Earth compared with modern day. The subsequent decrease in Zr and Th concentrations and in $\delta^{18}O$ values in zircons reflects a cooling Earth and decreasing drift rates.

Keynote PLANETARY DRIVER OF ENVIRONMENTAL CHANGE: GLOBAL SUPERCYCLES AND THEIR SIGNIFICANCE FOR A CHRONOSTRATIGRAPHIC PRECAMBRIAN TIMESCALE

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Hans Hoffman was a devotee of the Precambrian and influential in documenting the life that flourished over its eons, including some of the world's oldest stromatolites (c. 3.4 Ga Strelley Pool Formation). His work provided insight to the dynamic nature of early Earth, and he was interested in how that story could best be told within the broader community.

Towards that same goal, the Precambrian Subdivision of the International Commission on Stratigraphy has instigated a revision of the Precambrian timescale, based on a more naturalistic approach that is tied to the rock record and using GSSPs, where possible (Bleeker, 2004). The aim is to identify globally significant, and geologically rapid, events that have left their mark in the rock record, which Cloud (1972) identified as being "... more likely to result from events in atmospheric, climatic, or biologic evolution than plutonic evolution."

But it turns out that rapid changes in the outer shell of our planet (hydrosphere-atmosphere-biosphere) may be more closely linked to the slower changes affecting the interior (core-mantle) and crust of the planet than previously considered. Analysis of global geological data confirms the importance of Earth's supercontinent cycle, not only on the degree of crustal recycling rates that arises from the aggregation and dispersal of supercontinents, but also on mantle temperatures, crustal growth rates, and climatic conditions (Van Kranendonk, in press). Hot mantle periods that accompany supercontinent aggregation are characterised by mantle superplume events, increased crustal recycling and warm, reducing climatic conditions. Cool mantle periods during supercontinent rifting are characterised by low rates of crust production and cool, more oxidizing conditions, leading to widespread, occasionally global, glaciations.

Five global supercycles are identified since the inception of modern-style plate tectonics and the onset of the supercontinent cycle at c. 3.2 Ga, each with attendant changes in the hydrosphere-atmosphere-biosphere. Further changes to the outer shell result from feedbacks between climate, weathering, tectonics, and biological evolution. These changes have all left their mark in the rock record that can be used to develop a chronostratigraphic Precambrian timescale over most of Earth history and help communicate a more complete, more compelling, history of our planet within the geosciences community and to the general public.

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GEOLOGY AND IGNEOUS GEOCHEMISTRY OF THE MESO-PROTEROZOIC SEAL LAKE GROUP, CENTRAL LABRADOR

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The Seal Lake Group in central Labrador is a Mesoproterozoic back-arc supracrustal sequence composed of subaerial and shallow-marine sedimentary rocks, amygdaloidal basalt flows and ophitic gabbro sills. The rocks are disposed in a regional-scale syncline in which the southern limb has been strongly deformed and overturned in contrast to a weakly deformed northern limb, reflecting the decreasing effects of north-directed Grenvillian thrusting associated with the southern margin of the group.

Basalt flows and gabbro sills within the sequence exhibit similar transitional calc-alkaline to tholeiitic compositions suggesting derivation from a common magma source, and indicate a continental, within-plate environment. Rare earth element patterns are light-REE enriched and exhibit flat, heavy REE profiles which are indicative of continental tholeiites.

The igneous rocks in the sequence all exhibit compositional similarities, however, the basalt flows in three separate stratigraphic formations have different Ca, K, Ti, P, Mg and Cu contents and the gabbro sills have higher Ti and K than the basalts. The gabbro sills in two of the formations also show slight differences in Ti and K content. These trace element variations appear to reflect changes in the composition of the igneous rocks with basin development but may also be, in part, a feature of the strong alteration of the upper levels of the stratigraphy compared to weakly metamorphosed rocks of the lower formations on the northern limb of the syncline.

Some basalt flows and gabbro sills in the upper levels of the sequence contain vein-hosted copper mineralization associated with local shear zones and show evidence of Ba, K, and Rb depletion and enrichment in Sr compared to non-mineralized rocks and reflect the change in element distribution resulting from mineralizing fluids.

NEW INTERPRETATIONS OF THE AGE AND PROVENANCE OF METASEDIMENTARY ROCKS OVERLYING THE THOR-ODIN DOME IN THE SE BC: DETRITAL ZIRCON U-Pb DATA SUPPORT TECTONIC MODELS OF ALLOCHTHONOUS DEPOSITION

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The focus of this study is U-Pb LA-ICP-MS geochronology on detrital zircon in a quartzite from polydeformed mid- to upper amphibolite-facies supracrustal rocks in the metamorphic core of the southeastern Canadian Cordillera. The quartzite is located at Plant Creek, west of Lower Arrow

Lake in the Monashee Mountains. It is situated on the southern flank of the Thor-Odin dome, within a S-SW dipping panel of metasedimentary and metavolvanic rocks exposed in the footwall of the east-dipping Columbia River normal fault. The footwall rocks were penetratively deformed at Sil-Mus to Kfs-Sil-melt grade in the Late Cretaceous-Paleocene. Interpretations of their age and provenance include deposition on the margin of Laurentia in the Meso- to Neo-Proterozoic, or alternatively, deposition outboard of the Laurentian craton during the Cambrian to Mississippian.

The youngest detrital zircon grains from the Plant Creek quartzite are 151 Ma ± 6 and 184 Ma ± 18, and 8 out of 24 grains from the 90% concordant data are younger than ~200 Ma, indicating that the quartzite, and associated metasedimentary rocks, are Middle Jurassic or younger. Other zircon dates range between 300 and 450 Ma, and there is a notable lack of Proterozoic zircons. The age populations in this sample are inconsistent with a Laurentian cratonic provenance, rather, Paleozoic and Mesozoic sources of detrital zircons are more likely to have been derived from outboard terranes to the west such as the Cache Creek and Quesnel terranes.

The sampled quartzite lies structurally below greenschist-facies metasedimentary and metavolcanic rocks interpreted as Triassic Nicola and Jurassic Rossland groups of the Quesnel terrane. These low-grade rocks have been interpreted as either a klippe of the hanging wall of the Columbia River fault structurally juxtaposed against Sil-Kfs and Sil-Ms grade footwall rocks, or, as part of a supracrustal assemblage that unconformably overlies higher-grade rocks. The juxtaposition of older rocks over younger ones with contrasting tectonothermal histories supports the interpretation that there is a fault contact between the two units, in this case the Columbia River Fault. The age, provenance and probable correlations for the quartzite are all inconsistent with the model of unconformable deposition. Rather, they support interpretations of a transposed terrane boundary within the metamorphic package. The Jurassic ages for sedimentary rocks in particular also provides evidence for the dynamic nature of the Cordilleran orogen by showing that sedimentary rocks related to accreted arc terranes were caught up in the orogeny shortly after their deposition.

ARC COLLISIONS IN THE APPALACHIANS: HARD VS SOFT

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Ancient arc-continent collisions are commonly informally described as hard or soft, although the differences between these two are rarely defined. We herein define collisions as hard where the overriding arc (including infant arcs preserved in obducted ophiolites) has been significantly thickened in proximity to the suture zone due to internal deformation. In hard collisions upper plate deformation generally involved progressive underthrusting and thickening of parts of the arc-forearc terrane, presumably as a result of progressive widening of the subduction channel into the hangingwall. The Late Cretaceous Kohistan arc collision with Eurasia or India is taken as a type example of a hard collision. A more ancient example of a well-studied arc-continent collision is the Early-Middle Ordovician, (Taconic) collision between the Laurentian Humber margin and the Notre Dame arc in the Northern Appalachians. The collision was hard in Newfoundland where the arc was built on continental crust (Dashwoods), because parts of the ophiolitic forearc basement (Baie Verte oceanic tract) and the leading edge of the arc block were locally deformed and metamorphosed with conditions ranging from high pressure greenschist to amphibolite and/or granulite facies conditions. However, in the Quebec reentrant where the Notre Dame arc transgresses from a continental to an oceanic substrate, the style of collision appears to change from hard to soft and more resembles the relatively soft Late Cretaceous collision between the infant arc preserved in the Semail ophiolite and the Arabian continental margin. Underthrusting of the Humber margin lasted significantly longer (5-10 my) opposite the St. Lawrence promontory in Newfoundland than in the Quebec reentrant, which led to a much higher volume of syn-collision magmatism in the former. Syn-collisional magmatism probably thermally softened the upper plate significantly, which promoted widening of the subduction channel. Subsequent Ordovician-Silurian collisions involving arc blocks in the Appalachians were generally soft or had a more intermediate character between hard and soft such as the China-Luzon arc collision in central Taiwan. Here most of the forearc block appears to have been deformed and subducted, whereas the Luzon arc itself remained relatively undeformed. In general, soft to intermediate arc-collisions appear to be most common in the geological record. Hard collisions are relatively rare and demand special conditions.

DETERMINATION OF THE VOLCANIC ORIGIN OF THE FISH CREEK MOUNTAINS TUFF, BATTLE MOUNTAIN, NEVADA

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The Fish Creek Mountains Tuff (FCMT) is an early Miocene composite ash-flow tuff restricted to the Fish Creek Mountains, north-central Nevada. Three new Ar-Ar ages of the FCMT (24.91 ± 0.05 Ma, 24.95 ± 0.08 Ma, 24.88 ± 0.05 Ma) confirm that the tuff was deposited over a short period of time. This deposition occurred ca. 10 Ma after local intermediate to felsic volcanism ended (33.3 ± 0.3 Ma andesite and 33.8 ± 0.14 Ma dacite), indicating a 10 Ma hiatus in local volcanic activity. The FCMT eruption post-dates the formation of several nearby calderas, which were part of the "ignimbrite flare-up" related to rollback of the subducting Farallon slab. One such caldera produced the Caetano Tuff, a 34 Ma rhyolitic ash-flow tuff in north-central Nevada which extends for approximately 90 km along an east-west trending belt. One unit of the Caetano Tuff, named the Tuff of Cove Mine, outcrops in the northern Fish Creek Mountains. The Caetano caldera has undergone significant extensional faulting and tilting during the Miocene and is exposed from the caldera floor to the overlying cap rocks. Compared to other nearby caldera structures, the FCMT is unique in that it has remained upright and largely undeformed, with minimal out-flow tuff. This pristine confined system is ideal for reconstructing the volcanic history of the caldera.

The FCMT is rhyolitic in composition, and is composed of two flat-lying cooling units separated in some areas by a cooling break. The lower cooling unit has a thick nonwelded base of angular fragments of frothy white and/or grey pumice in a lithic-rich and crystal-poor matrix. The degree of welding increases upwards to the top of the unit, which is highly welded with a eutaxitic texture. The fiamme are abundant; rare two-toned white and grey fiamme occur, but most are black and rehydrated, sometimes containing cm-scale spherulites. Lithic fragments are abundant in this part of the section and crystals are rare or absent. The base of the upper unit is a very thin nonwelded tuff. The midsection of the unit is moderately welded with small, variably flattened grey or purple pumices which have thin glassy rims. Abundant crystals of quartz (smokey and clear varieties) and sanidine are present in the matrix and pumice throughout the unit, while lithic fragments are absent.

Samples of the FCMT exhibit negative Nb anomalies and enrichment in LIL-elements, similar to local ca. 34 Ma Tertiary rocks.

EVOLUTION OF THE STRANGE LAKE PLUTON: EVIDENCE FROM MELT AND FLUID INCLUSIONS

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The Mesoproterozoic Strange Lake peralkaline pluton (Québec-Labrador), which is host to a large rare earth element (REE) and high field strength element (HFSE) resource, comprises hypersolvus and subsolvus granites and pegmatites. The mineralization is developed in and around pegmatites in the most altered subsolvus granite, and comprises a large number of exotic minerals, including gittinsite, armstrongite, kainosite-(Y), bastnäsite, gagarinite-(Y), monazite, pyrochlore and gadolinite.

Formation of an ore deposit is commonly a complex process involving several stages of metal enrichment, and depends on the presence of efficient concentration mechanisms. In magmatic systems, concentration, for example of REE/HFSE, begins with fractional crystallization (enrichment of residual melts in incompatible elements). Immiscibility is another potentially important magmatic concentration mechanism; strong partitioning of elements into the immiscible phases can provide a rapid and extremely effective means of concentration. Melt-melt and fluid-melt immiscibility may govern the segregation of the mineralizing phase. Later fluid-fluid immiscibility (including fluid boiling and effervescence) can further concentrate ore components and also cause their precipitation due to oversaturation of mineralizing phases. Finally, late fluid remobilization events can also play a crucial role for mineralization. As some of these processes, e.g., melt and fluid immiscibility, may leave little macroscopic evidence of their participation in element concentration (immiscible phases become physically separated, migrate and undergo further separation and crystallization), it is necessary to use melt and fluid inclusions to reconstruct the melt-to-fluid evolution of the system.

Fortunately, the very earliest magmas forming the Strange Lake granites and pegmatites have been preserved as melt inclusions in early quartz phenocrysts. Furthermore, later stages of magmatic quartz also host melt inclusions and these preserve samples of more evolved magma. Fluid inclusions in early fluorite, associated with late magmatic quartz and occurring as inclusions in late arfvedsonite, preserve evidence of the timing of exsolution of fluid from the magma. This fluorite contains two types of inclusions: devitrified melt inclusions and NaCl-rich aqueous fluid inclusions. The next stage of melt-to-fluid evolution is recorded by quartz in miarolitic cavities, which contains abundant aqueous inclusions of variable salinity. The final stage of hydrothermal activity involved Ca-rich aqueous fluids, which were trapped as primary fluid inclusions in late hydrothermal fluorite and secondary inclusions in pegmatitic quartz. This study is providing a deeper understanding of the REE/HFSE mineralizing processes at Strange Lake and is revealing the important role played by fluorine in metal transport, and calcium in late hydrothermal REE/HFSE precipitation.

HIGH DENSITY ISOTOPIC MAPPING OF HYDROTHERMAL FLUID FLOW IN CARBONATE-HOSTED HYDROTHERMAL SYSTEMS: IMPLICATIONS FOR THE GENESIS OF, AND EXPLORATION FOR, CARLIN-TYPE Au-DEPOSITS

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Tracing hydrothermal fluid flow in the Earth requires a detailed understanding of the physical-chemical manifestations of the fluid flow system. Detailed mapping of patterns of mineral alteration and geochemical metasomatism in high-temperature and magmatic hydrothermal systems has proven successful for defining both the evolution of the fluid, and as far-field indicators of hydrothermal fluid flow. In low temperature sediment-hosted hydrothermal systems such as Carlin-type Au deposits, the physical-chemical expression of the fluid system may be subtle, especially at the distal margins of fluid circulation, owing to significant kinetic barriers to chemical alteration. Delineating potential fluid pathways outside of visually definable alteration relies on the use of cryptic indicators of wall rock alteration, such as stable oxygen and carbon isotope ratios in carbonate minerals. In the Banshee deposit of the northern Carlin trend, O and C isotopes in carbonate have been used to define a fluid flow network spatially coincident with Carlin-type Au mineralization. Stable isotope data collected from micro-drilled matrix carbonate at Banshee indicates that fault structures controlled fluid flow with fluid flow further influenced pre- and syn-mineral brecciation. At Banshee, $\delta^{13}C$ isotope depletion is restricted to the core of Au mineralization and is coincident with rocks exhibiting extensive carbonate dissolution. Depletion of $\delta^{18}O$ isotopes is consistent with increased integrated fluid fluxes at the core of Au mineralization and along primary structural fluid conduits. A range in $\delta^{18}O$ values from 5-25‰ (VSMOW) is inferred to be caused by variable alteration by a moderately exchanged meteoric ore fluid. The majority of $\delta^{13}C$ data indicates that the hydrothermal fluid was largely rock buffered with distinguishable depletion only occurring at relatively high water/rock ratios. The likely source of highly depleted $\delta^{13}C$ values is oxidation of organic reduced carbon. Results suggest stable isotopes can be a sensitive indicator of wall rock alteration of carbonate host rocks in Carlin-type Au systems. Due to the restricted nature of other indicators of wall rock alteration, the detection of pathways of contiguous isotopic depletion has the potential to define fluid flow pathways, resolve the degree of fluid-rock interaction, and act as a vector towards mineralization.

RECONSTRUCTING RANGEA: NEW DISCOVERIES FROM THE EDIACARAN OF SOUTHERN NAMIBIA

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The fractal frond Rangea Gürich, 1930 was the first large and complex Ediacaran fossil named and described anywhere in the world, and continues to represent one of the keystone taxa and universal images of the Ediacara biota today. Our discovery of more than 100 in situ specimens of Rangea from the Kuibis Subgroup in southern Namibia (ca. 550 Ma) increases the global Rangea dataset by a factor of five and reveals previously unknown details about its internal structure and taphonomy. The new Rangea fossils were preserved in a muddy mid-ramp setting just below normal wave-base, a probably photic environment characterized by gentle wave and current action and periodic disturbance by major storms. Rangea specimens are decimetre-scale fronds, each consisting of several vanes arranged in the pattern of a revolving door around an axial structure that traverses the length of the specimen. A prominent proximal ball may represent a basal holdfast. The axial structure and vanes are covered by rangeomorph elements, cm-scale structures showing several fractal orders of self-similar branching, that emanate from the axial structure laterally towards the periphery of the vanes and thus produce an apparently bifoliate branching pattern on any two facing vanes. This architecture is diagnostic of the Rangeomorpha, an extinct clade of multicellular eukaryotic life that dominated early, deep-water assemblages of the Ediacara biota. Rangeomorphs extended into shallow-water settings by the late Ediacaran, but they were rare and taxonomically depauperate relative to Namibian erniettomorphs and went extinct some time before the Cambrian explosion of shelly animals.

CRETACEOUS OUTCROP ANALOGUES FROM THE EASTERN ATLANTIC MARGIN FOR THE WESTERN ATLANTIC MARGIN HYDROCARBON RESERVOIRS

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Study of outcrops along the UK and Portuguese coastlines add further dimensions to building a comprehensive understanding of the subsurface petroleum reservoirs being evaluated offshore Atlantic Canada. The research provides new findings on the complex controls on reservoir distribution on both sides of the Atlantic during the period when the Central Atlantic was beginning to open in the Cretaceous. The coastal exposures of Cretaceous-age, reservoir prone sediments in the Channel Basin of the southern UK, and the Lusitanian Basin of Portugal provide a key to the subsurface reservoirs being exploited for oil and gas development offshore Atlantic Canada. These two coastal areas have striking similarities to the offshore region of Canada. Outcrops demonstrate a range of depositional environments ranging from terrigenous and non-marine, through shallow siliciclastic and carbonate sediments, through to deep marine sediments. These outcrops provide clearer understanding of key stratigraphic surfaces representing conformable and non-conformable surfaces. Validation of these analogue sections will be instrumental in the continued model building and prediction of oil and gas resource potential offshore in the Atlantic Region.

ARCHITECTURAL ELEMENTS OF MESOZOIC RIFT BASIN SEDIMENTS - OFFSHORE SCOTIAN MARGIN

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The Mesozoic Scotian and Fundy basins reveal the 250 million year evolution of the Atlantic Ocean from a failed rift zone through to the present passive margin. The stratigraphic successions within these basins comprise early rift sediments of siliciclastics and evaporites, carbonate deposits, through to fluvial, deltaic, and deep water depositional systems.

Exceptional 2D and 3D conglomeratic sandstone outcrop exposures of the Triassic Wolfville Formation along the Bay of Fundy provide a reservoir analogue of a braid channel and sheet sand depositional system representing early fill of the basin. New and innovative technologies (aerial and ground-based LiDAR, Digital GPS, Ground Penetrating Radar, high resolution photogrammetry, scintillometer and permeameter measurements) have remarkably enhanced our ability to understand gas and fluid connectivity between architectural elements. Integrating these technologies with well and seismic data, outcrop analysis, and thin section evaluation will allow for a comprehensive examination and delineation of architectural elements leading to one of the largest 2D and 3D geological outcrop-derived reservoir models for history-matching producing fields. These data are also applied to understand the potential of hydrocarbon systems within the Scotian and Fundy basins.

PLATE CONFIGURATIONS IN EARLY IAPETUS AND THEIR INFLUENCE ON THE APPALACHIAN-CALEDONIDE OROGEN

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In the opening of the Iapetus Ocean, numerous continental fragments were split from the major diverging blocks Laurentia, Amazonia -- West Africa, and Baltica. These fragments are classified as peri-Laurentian or peri-Gondwanan. In most cases this classification is based on the presence or absence of late Neoproterozoic 'pan-African' basement, but faunal provinciality, sediment provenance, and interpreted position in the early stages of Appalachian-Caledonide convergence have all provided evidence for the origin of individual slices.

The margin of Laurentia underwent protracted rifting from ~615 Ma or before, to perhaps 515 Ma, based on the age of the breakup unconformity in Newfoundland. In most reconstructions a Neoproterozoic 'early' Iapetan rift is shown to the east of Dashwoods and other peri-Laurentian microcontinents; this is shown as superseded by a western, early Cambrian rift, that developed between the peri-Laurentian fragments and the Laurentian margin. Analogies with modern oceans suggests that this rift-drift history would have substantially separated Dashwoods from the Laurentian margin.

This placement is confirmed by the Taconian/Grampian collisional history of these fragments. Ages of metamorphism and cross-cutting plutons, together with isotopic data indicating continental contributions to volcanics, all show that these offshore blocks were deformed and metamorphosed around 490 Ma while the Laurentian margin was still undergoing passive thermal subsidence and shelf sedimentation free of arc influence. The earliest stages of the Taconian/Grampian orogeny therefore took place well offshore in the Iapetus Ocean. Collision of the Laurentian margin did not begin until ~ 20 Myr later, in the Middle Ordovician, and the initiation of a foredeep on the former Laurentian shelf began in the Darriwilian, around 466 Ma.

Following the Taconian collisions, and a flip in the subduction polarity, the earliest peri-Gondwanan fragments of Ganderia began to arrive at the now active Laurentian margin by ~450 Ma. Although these fragments show a history of late Neoproterozic deformation and magmatism, characteristic of peri-Gondwana, occasional reports of 1 Ga detrital and inherited zircon suggest an origin adjacent to either eastern Laurentia or western Amazonia. It is therefore likely that both peri-Gondwanan and peri-Laurentian microcontinental blocks originated in a complex mosaic during Iapetan rifting, close to the triple junction that separated Laurentia, Amazonia, and Baltica.

STRATIGRAPHIC SETTING OF THE HALFMILE LAKE SOUTH DEEP ZONE, PART OF THE HALFMILE LAKE VMS DEPOSIT, BATHURST MINING CAMP

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The Halfmile Lake South Deep zone (HLSDz) was discovered in 1999 by Noranda Exploration Ltd. during drilling of a 3-D seismic anomaly and was intersected at a vertical depth of approximately 1200 m. This zone is interpreted to be the down-dip extension of the known Halfmile Lake South and Halfmile Lake North zones that collectively constitute a more or less continuous massive sulphide body with a strike length of > 950 m, and a thickness ranging between 2 and 75 m. This body dips northerly between 50 and 80o and extends to a vertical depth of at least 1100 m. The Halfmile Lake deposit has published an NI 43-101 compliant indicated resource of 6.2 Mt grading 8.13%Zn, 2.58%Pb, 0.22% Cu and 30.78g/t Ag, and in inferred resource of 6.08 Mt grading 6.69% Zn, 1.83%Pb 0.14%Cu and 20.5 g/t Ag. Tevali Mining Corp. began mining the near surface part of this deposit in January of 2012 and is presently developing the deposit to deeper levels.

The HLSD zone discovery hole (HN-99-119), was collared approximately 1500 m north of the surface exposure of the South Zone (Upper AB part) and passes through the axis of a southeasterly overturned, east-west striking anticline. In the upright limb, 80 m of rhyolite and tuff of the Flat Landing Brook Formation conformably overlie 540 m of quartz-feldspar phyric rocks of the Nepisiguit Falls Formation. The latter formation, comprising five eruptive units ranging in thickness from 26 to 218 m, conformably and gradationally overlies green to grey siltstone, shale and minor sandstone of the Miramichi Group that continues down hole for 600 m in the core of the anticline.

In the overturned limb, the Miramichi Group is in apparent conformable contact with a narrow interval (~20 m), of weakly sericite-chlorite altered, fine-grained volcaniclastic rocks (Nepisiguit Falls Formation), which give way down hole to exhalative massive sulphides (~40m). Stockwork stringer mineralization that is ubiquitous in other parts of the Halfmile Lake deposit is only locally developed in the HLSDz, whereas oxide facies iron formation, which is unknown in the other parts of the Halfmile Lake deposit, was intersected in two drill holes from this zone. The stratigraphic position of the Halfmile Lake deposit, at or near the base of the Nepisiguit Falls Formation, is similar to that of the Heath Steele deposits to the east, and much lower then the deposits of the Brunswick Belt.

RECENT PROGRESS IN UNDERSTANDING THE DISTRIBUTION OF STONY CORALS IN THE NORTHWEST ATLANTIC OCEAN

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Scleractinian corals are important carbonate-skeletoned animals contributing to genesis of cold-water carbonate sediments. International efforts are now underway to assemble new information on scleractinian geographic and bathymetric distributions in the North Atlantic. Here we present new records of scleractinians from the Northwest Atlantic, especially the continental margins of Atlantic Canada, and from seamounts in the Northwest Atlantic.

Scleractinian specimens were collected using Remotely Operated Vehicles (ROVs), rock dredges, research/survey otter trawls, as well as samples submitted by fisheries observers on commercial fishing vessels using various benthic gear types. In total there were 500 specimens and 172 additional records identified. Specimens were identified to the lowest taxonomic level of certainty from samples and specimen photos taken at sea

by technicians or fisheries observers. Only data that could be verified with physical samples and/or photo identifications with a high level of confidence were used. Many more scleractinian by-catch records have been reported by fisheries observers monitoring deep-water fisheries but were not verified beyond Order. As a result, data presented here most likely underestimate the occurrences of this group in the Northwest Atlantic.

Solitary scleractinians include: Fungiacyathus marenzelleri, Vaughnella margaritata, Caryophyllia ambrosia, Javania cailleti, Flabellum macandrewi, F. alabastrum, F. angulare, and Desmophyllum dianthus. Scattered colonies of the colonial cold-water scleractinian Lophelia pertusa have been observed in several localities along the continental margin of Atlantic Canada, but only dead fragments and one severely damaged Lophelia bioherm are known.

The geographic and bathymetric distributions of scleractinians were widespread. Scleractinians recovered in trawl bycatch occurred over a depth range of 350-1200 m. Scleractinian corals observed by ROV in deep waters of the Flemish Cap and Orphan Knoll occurred between approximately 1750 and 2200 m. Scleractinians may have been limited from waters deeper than 2200 m by the aragonite saturation horizon, as suitable substrates were observed in those depths.

Substrate preferences are species dependent with some species (i.e. Caryophyllia ambrosia and Flabellum spp.) found on soft mud substrates and others found on hard substrates such as boulders (Javania cailleti) or vertically exposed bedrock faces (i.e. Desmophyllum dianthus, Vaughnella margaritata). Desmophyllum and Javania were also observed on carbonate crusts associated with a possible cold seep.

New information provided here not only complement earlier studies but greatly improve the know occurrences of scleractinians on continental margins of Atlantic Canada.

COMPARISON OF LITHOSPHERE STRUCTURE ACROSS THE ORPHAN BASIN/FLEMISH CAP AND IRISH ATLANTIC CONJUGATE CONTINENTAL MARGINS FROM CONSTRAINED 3-D GRAVITY INVERSIONS

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Regionally-constrained 3-D gravity inversion results on the Orphan Basin/Flemish Cap and the Irish Atlantic conjugate continental margins are compared in order to investigate crustal structure, early rifting history and geological evolution of this part of the North Atlantic. The full-crustal density anomaly distributions provide some of the first depth images of how rifted structures compare along and across these conjugate margins. Broad similarities in crustal structure are identified with some noticeable differences, linked to rifting and crustal stretching processes. Extreme crustal thinning (stretching factors >3.5) is indicated beneath much of the southern Porcupine Basin, the western half of West Orphan Basin, the eastern half of Jeanne d'Arc Basin, the southeastern half of East Orphan Basin and in pockets beneath Rockall Basin. This appears to have resulted in the serpentinization (and possible exhumation) of mantle lithosphere on the Irish Atlantic and Flemish Cap margins but not beneath Orphan Basin. A simple evolution model is proposed for the early stages of rifting between the margins. It is suggested that ancient orogenic sutures played an important role in controlling the northward migration of rifting and the rotation and displacement of Flemish Cap out of Orphan Basin.

EMPLACEMENT, ALTERATION HISTORY, ORE GENESIS, AND TIMING OF MINERALIZATION, OF IRON OXIDE APATITE ORES AND THEIR HOST ROCKS IN THE NORRBOTTEN REGION OF NORTHERN SWEDEN – PRELIMINARY RESULTS

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Iron oxide apatite (IOA) deposits, often referred to as Kiruna-type deposits, are considered a subgroup or end-member of iron oxide copper gold (IOCG) deposits, containing no economic grades of copper or gold. Both IOCG and IOA deposits are characterized by abundant low-Ti Fe oxides, an enrichment in REE, and intense sodium and potassium wall-rock alteration adjacent to the ores. Deposits of these types are of a great economic importance, not only for iron, but also for other elements such as uranium and rare earth elements (REE). The type locality of the IOA type of mineral deposits is in the Norrbotten region of northern Sweden and the object of this study. The anticipated results will provide a better understanding of the nature of the IOA type of mineral deposits and their relation to IOCG deposits such as Olympic Dam in Australia.

An array of geochemical methods is used in order to gain insights on the emplacement history of the host rocks, their subsequent alteration, and the ore genesis of these deposits. This includes *in situ* U/Pb geochronology to constrain the timing between host rock emplacement, alteration and mineralization. Notably, the ores in the Norbotten region have never been directly dated. Isotope geochemistry on whole rock and in situ at mineral scale will provide clues on the involvement of hydrothermal fluids and their possible sources, as well as on the sources of iron, U, and the rare earth elements. Tracer radiogenic isotopes in situ at mineral scale (e.g., Lu-Hf in zircon, and Sm-Nd in monazite, apatite, titanite) and trace elements in the above mentioned accessory minerals, and O isotopes in zircon, are considered especially useful to decipher the history of hydrothermal alteration and mineralization.

Preliminary U/Pb dating confirms a previously documented event around 1880 - 1900 Ma in the Norrbotten region. Also, the data suggest two further events at ca. 1650 - 1700 Ma and at ca. 1050 Ma, both periods of known activity in Fennoscandia. Further investigation and data is needed to confirm those dates. Overall, the study also intends to develop a predictive model for exploration of similar iron oxide apatite deposits worldwide.

THE PRE-CARBONIFEROUS GEOLOGY OF NORTHERN MAINLAND NOVA SCOTIA, CANADA: A REVISED INTERPRETATION OF PART OF AVALONIA IN THE NORTHERN APPALACHIAN OROGEN

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New field observations, petrological data, and ages have changed and simplified geological interpretations of the Antigonish Highlands. The oldest rocks are Late Neoproterozoic (ca. 621 to 612 Ma) calc-alkaline volcanic and sedimentary rocks of the Georgeville Group. The Georgeville Group is intruded by dioritic to syenogranitic plutonic units, of which some were previously interpreted to be mid-Paleozoic and some were mapped as volcanic units. However, petrological data and new and previously published U-Pb zircon ages show that these plutons are co-magmatic with their volcanic host rocks and range in age from ca. 615 to 605 Ma. Volcanic rocks in the former "Bears Brook Formation" are now included in the Georgeville Group, based on the fact that they are intruded by the ca. 615 Ma Burroughs Lake pluton. The redefined Bears Brook Formation is now used for the dominantly sedimentary part of the former unit, combined with sedimentary rocks of the former Malignant Cove Formation, previously included in the basal part of the Cambrian sedimentary-volcanic succession. This interpretation is substantiated by previously published detrital zircon U-Pb ages which indicate pre-585 Ma ages for these rocks.

The redefined Iron Brook Group in the northern Antigonish Highlands consists of a fault-bound package of sedimentary rocks, for which an Early Cambrian age previously indicated by macrofossils was confirmed by microfossils identified in the present study. Mafic and felsic sills in this unit were previously interpreted as flows. Volcanic rocks of the former Arbuckle Brook Formation are now considered to be Late Neoproterozoic and not part of the Iron Brook Group.

All of these Neoproterozoic and Cambrian rocks are intruded by widespread ca. 485 to 470 Ma syenite to alkali-feldspar granite and tholeiitic transitional to alkalic gabbro of the West Barneys River plutonic suite, formed in an extensional setting. Mafic and felsic sills, previously interpreted as flows, in the Bears Brook Formation and older units have

compositions suggesting that they are related to this major Ordovician plutonic event. North of the Hollow fault, extension continued until at least ca. 454 Ma with the deposition of the bimodal volcanic rocks of the Dunn Point and McGillivary Brook formations. The contact of the latter formation with the overlying Early Silurian to Early Devonian Arisaig Group appears to be conformable. The Dunn Point and McGillivary Brook formations are absent south of the Hollow fault where the overlying Arisaig Group rests with an angular unconformably on the older units.

STRUCTURE AND DEFORMATION HISTORY OF THE APPALACHIAN THRUST FRONT IN THE PARSONS POND AREA, WESTERN NEWFOUNDLAND: IMPLICATIONS FOR PETROLEUM EXPLORATION

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The Parsons Pond area, in western Newfoundland, is dominantly underlain by rocks of the Humber Arm Allochthon - a stack of structurally imbricated deep-water continental margin successions that have been assembled and emplaced over adjacent platform rocks during the mid-Ordovician Taconian orogeny. Later Paleozoic deformation generated a zone of deep-seated, west-vergent thrusts, which unlike Taconian thrusts extend deep into Grenville basement. On the Port au Port Peninsula, these faults are interpreted to have a protracted history, having been active since Proterozoic rifting and later reactivated and inverted during Acadian deformation. Between Parsons Pond and Portland Creek, the Acadian thrust front has traditionally been viewed as a narrow, weakly emergent zone dominated by the Long Range Thrust. The Long Range Inlier is interpreted to have been thrust over platform rocks and rocks of the Humber Arm Allochthon along this main fault.

Surface mapping and 2D seismic reflection data show however, that the Parsons Pond Thrust structurally juxtaposes rocks of highly contrasting tectonic environment. Deep water carbonates and siliciclastics of the Shallow Bay Formation and Lower Head Formation respectively, are structurally overlain by correlative platform rocks and, at Portland Creek, by siliciclastics of the mid-Ordovician Goose Tickle Group. Previous authors view the Parsons Pond Thrust as a minor splay thrust, related to the main Long Range Thrust. Recent mapping and interpretation of on-land industry seismic data however, has led to the interpretation that the Parsons Pond Thrust may be the main, leading trust of this system, placing basement and platform rocks above the Humber Arm Allochthon. 2011 field mapping suggests that the Parsons Pond Thrust runs offshore, near Daniel's Harbour.

Recent economic interest and exploration in the Parsons Pond area has warranted improved geologic mapping at a detailed scale. Using surface mapping results, combined with on-shore 2D seismic, a 3D model of the subsurface can be generated and hence a better understanding of the subsurface geology can be achieved.

DEVELOPING A GEOLOGICALLY CONSTRAINED DEFORMABLE PLATE RECONSTRUCTION FOR THE NEWFOUNDLAND AND IRISH CONJUGATE MARGINS

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As petroleum exploration focuses increasingly on deep-water continental margins, plate tectonic reconstructions are being recognized as an important exploration tool. Current plate kinematic models for the North Atlantic are inadequate when it comes to understanding the pre-breakup history of the region and its influence on basin geometry. A two-year government sponsored research project to develop A New Kinematic Plate Reconstruction of the North Atlantic between Ireland and Canada is nearing completion. The project team, comprising researchers from academia, government, and industry on both sides of the Atlantic, is led by GeoArctic Ltd and includes researchers from Badley Geoscience Ltd., University College Dublin (UCD), Memorial University of Newfoundland (MUN), University of Liverpool, the Dublin Institute of Advanced Studies (DIAS), the Geological Survey of Canada (GSC), and others.

The deformable plate reconstruction method employed on the project takes into account the wide range of geological processes responsible for basin development by incorporating new seismic, magnetic and geological interpretation with analytical techniques that include 2D and 3D gravity inversion, flexural backstripping, fault restoration and forward modelling. The total amount of crustal thinning around the margin is modelled using gravity inversion calibrated using seismic refraction data where available. A regional seismic grid has been interpreted on each conjugate margin using a combination of high quality industry data, as well as reflection and refraction seismic profiles from government and academia. Industry seismic lines include deep long-offset seismic data on the Irish margin (courtesy of ION-GX Technology) and the Orphan Basin (courtesy of TGS-Nopec). Major tectonostratigraphic sequences and tectonic events have been defined using these data and the amount of crustal extension is sub-divided into individual tectonic events or time intervals and converted to a stack of Beta factor grids (ßeta-STACK). These Beta factor grids are constrained both by the plate kinematic model and by all available onshore and offshore geological data. The ßeta-STACK forms the key component of the deformable plate model and can be fully integrated with the plate kinematic model.

The ability to apply the results of deformable plate modelling to restore pre-breakup geometry represents a major advance over the rigid plate models. Restored structure maps, palaeogeography maps, sediment source area maps, source rock and reservoir facies maps may be reconstructed to their palaeo-position to be used to evaluate source rock and reservoir potential.

REVEALING BIOTAS IN CHARNWOOD FOREST (UK): A CLEARER WINDOW ON THE AVALON ASSEMBLAGE

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The Ediacaran (late Neoproterozoic) Avalon Assemblage preserves the oldest evidence of diverse macroscopic life and underpins current understanding of early benthic marine communities. However, it is poorly known beyond the classic localities of Newfoundland. Correlative biotas in Charnwood Forest (UK) were first reported as early as 1848 and have yielded the holotypes of several key taxa (Charnia, Charniodiscus, Bradgatia), but they have generally been regarded as representing an impoverished fauna and have received comparatively little attention. Consequently, the total diversity of the Avalon Assemblage and thus the extent to which the Newfoundland biotas may be considered representative of the wider deepwater biotope has remained unclear.

A systematic programme of silicon rubber moulding in Charnwood Forest, including all of the most important currently known fossiliferous surfaces (totalling >150m^2), has revealed the presence of several high diversity (up to 19 taxa) biotas. These include a number of new taxa, as well as some that may be allied to ones previously considered endemic to Newfoundland. Frondose forms dominate and exhibit a strong preferred orientation, consistent with them having been felled and smothered en mass by the overlying turbidite. Direct comparisons are therefore possible with the Newfoundland biotas, allowing an assessment of the relative significance of primary (i.e. ecological, provincial, age) versus secondary (i.e. taphonomic) drivers in controlling the observed differences in the structure of their communities. Notably, prostrate forms (e.g. Fractofusus and Hapsidophyllas) that are so abundant in many of the Newfoundland communities appear to be absent from Charnwood Forest, perhaps reflecting disparate hydrodynamic or depositional regimes between the two regions. Additionally, certain bedding surfaces in Charnwood Forest preserve abundant intact fronds (i.e. with holdfast attached) and therefore have considerable potential for elucidating the ontogeny and population dynamics of these rangeomorphs.

A DESCRIPTIVE MODEL FOR ALBITITE-TYPE URANIUM

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The albitite-type uranium deposit group is a widespread deposit type occurring on all continents and collectively contains as much uranium as the unconformity-type group, although grade is much lower. Production is limited to deposits in the Kirovograd-Krivoi Rog district of the Ukraine

and the Lagoa Real deposits in Brazil. Future production is likely from Labrador's Central Mineral Belt.

Albitite-type uranium deposits are located in Proterozoic, particularly Orosirian, rocks. Deep-penetrating faults and large-scale synclinal axes control ore deposit location at the regional scale. Faults are marked by early pegmatite intrusion, cataclasis and mylonitisation. Albitites generally postdate mylonitisation but are postdated by brecciation and uranium deposition. Host terranes range from those dominated by high grade metamorphic rocks, such as gneiss and migmatite (e.g. Kirovograd, Lagoa Real) to those dominated by greenschist- to amphibolites facies meta-volcanic and sedimentary rocks (e.g. Central Mineral Belt). In the Kirovograd district, uranium occurs in a wide range of albitized rocks including schist, ferruginous hornfels, meta-conglomerate, gneiss, migmatite and granite. Albitisation shows no preference for specific host-rocks, and the mineralogy of the host-rock appears irrelevant. Thus chemical interaction of the ore-forming fluids and host-rock was not a critical factor in ore formation. More significant are the mechanical properties of the host rocks.

Uranium minerals include coffinite, uraninite and various U-Ti and U-Zr phases. Gangue minerals include substantial volumes of fluorapatite and Ca- and Mg-rich carbonate minerals include riebeckite, aegirine, calcic garnet, magnetite, hematite and hydrothermal zircon. Presumably higher temperature minerals such as riebeckite, aegirine tend to be present at depth and grade upwards to lower temperature phyllosilicate and/or epidote-rich assemblages. Bulk Ca abundance can exceed that of Na and there is major loss in SiO_2 and K_2O from host rocks. Uranium correlates well with a suite of high field strength elements including REE, Nb, Hf and Ta. These elements are seldom present in economic abundance and their mineralogical residence is often poorly documented.

Several genetic models have been proposed to explain these deposits, but we favour genesis involving F-rich gases derived from an alkaline suite of subjacent intrusions. At Mount Isa (Australia) regional albitisation is linked with IOCG copper-gold deposits that carry anomalous, but sub-economic uranium. A genetic link between IOCG and albitite-type uranium has been previously mooted, but remains unconfirmed. More research is required to clarify many aspects of this enigmatic group of deposits.

REGIONAL INTERPRETATION OF THE LATE ORDOVICIAN UTICA SHALE PLAY IN THE APPALACHIAN BASIN

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The Late Ordovician Utica shale was deposited in a foreland basin setting adjacent to, and on top of, the Trenton and Lexington carbonate platforms. Initial deposition of the Trenton and Lexington platforms began on the relatively flat Black River passive margin. Early tectonic activity from the Taconic orogeny created the foreland bulge that would become the Trenton and Lexington platforms. Carbonate growth was able to keep up with the overall rise in sea level while the areas between stayed relatively deeper until increased subsidence in the foreland basin lowered the ramps out of the photic zone and inundated the passive margin with fine grained clastics.

While the number of producing Utica wells is still low, there is sufficient data by which to construct a regional framework. Facies determinations from a regional data set of well logs helps identify the platform, slope, and trough facies. A regional sequence stratigraphic interpretation of the Late Ordovician succession allows for correlation between the carbonate platforms and through the trough. Sequences are identifiable as a series of transgressive and highstand systems tracts. Lowstand systems tracts are not commonly deposited on the platforms tops and often difficult to discern within the trough. Mapping the facies for each sequence over the complete succession shows the evolution of the basin. Facies modeling, when incorporated with core, XRD, and mineral models allow for reservoir prediction and the development of completions strategies.

Deposition and preservation of organic matter is directly tied to the sequence stratigraphic framework and facies. A geographically and stratigraphically extensive database of TOC measurements show a strong correlation when merged within the sequence stratigraphic framework with the highest amounts of present day TOC occurring in the lateral equivalents to the platform tops. Maturation patterns in the Appalachian basin have also been studied and the CAI has been mapped to identify different phases of hydrocarbons. Maturation patterns are strongly linked to present day depth of burial, although post-Alleghenian erosion must also be taken into consideration. The results strongly match the existing production. This regional framework incorporating existing well logs and geochemical data, when combined with a geologic model for the depositional history, has proven to be a useful tool in the early evaluation of an emerging play.

FROM ROCKS TO ROLLS

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Compared to 40 years ago, many more learning resources are available to geoscience educators working within the school system or in outreach. However our approach still tends to follow a decades old philosophy that is focused on highly abstract concepts in the K-12 systems and on beauty in the museum sector, both of which have resulted in little or no learning about Earth. We have lost our connections to industry and the technology in people's lives. We have become more conscious about resources and recycling but as a culture we have no understanding of how our consumer products have been formed. We sort of know that minerals come from the ground and that somehow our cars, stoves and televisions for example come from those minerals but the big gap in understanding the links between the resource and the product still remain. Schools and museums have collections of beautiful minerals but nothing about the more mundane examples of those minerals in typical ore samples. We ignore the processing of that ore into the metal and the primary fabrication of those metals. The population knows little or nothing about how sewage pipes, structural beams, power lines, transmission towers, washing machines, window frames or cars are created. Until the population, through the efforts of schools and outreach facilities, develop a greater understanding of how we use our resources we will continue to have little or no understanding of the value and limits to those resources, or the importance of conservation and recycling for such resources to be available for future generations. This presentation will review some of the primary metal processing technologies and show how they can be integrated into the classroom or as a museum display to develop greater understanding.

Keynote THE HYDROTHERMAL MOBILITY OF THE RARE EARTH ELEMENTS

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Although it is widely recognized that the REE can be concentrated to exploitable levels by magmatic processes, e.g., by gravity settling of REE minerals or, their enrichment in residual liquids, it is also clear that the REE may be hydrothermally mobilized, and that hydrothermal processes may dominate some ore-forming systems. Indeed, there is compelling evidence that the World's largest REE deposit, Bayan Obo, China, is entirely hydrothermal in origin; the deposit is hosted by a dolomitic marble in which the REE ore minerals, bastnäsite and monazite are associated with iron oxides and fluorite. Recent experimental investigations by the authors have shown that the REE form strong aqueous complexes with fluoride ions. Moreover, these experiments have shown also that the stability of the REE fluoride complexes is higher for LREE than for HREE. Assuming that the relative mobility of individual REE is controlled mainly by the stability of their aqueous species (there is evidence for monazite that its solubility increases from La- to Nd-rich variants), this implies that LREE should be more mobile than HREE, if complexed by fluoride. This is observed at the Nechalacho deposit, NWT. In this deposit, primary cumulate REE-bearing zircon and eudyalite were subjected to intense hydrothermal alteration, which leached REE, and preferentially mobilized LREE into the upper parts of the deposit where they precipitated as fluorocarbonate minerals (mainly bastnästite) together with fluorite. Similar mobility is evident in the Strange Lake deposit, Québec-Labrador, where the REE occur with fluorite, mainly as secondary Ca-bearing

minerals, although because of restriction of the mineralization largely to pegmatites, differential REE mobility is less evident. The association of REE mineralization with fluorite in each of these deposits suggests a common hydrothermal process. We propose that this process involved transport of the REE as fluoride complexes, and interaction of the ore fluids with a calcium source (dolomitic marbles at Bayan Obo, and a Ca-bearing fluid in the Nechalacho and Strange Lake deposits) that saturated the ore fluid in fluorite, thereby destabilizing the REE-fluoride complexes, inducing deposition of REE minerals. We further propose that the greater stability of LREE aqueous species ensured the distal concentration of LREE minerals, although we accept that for Bayan Obo, a carbonatitic fluid source may have been a factor in the LREE-rich nature of the deposit.

VOLCANO-STRATIGRAPHY AND MAJOR ELEMENT GEO-CHEMISTRY OF THE SOUTHERN LOBE OF THE NATKUSIAK FORMATION FLOOD BASALTS OF VICTORIA ISLAND: INSIGHTS INTO THE INITIATION OF THE NEOPROTEROZOIC FRANKLIN MAGMATIC EVENT

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The Natkusiak Formation flood basalts of the ca. 720 Ma Franklin Magmatic Event are exposed in the Canadian Arctic along a northeast trending shallow syncline on Victoria Island. The exposures are erosional remnants and occur as Southern and Northern Lobes that cap the four kilometer thick succession of Proterozoic sedimentary rocks known as the Shaler Supergroup. This succession was deposited within the Minto Inlier of the Amundsun Basin and is intruded by the diabase sills and dykes of the Franklin Magmatic Event, which is thought to be the result of a mantle plume-generated hotspot related to the rifting and breakup of Rodinia.

By means of systematic detailed and regional mapping this study aims to characterize the stratigraphy and major element geochemistry of the Southern Lobe by identifying important structures, textures, and trends that may better constrain the evolution of the basalts. The basal unit consists of laterally discontinuous 1 to 10 m thick, sheet, lobate, and pahoehoe type flows with locally interbedded volcanic sandstone. The contact with the underlying alluvial-fluvial quartz arenite is generally sharp, with occasional hyaloclastite, pillows, and peperites. Sheet flows indicating the onset of main phase volcanism occur next and are up to 50m thick with typical colonnade and entablature structures. Two distinct volcaniclastic units are also present within the Southern Lobe and are correlatable with units in the Northern Lobe. When present, both occur between the basal flows and the sheet flows; the first is a massive, heterolithic unit, maroon in colour and with little to no depositional structures while the second is green in colour and clast supported, often occurring as planar or crossed beds. Both are up to 50 m thick and appear to be infilling paleovalleys. Major element geochemistry indicates that the Natkusiak basalts are continental tholeiites with an alkalic component. The basal and sheet flows show MgO evolution consistent with that of previous authors. The sheet flows are enriched in Ti, V, Ca and Al, and are depleted in Cr and Sc as compared to the basal flows. Most major and minor element disparities occur between 40 and 60 m, which corresponds with the volcaniclastic units within the stratigraphy. Ni shows a slight and consistent decrease moving up section. Native copper was observed within the more massive flows and was also discovered as veinlets proximal to scoria deposits and were coated by malachite, calcite, zeolites and prehnite.

CONTRASTING PT-EVOLUTION DURING AN ORDOVICIAN ARC-CONTINENT COLLISION AT THE LAURENTIAN MARGIN IN WESTERN NEWFOUNDLAND (CANADA)

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Humber margin sediments (Fleur de Lys Supergroup) in western Newfoundland (Baie Verte Peninsula) experienced a metamorphic evolution different from rocks of the adjacent Notre Dame arc and intervening ophiolitic forearc (Baie Verte oceanic tract), which collided with the Laurentian Humber margin during the Early to Middle Ordovician. We modeled the various metamorphic evolutions by calculating P-T pseudosections for phengite-bearing samples of metabasic, metafelsic as well as metapelitic rocks from the above units in the system SiO_2-TiO_2-Al_2O_3-FeO-O_2-MnO-MgO-CaO-Na_2O-K_2O-H_2O. These pseudosections were contoured by various modal and chemical parameters of minerals and rocks.

Garnet mica schist, the main rock type of the Fleur de Lys Supergroup, experienced peak pressure conditions up to 18 kbar at 500°C. Eclogite lenses in the mica schist record conditions of 20 kbar at 600°C. Both rock types show a clockwise PT path with a distinct stage of thermal relaxation, i.e. heating during early decompression. We conclude that the clastic sediments of the Humber margin were deeply buried during early collision as a result of southeastward subduction of the intervening oceanic Taconic seaway. The eclogite represents mafic rocks that were somewhat deeper subducted and emplaced within the metasediments during upward-directed forced flow in a subduction channel.

By contrast, the low-grade rocks of the overriding ophiolitic forearc show a low to intermediate pressure overprint. Most wide-spread conditions are at 3.5-4.5 kbar, 300-330°C. However, more deeply buried slices with a variable intermediate to high pressure overprint (5.0-7.3 kbar, 300-330°C) are intercalated within the crustal stack. The medium to high pressure metamorphism was caused by widening of the Taconic subduction channel into the overriding plate and progressive underthrusting of forearc material beneath the Notre Dame arc. Whereas the northeastward-directed crustal stacking predominantly occurred during a late stage of the Taconic collision this thrust stack was reactivated during the Silurian Salinic orogeny.

SIMILAR CRUSTAL EVOLUTION OF THE WEST AND EAST AVALONIAN MICROPLATES SUGGESTED BY U-Pb AGES AND Hf ISOTOPIC SIGNATURES OF DETRITAL ZIRCON

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Detrital zircon provides a powerful archive of continental growth and recycling processes useful for paleocontinental reconstructions. We determined U-Pb ages and Hf isotopic signatures of detrital zircon grains from Cambrian clastic sedimentary units in Cape Breton Island (Nova Scotia, Canada) and the Ardennes (Belgium). The sampled sedimentary units constitute parts of the peri-Gondwanan West and East Avalonian microplates, respectively, and were deposited before collision with Laurussia. The results show coincidence of data for both continental fragments pointing to a common origin. Crustal evolution trends defined by $\varepsilon_{Hf(T)}$-data varying with ages predict two periods of juvenile magma production in the original continent at 2.5-3.0 Ga and 1.4-2.2 Ga. Also three periods of mixing of juvenile and recycled crustal material in continental magmatic arcs can be distinguished at 1.9-2.1 Ga, 1.3-1.6 Ga, and 0.5-0.72 Ga. The latter period corresponds to episodes of calc-alkaline igneous activity in Cape Breton Island at ca. 575, 620, and 680 Ma. The stages of crustal mixing correspond to three pronounced maxima in the age spectra at 0.62-0.67 Ga, 1.5-1.6 Ga and 2.0-2.1 Ga. The youngest is the most pronounced maximum. It coincides with igneous crystallisation ages of ca. 667 Ma and 672 Ma in calc-alkaline granitoid pebbles in a Late Precambrian conglomerate in Cape Breton Island. Minor age maxima are at 0.50-0.57 Ga (defining maximum depositional ages for the sampled sediments), 0.81-0.85 Ga, 1.10-1.35 and 2.7 Ga. The overall crustal signature of Avalonia strongly contrasts with patterns known from Laurentia and Amazonia which display most pronounced Mesoproterozoic (Grenvillian) age maxima of zircon from juvenile to strongly recycled sources. These Mesoproterozoic ages are to a large extent missing or rather minor in the Avalonian samples. Hence, we conclude that Avalonia was situated close to a continent such as West Africa which had not experienced significant influence of the Grenvillian orogeny.

CANADIAN METEORITES: A BRIEF REVIEW

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We present a brief overview of Canadian meteorites with a focus on noting significant recent falls, finds and research developments. To date, 60 Canadian meteorites have received official international recognition from the Nomenclature Committee of the Meteoritical Society, while at least 13 more are "in process" for submission to the Meteoritical Bulletin, that organization's official database of the world's meteorites. The 60 Met. Bull. records (44 finds and 16 falls since the recognition of the Madoc iron in 1854) include 25 irons, 3 pallasite stony-irons and 32 stony meteorites. The latter include 14, 11 and 3 H, L and LL chondrites, 2 carbonaceous chondrites and 2 enstatite chondrites, but no achondrites. The most intensively researched meteorites are Tagish Lake (C2 ungrouped) and Abee (EH5), followed by Bruderheim (L6) and Springwater (pallasite). Bruderheim, a 1960 fall, is widely distributed, being the heaviest reported Canadian meteorite at 303 kg total known weight (TKW). Seven Canadian meteorites exceed 100 kg TKW, 36 are between 1 and 50 kg, and 17 are <1 kg.

Recent years have seen the addition of the Tagish Lake, Buzzard Coulee and Grimsby meteorite falls, all of which have well-determined fireball trajectories and therefore well-known orbits, a striking Canadian addition to the handful that are known worldwide. The discovery of the Holocene Whitecourt iron impact crater is similarly a significant recent development in understanding the impactor flux. Meteoritic research in Canada is on the upswing: advanced programs include the optimization of fireball tracking networks to aid in impactor flux determination and possible meteorite recovery, and development of techniques for materials characterization of the payloads of sample-return missions. The lessons learned on meteorites will in the next generation be applied, in all probability, to newly recovered samples from the Moon, Mars, asteroids and comets.

THE VOISEY'S BAY FOOTPRINT – TRACKING THE GEOCHEMICAL SIGNAL OF MAGMATIC Ni-Cu-Co SULPHIDE MINERALIZATION IN NORTHERN LABRADOR

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The Voisey's Bay (VB) deposits constitute a significant new (discovered 1993) style of orthomagmatic Ni-Cu-Co sulphide mineralization. The sulphides are hosted by troctolites (VBT) in a feeder and magma chamber system which constitutes only a minute component of the aerially extensive (19,000 km^2) Nain Plutonic Suite (NPS); the VBT is one of the oldest assemblages (ca. 1330 Ma) in the NPS and is essentially swamped by younger anorthosite and granite suites. The VBT is intrusive into Archean Nain Province orthogneiss and Paleoproterozoic Churchill Province enderbite and paragneiss. Notwithstanding intensive exploration of the NPS and host gneisses, no other examples of this type of mineralization have been found.

We report the preliminary results of three research projects funded by the Research and Development Corporation (RDC), Government of NL, through the GeoExplore program to detect and track geochemical footprints of the VB mineralization. Project 1 is examining the massive sulphide mineralization from two perspectives, viz.; (1) mechanisms of sulphide mineral breakdown due to oxidation by the atmosphere and ground waters, and the nature of mineral residues in till cover, and (2) conversely, explaining why upper surfaces of the Ovoid deposit were not oxidized. Project 2 is investigating three temporally distinct geochemical haloes that might be associated with the VB mineralization, viz.; (1) an Emplacement Halo in the contact aureole of the gneissic country rock associated with the VBT intrusion, (2) a Late Aqueous Emplacement Halo formed as the VB sulphides were cooling, and (3) a Post Emplacement Halo in younger NPS granitoids. Early analyses of primary fluid inclusions in quartz veins, seemingly derived during the late cooling of sulphides, suggest the presence of two phase (liquid + vapour), low salinity (< 7 eq. wt% NaCl) H_2O + NaCl inclusions with a wide range of homogenization temperatures and phase ratios that precipitated from a boiling fluid at relatively low temperatures (<250°C) and depths (< 300m). Project 3 is evaluating whether a biogeochemical halo is present in back spruce trees and Labrador Tea shrubs surrounding the VB deposits. Preliminary results indicate Ni concentrations of up to 25.5 ppm Ni in spruce bark from south of the Ovoid deposit compared with levels below detection limits in tree bark from the control area near Anaktalak Bay.

URANIUM MINERALIZATION AT THE NOTAKWANON PROJECT, NORTHERN LABRADOR

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Uranium mineralization was initially discovered by provincial government geologists in the Notakwanon River area of northern Labrador during stream sediment sampling programs in 1980, the first such report of uranium mineralization in this part of Labrador. Altius has since discovered approximately 20 additional uranium occurrences in a variety of host rocks. The Rumble Prospect has yielded values of up to 3.49% U_3O_8 in grab samples and up to 0.48% U_3O_8 over 2.5 metres in saw-cut channel samples.

The property is underlain by Paleoproterozoic Churchill Province gneiss and Mesoproterozoic Nain Plutonic Suite intrusive rocks, including the Notakwanon River Batholith granitoids of Neoproterozoic age. Uranium mineralization is hosted in both biotite-muscovite granite gneiss and cordierite-rich, sulphide-bearing meta-sedimentary rocks.

At the Rumble Prospect, where much of the work has been focused, uranium mineralization occurs as veins and veinlets associated with a brittle-ductile shear zone within metasedimentary rocks that occur as roof pendants within the batholith. The metasedimentary rocks contain abundant sulfides and oxides that pre-date metamorphism and the uranium mineralization. Within the veins, micro-scale botryoidal and delicate circular aggregates of uraninite are common. Galena is also a common sulphide that appears to be contemporaneous with the uraninite mineralization. Geochemically, Au, Ag, As, Bi, Cu, Pb and Mo are elevated with U in rock samples from the Rumble Prospect. Biotite and hematite, and to a lesser extent chlorite and actinolite, are present in wall rock adjacent to uraninite veins.

The Notakwanon project represents a new style of uranium mineralization in northern Labrador. Although the project is at an early stage of exploration, work to date has demonstrated that a uranium fertile environment exists with mineralization occurring in a number of lithologies, generally with structural controls. More work is required to understand the genesis of uranium mineralization, but at this stage a close analogue may be the Beaverlodge district of Saskatchewan.

EVIDENCE FOR A SALINIC EVENT IN SOUTHERN NEW ENGLAND

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Evidence is accumulating that igneous and metamorphic processes related to the Salinic orogeny may lie hidden behind and overprinted by Acadian metamorphism. One line of evidence is the occurrence in western Connecticut of Late Ordovician and Silurian plutonic rocks of generally dioritic and granodioritic composition (~446-428 Ma; Sevigny and Hanson, 1993; 1995). Their common Pb isotopic compositions show an increasing contribution to the magma of Gander-like crust with decreasing age. This suggests that the magmas monitor the progressive arrival of Gander as it wedged into Laurentian lower crust. These plutons and their country rocks were metamorphosed to regional staurolite-kyanite grade conditions- to pressures > 8 kb equivalent to > 25 km of loading. Amphibole cooling ages as old as 400 Ma mark the end of this loading and

heating, and show that peak loading was early Devonian or older. In contrast, 1-dimensional thermal modeling suggests peak loading occurred in the mid Silurian, consistent with the Salinic event. Abundant Middle and Late Devonian mineral ages mark the crystallization of strong Acadian fabrics, but these post-date peak-Salinic loading by tens of m.y. Mafic and ultramafic rocks define the eastern margin of the western Connecticut 'Acadian metamorphic high.' These are flanked to the east by anatectic rocks of the Kingston arc (Aleinikoff *et al.*, 2007). Thus this mafic suite could mark remnants of obducted oceanic crust from a Mascarene-like intra-arc and/or back-arc basin. In eastern Connecticut we recognize a thick package of early Silurian sediments overlain by locally conglomeratic sandstones (now quartzites) across an angular unconformity. Together these observations build a scenario consistent with the early Silurian arrival of Gander rocks wedging Laurentian crust, followed by mid-Silurian burial of these rocks to >25 km. Ultramafic rocks between two bodies of Ganderian crust suggest the closure of a Mascarene-like basin, and an angular unconformity on early Silurian rocks in eastern Connecticut suggests brief exhumation before Devonian loading. Work is in progress to test these hypotheses.

THE WESTWOOD DEPOSIT, SOUTHERN ABITIBI GREEN-STONE BELT: A "HYBRID" OR "TRANSITIONAL" ARCHEAN GOLD DEPOSIT

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The Westwood deposit (~3.7 Moz of Au) is part of the Doyon-Bousquet-LaRonde mining camp that is located in the eastern part of the Blake River Group in the southern Abitibi greenstone belt. The deposit is hosted in the volcanic rocks of the 2699-2696 Ma Bousquet Formation, which forms a steeply south-dipping, east-trending homoclinal sequence that faces south. The Bousquet Formation, which is interpreted as the remnants of a stratovolcano, has been divided in a lower member composed of mafic to felsic volcanic rocks of tholeiitic to transitional affinity and an upper member dominated by intermediate to felsic volcanic rocks of transitional to calc-alkaline affinity. The study area is metamorphosed to the greenschist-amphibolite facies transition and the deformation is regionally heterogeneous with highly strained corridors.

The deposit consists of three distinct mineralized corridors that are stacked from north (base) to south (top): (1) Zone 2 Extension; (2) North Corridor; and (3) Westwood-Warrenmac Corridor. Mineralization in the Zone 2 Extension consists of cm- to dm-wide pyrite- and chalcopyrite-rich auriferous quartz veins. The North Corridor mineralization consists of cm to dm-wide auriferous quartz-pyrite-chalcopyrite ± sphalerite veins as well as thin, semi-massive to massive sulphide veins. The veins and alteration halo of these two corridors are slightly discordant to the stratigraphy and main foliation and are possibly associated with the Mooshla synvolcanic pluton located west of Westwood. Finally, the Westwood-Warrenmac Corridor mineralization consists of discontinuous, stratabound Au-rich polymetallic semi-massive to massive sulphide lenses and disseminations.

The Warrenmac lens, which is representative of the VMS-type Westwood-Warrenmac Corridor mineralization, is characterized by pyrite-sphalerite-chalcopyrite ± galena-pyrrhotite massive sulphides overlain by a highly transposed pyrite-sphalerite ± chalcopyrite stringer zone. The footwall of the lens is characterized by a volcaniclastic dacite cut by a massive andesite sill (?), whereas the hangingwall composition is variable and consists of andesite, volcaniclastic dacite-rhyodacite, and quartz-phyric rhyolite. Sericite, quartz, Mg-chlorite and Mn-garnet define the main proximal alteration assemblage (metamorphic equivalents of primary alteration-related minerals) to the Warrenmac lens.

Studying the Westwood deposit and its environment represents a unique opportunity to test the working hypothesis of a continuum between vein-type mineralizations associated with a synvolcanic intrusion and auriferous massive sulphide lenses, and therefore contribute to a better understanding of Archean auriferous magmatic-hydrothermal systems. The knowledge gained in this project will help improve the current exploration models for Au and VMS deposits in the Abitibi greenstone belt and elsewhere.

MAKING AND BREAKING OF AN ARC: RECURRING EXTENSIONAL MAGMATISM IN THE ANNIEOPSQUOTCH ACCRETIONARY TRACT, NEWFOUNDLAND APPALACHIANS

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The Annieopsquotch accretionary tract (AAT) comprises a thrust stack of Lower to Middle Ordovician arc and backarc terranes that were accreted to the Laurentian margin of Iapetus during Middle to Upper Ordovician. Geological relationships suggest that the constituent terranes of the AAT initially formed outboard of the peri-Laurentian Dashwoods microcontinent in an extensional arc that underwent multiple phases of rifting prior to accretion to the composite Laurentian margin. The initiation of AAT magmatism followed a subduction flip, which led to the development of an earliest Floian supra-subduction zone ophiolite that separated a ribbon of Dashwoods from its parent. This crustal block formed the basement to subsequent Floian to Darriwilian AAT arc magmatism. The Floian Robert's Arm arc rifted, which led to the development of the Lloyds River backarc basin floored by backarc oceanic crust. The latest Floian to earliest Dapingian arc magmatism occurred above thickened crust, locally leading to eruption of andesitic rocks. The establishment of the Darriwilian Red Indian Lake – Buchans arc system followed further upper plate extension, as preserved by the ophiolitic Skidder formation. Darriwilian arc magmatism shows great diversity. The Red Indian Lake Group appears to be the most continentally contaminated, whereas the Roberts Arm Group appears to be the most juvenile. The diversity of the magmatism can be attributed to fragmentation and magmatic reworking of the Dashwoods derived basement along strike in the same arc, or to a transition from continental to oceanic basement along strike.

MESOSTRUCTURAL EVIDENCE FOR VERTICAL THINNING AND SUBHORIZONTAL EXTENSION OF THE OTTAWAN THRUST-SHEET STACK, GRENVILLE PROVINCE OF SOUTHEAST ONTARIO

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In the northwestern Composite Arc Belt (CAB), its basal boundary zone and the structurally underlying Muskoka and Algonquin domains, weakly strained dilation dikes of granite pegmatite (1), metre-scale oblique or normal faults and narrow shear zones (2), and winged lithic inclusions and feldspar porphyroclasts oblique to the main foliation (3) attest to vertical thinning and northwest-southeast extension of the Ottawan thrust-sheet stack. The normals to most weakly strained pegmatite dikes are subhorizontal or plunge <30°. In conventional stereoplots, the contour pattern of the dike normals includes a broken northwest-southeast girdle with a moderately-plunging maximum that attests to a regional component of orogen-normal extension. The prestrained walls of many mesoscopic dislocations and some weakly deformed pegmatite dikes contain gneissic layers whose curvature attests to southeast-directed normal-shear components. In XZ sections through mylonitic granitoid gneisses with L-S mineral fabrics, however, <50% of rotated, winged feldspar porphyroclasts have geometries explicable by southeast-directed normal-sense shear.

As demonstrated by other workers, between the villages of Gooderham and McArthur Mills, the extensional Bancroft shear zone (BSZ) marking the upper boundary of the Bancroft domain is characterized by narrow subzones of marble mylonite. The Bancroft-McArthur Mills segment of the BSZ, however, is much broader than shown in published figures, and contains a network of curved ductile faults apparently initiated as ductile thrusts during Ottawan crustal thickening. Metre-scale structures in highly strained marbles of this BSZ segment include rotated remnants of mafic layers with mineral assemblages formed at or near the metamorphic peak. The geometry of XZ sections through winged ovoidal remnants attests to southeast-directed components of normal-sense shear. Evidently, the conspicuous mesostructure of the BSZ

pertaining mainly to post-thrust normal-sense shearing at least locally overprints structural features generated during crustal thickening at or near the metamorphic peak. The same may also hold true for the porphyroclastic gneisses in the CAB boundary zone and parts of the Bancroft, Muskoka, and Algonquin domains.

In summary, mesoscopic structural features generated or overprinted during crustal thinning, normal-sense shearing and subhorizontal extension of the Ottawan thrust-sheet stack have been identified, at many localities, by means of dilation and shear sense indicators as well as retrograde mineral assemblages. But in other places, discrimination between the influence of crustal thickening and crustal thinning on the regional strain fabric remains an outstanding issue hindering precise assessment of the regional tectonic evolution.

ORDOVICIAN STRATIGRAPHY AND OIL SHALE, SOUTHERN BAFFIN ISLAND, NUNAVUT TERRITORY

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Southern Baffin Island retains part of Foxe Basin, one of Canada's Paleozoic sedimentary basins. The Ordovician on southern Baffin Island was previously divided into the Middle Ordovician Frobisher Bay Formation, and the Upper Ordovician Amadjuak, Akpatok and Forster Bay formations, consisting mainly of carbonate with minor shale. The stratigraphy and hydrocarbon potential of the Ordovician sequence in Foxe Basin are poorly understood. Over the past few decades there has been considerable debate on whether there is oil shale within the Ordovician on southern Baffin Island. If there is, where is its stratigraphic position? Is it geographically widely distributed? Does it have any petroleum potential? Answers to these questions are being addressed by the GEM Hudson Bay – Foxe Basin project. In 2011, field studies were designed to test stratigraphic position, geographic distribution and petroleum potential of oil shale on southern Baffin Island.

Extensive field studies and detailed sampling prove that:

1) One oil shale interval in a large Paleozoic outlier by Jordan River is in the lower Amadjuak Formation, rather than between Amadjuak and Akpatok formations as previously interpreted.
2) Owing to the facies change, this oil shale interval laterally changed into non-oil shale, which is seen on the western shore of Amadjuak Lake.
3) Previously interpreted Forster Bay Formation does not exist on southern Baffin Island owing to the erosion.

Preliminary, Rock Eval data show that:

1) A 2-m-thick outcrop of lower Amadjuak Formation by Jordan River contains TOC 1.68%–12.97% (average of 7.79%). It is primarily immature Type I marine oil shale. Another 2-m-thick outcrop of lower Amadjuak Formation on the western shore of Amadjuak Lake, stratigraphically at the same level as that by Jordan River, only contains TOC 0.31%–0.76%, showing no potential.
2) Black oil shale rubble samples from various locations, containing same trilobite and graptolite as 2-m-thick outcrop of lower Amadjuak Formation by Jordan River, contain TOC 8.83%–14.91% (average of 12.68%) with immature nature.
3) Brown argillaceous limestone rubble from various locations is either covering outcrop of Amadjuak or Akpatok Formation and most likely belongs to Forster Bay Formation which has been eroded off in the study area, containing TOC 2.82%–5.13% (average of 4.21%). The brown argillaceous limestone might exist in the offshore area as another low yield source rock.

WHOLE-ROCK GEOCHEMISTRY OF MESOZOIC SANDSTONES AND MUDROCKS IN THE OFFSHORE SCOTIAN BASIN: IMPLICATIONS FOR PROVENANCE STUDY

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A geochemical dataset of several hundred Mesozoic sandstones and mudrocks from the offshore Scotian Basin has been investigated in this study to better constrain the provenance of clastic sediments in different parts of the basin and at different stratigraphic levels. The data were first screened to exclude the effect of severe diagenesis and appraised for the influence on element variation of weathering, grain size, hydraulic sorting and polycyclic concentration of heavy minerals. Mudrocks are considered separately from sandstones. Key elements have been defined from our data using scatter plots and principal-component analysis (PCA). Transport and recycling were evaluated using the concentration of heavy minerals and various tectonic hypotheses that may have affected supply and pathways of deposited sediments. The results confirm that three principal river supplied different parts of Scotian Basin. They also show that: a) significant climate changes in the lower Cretaceous influenced the type of detritus supplied to the basin. b) the elemental abundances of mudrocks from different geographic and stratigraphic units systematically reflect changes in both climate and provenance known from other data. c) the correlation of elements such as Zr, Ce, Ti and Cr concentrated in heavy minerals can be used to recognize the presence of polycyclic heavy minerals, which are known to be of value as indicators of source. d) Barremian-Aptian volcanoes in the Orpheus graben played an important role in the provenance of clastic rocks in the east and central Scotian Basin. Industry chemostratigraphic studies used for correlation in the Thebaud field were based mainly on bulk cuttings of silty mudrock mixed with sandstone, limiting the use of correlation and interpretation of sediment provenance. However systematic investigation in several wells indicates chemostratigraphy is a good tool for revealing gaps in the stratigraphic record.

CARBON AND OXYGEN ISOTOPIC CHEMOSTRATIGRAPHIC CONSTRAINTS ON THE AGE OF THE EDIACARAN LANTIAN BIOTA OF SOUTH CHINA

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The Lantian biota consists of a diverse assemblage of morphologically differentiated, mostly benthic macrofossils that are preserved as carbonaceous compressions in black shales of the lower Ediacaran Lantian Formation in southern Anhui Province, South China (Yuan *et al.*, 2011). Regional lithostratigraphic correlation suggests that Lantian biota is of early Ediacaran age shortly after the termination of the Marinoan glaciation. Carbon isotopic profiles for Lantian Formation carbonate rocks at the Lantian, Jinlongshan, and Shiyu sections in southern Anhui show consistent stratigraphic features. Of particular importance is a pronounced negative $\delta^{13}C$ excursion (with a nadir at –19.2‰, VPDB) in the upper Lantian Formation that can be correlated with EN3 in the upper Doushantuo Formation in the Yangtze Gorges area of South China (McFadden *et al.*, 2008) and further with the Shuram event in Oman (Le Guerroue *et al.*, 2006). Negative $\delta^{13}C$ excursions of similar magnitude (to a nadir of < –10‰, VPDB) have also been reported from middle Ediacaran rocks in Death Valley (Kaufman *et al.*, 2007), Australia (Calver, 2000), Norway (Melezhik *et al.*, 2008), Scotland (Prave *et al.*, 2009), and Siberia (Pokrovskii *et al.* 2006). It has been proposed that the Shuram event may be associated with the ~580 Ma Gaskiers glaciation (Halverson *et al.*, 2005), and a glacial linkage is supported by the extreme negative $\delta^{18}O$ values (ca. –25‰, VPDB) associated with the Shuram-like $\delta^{13}C$ values in the upper Lantian Formation (Zhao and Zheng, 2010; and this study). If this glacial linkage is confirmed, then the Lantian biota, which occurs in the lower Lantian Formation below the Shuram-like carbon isotopic excursion, should be older than both the Gaskiers glaciation and the Ediacaran Avalon biota.

Late Additions

TACONITE AND DIRECT SHIPPING ORE (DSO) DEPOSITS OF WESTERN LABRADOR AND NORTHEASTERN QUEBEC - NEW MILLENNIUM IRON CORP.

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The Proterozoic rocks occurring near Schefferville, commonly referred to as the Kaniapiskau Supergroup, include the Sokoman Formation, which is the principal source of the economic iron ore deposits. New Millennium Iron Corp. (NML) has been actively exploring this area for magnetic taconite iron ore and for direct shipping iron ore deposits (DSO) since 2003. NML has developed three major taconite deposits in Newfoundland and Labrador and Quebec. In the DSO areas, NML by drilling upgraded in resources several known deposits. In collaboration with Tata Steel Canada Ltd. (TSMC), NML is developing several deposits for production in late 2012.

PROTEROZOIC TO PALEOZOIC U-Pb AND Lu-Hf ZIRCON SIGNATURES OF THE NORTHERN SOUTH AMERICAN MARGIN: IMPLICATIONS FOR THE TRACING OF AMAZONIAN-DERIVED TERRANES WITHIN THE APPALACHIAN/VARISCAN PERI-GONDWANAN REALMS

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The late-Neoproterozoic to Paleozoic time period was characterized by intense terrane-transfer tectonics between the (present) northern Gondwana margin and the developing Appalachian/Variscan orogenic belts. Docking of peri-Gondwanan allochtonous blocks to the Laurentian and Baltican margins was punctuated by key orogenic events related to the closure of the Iapetus/Tornquist Oceans in the late Ordovician and the Rheic Ocean in the Carboniferous, resulting in a complex collage of tectonically juxtaposed terranes with complex evolutionary histories. In the North American case, despite the fact that at least half of the crust included within the Appalachian Orogen is believed to be of peri-Gondwanan origin (See map of Hibbard *et al.* 2007), there is still significant uncertainty regarding the paleogeographic position of the different terranes within the Gondwana margin prior to their detachment. This is mostly due to the scarcity of geochronological and isotopic data in key source-regions such as the northern Amazon and West African cratons, resulting in hypothetical paleogeographic linkages that are only loosely constrained. In this contribution, we present new U-Pb geochronological and Lu-Hf isotopic data from zircons extracted from Precambrian crystalline basement and Neoproterozoic to Ordovician clastic units from a) exposures found in the Amazonian lowlands of Colombia and Venezuela, b) deep exploratory wells that cored these units under the Andean foredeep, and c) exposures of reworked basement massifs within the north Andean Cordillera. This dataset places further constraints on the typical age patterns and range of Hf isotopic signatures that were typical of northern Amazonia during the Neoproterozoic and Paleozoic, and allow a better assessment of the hypothesized Amazonian ancestry of certain peri-Gondwanan terranes.

Hibbard, J.P. *et al.*, 2007. American Journal of Science, v. **307**, no. 1, p. 23–45.

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