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Fingerprinting of conflict minerals: columbite-tantalite ("coltan") ores

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Introduction

Illegal mining of gold, diamonds, copper, cobalt and, in the last decade, "coltan" has fuelled ongoing armed conflicts and civil war in a number of African countries. "Coltan" – an important tantalum source - is a central African trade name of mineral concentrates chiefly composed of members of the columbite-tantalite group [(Fe,Mn)(Nb,Ta)$_2$O$_6$]. Tantalum is a rare metal (Dec 2007: 77 US$/kg tantalite, 30% Ta_2O_5) whose strength, chemistry and electronic properties make it valuable in many high-technology and medical applications. The use of tantalum has, for instance, been instrumental in reducing the size of mobile phones. Coltan is mined from highly specialized granitic rare metal pegmatites (e.g. Černý, 1992), which commonly show complex zoning, and from related placer deposits.

Although the major producers of tantalum in Australia, Brazil and Canada account for more than 80 percent of the world production (2006: ~1,290 metric tons tantalum metal; USGS Mineral Resources Program), artisanal and small-scale mining of coltan is essential to many local economies in Africa (e.g. Mozambique, Ethiopia, Rwanda, DR Congo (DRC), Nigeria, Namibia). Moreover, Africa is estimated to host about three quarters of the world's tantalum resources. The term "blood coltan" was coined in the Congolese civil war, as the sale of this mineral fuelled fighting especially in the eastern provinces of the DRC. Various governmental and rebel armed groups moved in to take control of its production and trade. A sharp price increase for tantalum on the market at the beginning of the century from 60 to 480 US$/kg Ta_2O_5 made this trade highly profitable. Large quantities of coltan were smuggled from the DRC into the neighboring countries to be sold illegally.

The expert group for the DRC of the United Nations Security Council recommended the development of a traceability system that would proof the origin of coltan. Such a system would allow ore produced within regions affected by civil war to be distinguished from other sources. Results of a pilot study funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) are presented here. Combined mineralogical-geochemical-geochronological signatures of columbite-tantalite ores are used to trace the origin of ore concentrates.

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From the President of SGA

David I. Groves
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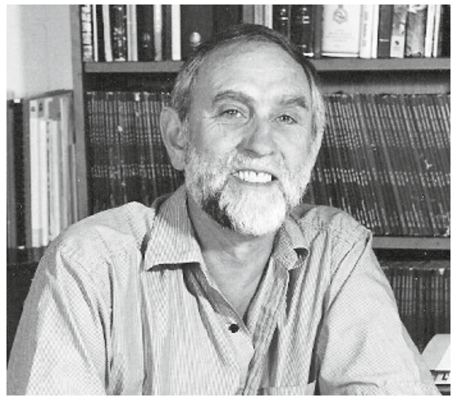

It is a great honour to be elected President of SGA, particularly as an Australian so far from the European heart of the Society. The fact that I am a former President of SEG shows that international collaboration, rather than competition, is seen as the way forward as we seek to maximise service to our Membership.

As President, I have a number of goals that I will be seeking to achieve in collaboration with the outstanding Executive and Council that has been elected for 2008/2009. I would like to see our Membership increase by at least 25 percent over the next two years, and the Society also achieve a firmer financial foundation, particularly through strategic planning headed by Dave Leach, our Treasurer. I am also determined that our biennial meeting, SGA 2009, in Townsville, Queensland, Australia in August 2009, will be a great scientific success for SGA. We have an impressive Organizational Committee, chaired by Pat Williams and strongly supported by his colleagues at EGRU at James Cook University. The other two university-based economic geology centres, CODES at U Tas and the Centre for Exploration Targeting at UWA, are also involved in the organisation. Collaboration with SEG through Rich Goldfarb will involve a day of invited talks to complement the normal SGA sessions.

Council also need to aid the Editors of Mineralium Deposita in any way they can to maintain the extremely high standards of the journal. Over the past five years, Mineralium Deposita has become the premier journal in economic geology in terms of its academic and industry impacts.

After the next Council Meeting to be held in Quebec City, Canada in late May, the Membership will be canvassed to approve some changes to the Satutes of the Society which will help us expedite our business and allow us to better interact with SEG and IAGOD who have ex-officio members on our Council. Your assistance in responding to our requests for your vote on these matters will be greatly appreciated.

After the next Council Meeting, I hope to be able to write a more detailed article on our strategic plans, a more definitive view of SGA 2009, and an indication of the location of SGA 2011.

APPLICATIONS to SGA for meeting sponsorship must be submitted to Jan Pasava, SGA Executive Secretary, on appropriate forms available at the SGA home page on Internet: www.e-sga.org

Other requests will be not considered.

Your suggestions and ideas for any topic of interest to SGA are welcome!
They can be addressed to any Council member or to

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SGA Executive Secretary

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SGA news

No. 23 June 2008

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News of the Society

News of the Council

2007 SGA ballot

Below are reported the results of the 2007 SGA Ballot to elect Administrative Officers for the terms of two years (January 1, 2008—December 31, 2009)

		YES	NO
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Vice-President:	Fernando Tornos (Spain)	184	14
Exec. Secretary:	Jan Pašava (Czech Rep.)	193	5
Treasurer:	David Leach (USA)	184	14
Promotion Man.:	Gregor Borg (Germany)	183	15
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Larry Meinert (USA)		190	8
Chief editor of SGA News:			
Massimo Chiaradia (Switzerland)		193	5
Cheif editor of SGA Website:			
Georges Beaudoin (Canada)		195	3
Student Representative:			
Anna Vymazalová (Czech Republic)		190	8

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Australia/Oceania:	D. Huston (Australia)	192	6
Europe:	Richard Herrington (UK)	191	7
Middle East:	H. Harbi (Saudi Arabia)	192	6
North Africa:	S. Bouhlel (Tunisia)	192	6
North America:	A. Conly (Canada)	194	4
South Africa:	John Moore (South Africa)	194	4
South America:	Carmen Holmgren (Chile)	193	5

Councillors for the term – January 1, 2008 - December 31, 2011

F. Bierlein (Australia)	189	9
K. Kelley (USA)	188	10
P. Williams (Australia)	193	5
R. Foster (UK/Turkey)	189	9
R. Presnell (USA)	188	12
V. Shatov (Russia)	190	8

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(179 electronic and 19 hard copies)
TOTAL VALID VOTES 198

Prague, December 20th, 2007

Jan Pašava Bohdan Kříbek Anna Vymazalová

Future activities

-SGA presence at the 2008 IGC (Oslo, Norway)
1. SGA ORGANIZED SESSION:
Half a day MRD-13 Symposium on "Black shale hosted Ore deposits associated with black shales: from their origin to their Environmental impacts", convened by J. Pašava and H. Frimmel
Black shale formations occur in different geological environments throughout the geological record. Black shales are of interest in exploration since they host numerous types of ore deposits such as base metals (copper, lead zinc +- barite), noble metals (gold and platinum group elements), uranium, molybdenum, nickel, manganese, vanadium, mercury, antimony, tin, phosphorus and others. Previously, some of the deposits were sub-economic, containing large amounts of low-grade mineralized black shale, but with the recent development of ore processing methods like bioleaching, many of these low-grade prospects became economically profitable. Both scientific results into the genesis and environmental issues related to mining and processing of black shale-hosted ores will be a major focus of this session.
Schedule:
10 oral presentations
9 poster presentations
Keynote speakers:
Paul Emsbo – USGS Denver
Alan Kaufmann – University of Maryland

2. SGA SPONSORED SESSIONS:
MRD-10 Symposium on "Large ore provinces of Central Asia", convened by Ginayat R. Bekzhanov, Bernd Lehmann and Dmitry Pusharovsky
The geological situation of Central Asia is dominated by a huge collage of Phanerozoic subduction-accretion complexes (Altaid orogenic system) in between the Urals to the west, Siberian platform to the north, Circum-Pacific orogenic belt and North China Craton to the east, and the Cenozoic Alpide mountain ranges to the south. This region hosts a number of major ore provinces with a wide spectrum of worldclass mineral deposits, of which precious metals, base metals, and rare metals stand out. The Symposium wants to contribute to the better understanding of the major controls on the formation of large ore provinces, and invites detailed mineralogical and geochemical studies as well as regional metallogenic studies and review papers on Central Asian ore deposits. Focus should be on modern research and new findings.

MRD-15 Symposium on "Ni-Cu-PGE sulphide deposits", convened by H. Papunen and A. Naldrett
The historic high prices of nickel and platinum-group metals (PGE) have aroused worldwide interest in the exploration and exploitation of magmatic Ni-Cu-PGE deposits, which are related to mafic-ultramafic intrusive rocks and ultramafic extrusives. Tectonic environments and magmatic evolution vary from one deposit type to the other, but a number of common rules control the formation of sulphides in magmatic systems and the distribution of metals between co-existing phases. Papers dealing with general aspects of magmatic Ni-Cu-PGE ore formation and descriptions of new discoveries are welcome. Nickel has long history in Fennoscandia: the metal was first discovered in Sweden 1756 and Norway produced the bulk of the world's nickel in the 19th century. Norwegian Caledonian deposits and the numerous deposits in the Svecofennian area of central Fennoscandia are examples of orogenic Ni-Cu

deposits; hence the papers on this Ni-Cu ore type worldwide would be welcome. Due to their high exploration potential in Fennoscandia Ni-Cu-PGE deposits related to mafic layered intrusions are also favoured in the session.

MRD-19 Symposium on "Uranium deposits", convened by M. Cuney, C. Caillat and O. Aikas
This symposium is devoted to oral and poster presentations on uranium ore deposits. Exploration activities for uranium deposits have boomed during these last three years because uranium prices have experienced a spectacular jump. A particular attention will be given here to the deposits from the Fennoscandian shield including Karelia and Kola Peninsula and from the Laurentia. The presentations may concern deposits or prospects, as well as whole belts and provinces, and describe their geological, mineralogical, geochemical, isotopic and tectonic characteristics, resource assessments and exploration potential. We are strongly encouraging the presentation of innovative genetic models. Comparative papers on the metallogeny of Fennoscandia with that of other similar crustal blocks from other parts of the world are also welcome. A joint participation to the symposium of geoscientists from geological surveys, consulting, exploration and mining companies together with those from academic institutions is expected.

-SEG-GSSA 2008 Meeting (July 5-9, 2008, Johannesburg) – SGA will have a free booth there and run a 2-days short course on diamonds – SGA activities coordinated by J. Moore and H. Frimmel.
-UNESCO-SEG-SGA XXVI Latin American Course on Metallogeny (2008, Bolivia) – F. Tornos.
-XIII Latin-American Geological Congress with XIV Peruvian Geological Congress (September 29-October 3, 2008 Lima, Peru).

LIST OF NEW SGA MEMBERS (AUGUST 10, 2007-APRIL 22, 2008)

55 Regular Members, 41 Student Members, and 4 Senior Members applied for membership from August 10, 2007 to April 22, 2008

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Website NEWS! SGA Mineral Deposit Archive

Georges Beaudoin, Chief Editor SGA website

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The SGA Mineral Deposit Archive is a repository of mineral deposit or district descriptions offered by SGA members to the scientific community. The SGA is distributing for free these geological summaries of important mineral deposits. The Mineral Deposit Archive offers an overview of the geological setting and geological features of important mineral deposits or districts of the world.

A Mineral Deposit Archive typically provides information 1) on the regional geology and geodynamic setting, 2) the geological and structural setting of the deposit/district, 3) typical features of ore and hostrocks using photographs of outcrops, samples or photomicrographs, 4) geochemistry of mineralization and hostrocks, 5) a review of current interpretations on the deposit/district metallogeny.

A Mineral Deposit Archive consist of a .pdf file comprising a set of slides and their presentation notes where each slide is accompanied by a text explaining the features in the slide.

To submit a proposal for a Mineral Deposit Archive, go to our website, www.e-sga.org, then navigate to >Publications>Mineral Deposit Archives where Instructions to Authors and templates to prepare your contribution can be downloaded.

New Mineral Deposit Archive: The Rammelsberg Deposit

Andreas Mueller

Andreas G. Müller (Maylands/Australia), andreas@conceptual.net.au

The Rammelsberg Cu-Zn-Pb sulfide-barite deposit in the Harz mountain range, northern Germany, was mined almost continuously for more than a 1000 years (968-1988 AD). The mine, located south of the medieval town centre of Goslar, is now a UNESCO world heritage site. The Rammelsberg is a type locality for shale-hosted, sedimentary-exhalative (SEDEX) Zn-Pb-Ag deposits but is unusual because of the high grade (27 Mt at 19% Zn, 9% Pb, 160 g/t Ag) and high copper-gold content (1% Cu, 0.5-1 g/t Au) of the sulfide ore.

The Harz is part of the unmetamorphosed slate belt of the Variscan orogen, formed in the Carboniferous during the collision of the paleo-continents Laurussia and Gondwana. The Rammelsberg deposit occurs in a NE-striking, overturned isoclinal syncline of Middle Devonian calcareous black shale, which is enclosed in sand-banded black shale and structurally overlain by Lower Devonian shelf sandstone. In the structural hanging wall but stratigraphic footwall of the sulfide ore, the black shale is altered to a hard quartz-chlorite-ankerite rock termed Kniest. The tightly folded Kniest wedge spans the entire width of the deposit. Pyrite, arsenopyrite and sphalerite disseminations in the Kniest, and sulfide mantos and spotted zones in the Lower Devonian sandstones define a broad zone of epigenetic footwall mineralization. The high-grade massive sulfide, located in the overturned fold limb beneath the Kniest is strongly deformed, recrystallized to a tectonic banding, and separated into two major lenses by reverse movement of the Kniest mass.

The massive sulfide grades laterally into a fringe of shale-banded ore (2 Mt at 6.5% Zn, 3.5% Pb) and is compositionally zoned, stratigraphically higher sulfide-gangue lenses spreading beyond the lower ones. The lowermost lens consists of low-grade pyrite + Fe-dolomite + quartz, overlain by pyrite + Mn-dolomite with layers of chalcopyrite and sphalerite, and blanketed by gold-rich chalcopyrite-sphalerite-galena ore containing 5-10% Fe-dolomite and barite. The uppermost and most extensive layer consists of silver-rich sphalerite-galena ore with intercalated barite beds. Another two beds of sulfide-poor barite occur stratigraphically above the massive sulfide, separated by about 30 m of black shale. Laterally, the sulfide ore grades into the dolomite-rich ore horizon, marked by beds of felsic tuff and traced in drill holes 3 km to the northwest. The ore horizon contains more metal (13 Mt Zn + Pb) than the deposit itself (7-8 Mt Zn + Pb) defining a huge sedimentary-exhalative dispersion halo. The Kniest feeder system, ore textures, and sulfur isotope ratios suggest vent-proximal deposition of sulfide muds in a brine pool by a reduced, H2S-bearing fluid discharging at about 300°C. Radiogenic lead and osmium isotope data indicate deep fluid circulation and metal leaching from the thick pile (>1000 m) of Lower Devonian shelf sandstones and from paragneisses in the continental crust below.

Paleogeographic reconstructions of the Middle Devonian show that the Rammelsberg deposit formed at the faulted margin of an euxinic basin, part of the basin-and-ridge topography of a marine back-arc rift located at the southern margin of the Laurussian continent. Spilitized alkali basalt and trachyte/rhyolite, associated with hematite ore and pyrite mineralization on volcanic ridges, indicate high heat-flow and extensive seawater circulation. The plate-tectonic setting is remarkably similar to that of the present northwest Pacific, where the Okinawa Trough and the Sea of Japan represent sediment-filled marine rift basins opened in continental crust behind active arc-trench systems. The Japanese Kuroko volcanogenic massive sulfide deposits display ore grades and sulfide-gangue zones almost identical to those of the Rammelsberg, providing a genetic link between VMS and SEDEX, the two main classes of syn-volcanic and syn-sedimentary sulfide deposits.

To download the Rammelsberg Mineral Deposit Archive go to www.e-sga.org > Publications/Mineral Deposit Archive/The Rammelsberg deposit

>>> page 1 Fingerprinting of conflict minerals: columbite-tantalite („coltan") ores

Fingerprinting – how does it work?

The focus of this study is to develop a methodological approach capable of distinguishing the origin of tantalum ore concentrates with the utmost probability. A number of factors must be taken into consideration. (1) The quality and composition of the coltan ore concentrates available on the market may vary considerably depending on the technical equipment for ore processing used and the experience of the miners. (2) The mineralogical and chemical composition of Ta-Nb ores is extremely complex, based on the wide range of minerals of the columbite-tantalite solid solution series (columbite-group minerals, CGM) and the ability of CGM to incorporate a large number of additional elements. Furthermore, coltan ores may also contain other tantalum-bearing mineral phases like tapiolite ($FeTa_2O_6$), wodginite [$(Mn,Sn,Fe,Ti,Li)Ta_2O_8$], ixiolite [$(Nb,Ta,Sn,Fe,Mn,Ti)_4O_8$], bismutotantalite [$Bi(Nb,Ta)O_4$], stibiotantalite [$Sb(Nb,Ta)O_4$], minerals of the pyrochlore group such as microlite [$(Ca,Na)_2Ta_2O_6(O,OH,F)$], and minerals of the complex fergusonite, aeschynite and euxenite mineral groups. Although confusing at first, these large variations in Ta-Nb minerals and ores also offer chances to develop a scheme of fingerprinting. (3) The analytical time and effort of the fingerprint have to be kept at a reasonable level.

The methodological approach summarized below is based on an extensive mineralogical-geochemical-geochronological database acquired and compiled for samples from the world's major coltan producing areas. Special attention is, however, directed to samples and concentrates from Ta-Nb-(Sn-Li) provinces in Africa (e.g. the Alto Ligonha Province in Mozambique; the Kivu Province in the DRC, Rwanda and Burundi; southern Ethiopia; southern and northern Namibia; Fig. 1). So far, more than 350 samples have been investigated (individual crystals, ore concentrates) with more than 60% from central and southern Africa. Most samples are from rare metal pegmatites and their eluvial and alluvial placers, especially from tin granites and rare metal granites of Archaean to Pan-African age.

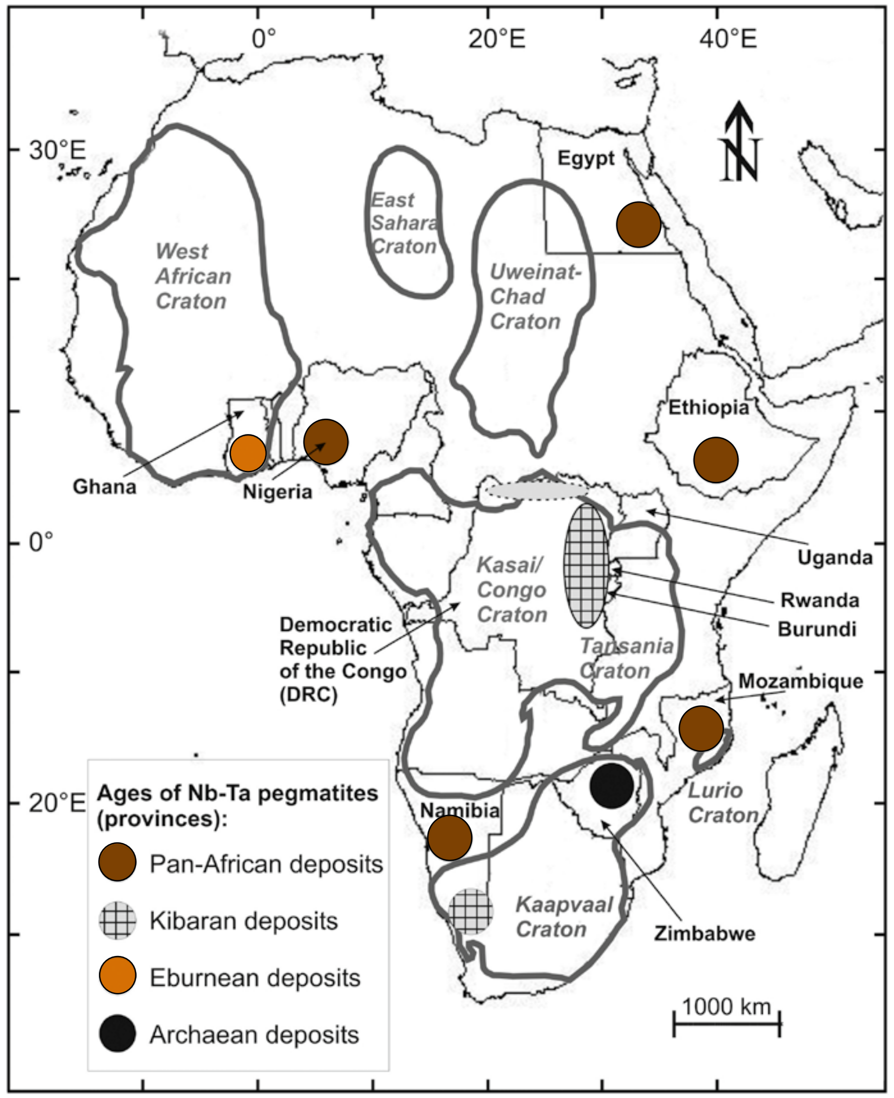

Figure 1: Location of important ore provinces with Nb-Ta mining activities in Africa. See text for discussion of the ages. The position of the Archaean to Palaeoproterozoic craton areas in Africa is added for illustration (modified from Schlüter, 2006).

Analytical Methods

Coltan concentrates are studied and analyzed in a step-by-step mode (Fig. 2). One goal is to characterize their complete mineralogical and chemical variability. Major and trace element concentrations are obtained by WD-X-ray fluorescence analysis on bulk samples. The mineralogical composition of bulk samples is determined by X-ray diffraction analysis; application of Rietveld refinement procedures allows estimates of modal proportions. Polished sections are prepared and investigated by reflected light microscopy, followed by quantitative mineralogical analysis using the Mineral Liberation Analysis software (MLA; JK Tech Pty Ltd, Australia) on a Quanta 600 FEG scanning electron microscope equipped with an EDAX module. For major and trace element analysis by magnetic sector ICP-MS and ICP-OES, one or several hand picked grains (5 to 100 mg of sample material) are ground and dissolved in a mixture of hydrofluoric acid 48% (20 – 200 µl) and nitric acid 65% (200 µl).

CGM and other Ta-Nb-bearing mineral phases are analyzed for major and trace elements by electron microprobe (CAMECA SX100) with detection limits of 200 ppm for trace elements. For determination of low levels of trace elements the Laser Ablation Inductively Coupled Plasma Mass Spectrometry technique is applied (LA ICP-MS; Nd:YAG laser - 266 nm New Wave Merchantek LUV; Agilent 7500i quadrupole ICP-MS; University of Würzburg). The spot size varies from 30 to 50 µm. The glass reference material NIST SRM 612 with the values of Pearce et al. (1997) is used for external calibration and calculation of trace elements by GLITTER Version 3.0 (Macquarie Research Ltd., 2000).

Uranium-lead dating is carried out both on crystal fragments using conventional thermal ionization mass spectrometry (TIMS)

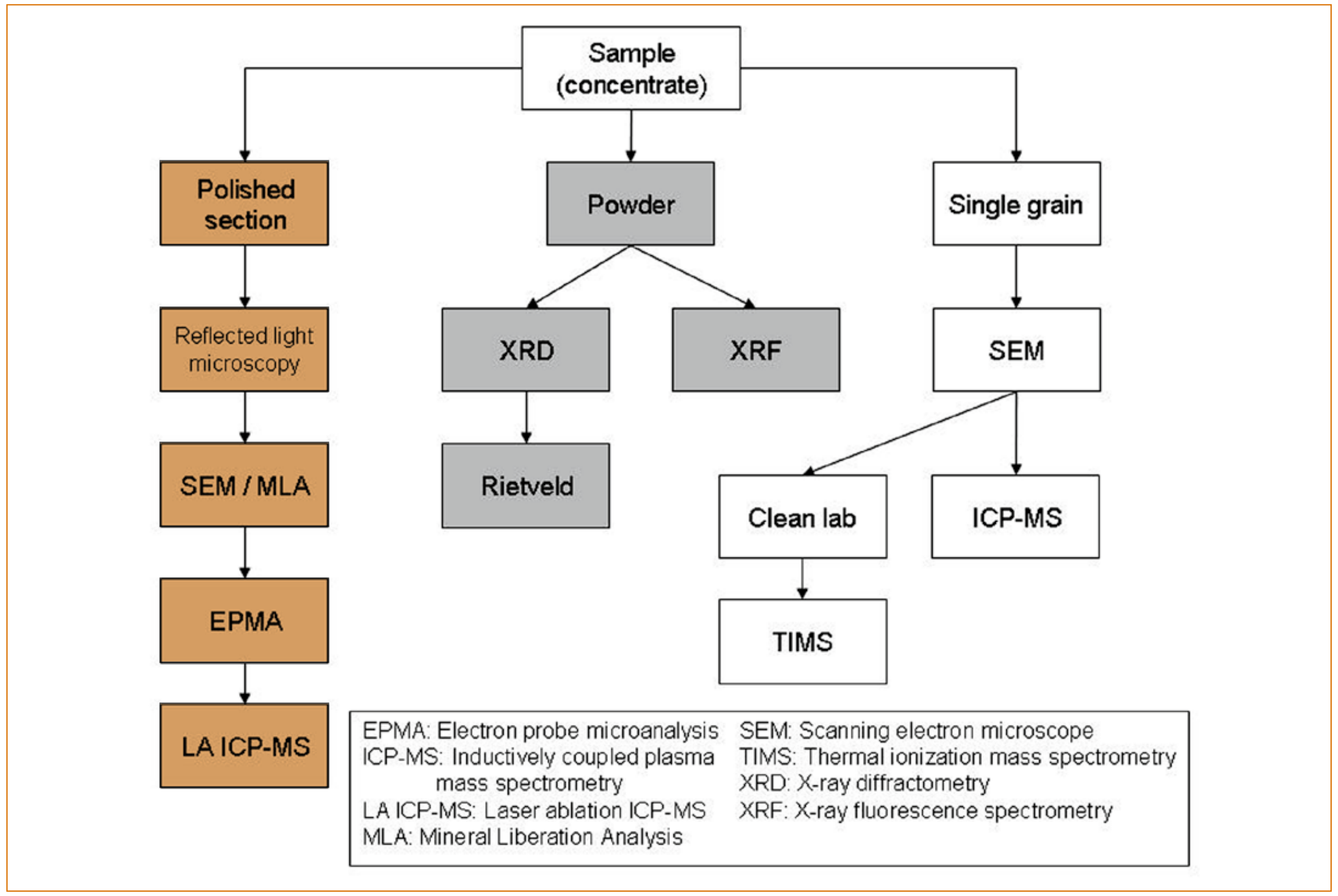

Figure 2: Methods used in the pilot study for characterization of the mineralogical parameters and geochemical compositions of Ta-Nb concentrates.

(BGR and University of Toronto), and in-situ analysis by LA ICP-MS at the University of Frankfurt using a Thermo-Finnigan Element II sector field ICP-MS coupled to a New Wave UP213 ultraviolet laser system. Spot size ranges from 30 to 60 µm. Raw data are corrected for background signal, common Pb, laser induced elemental fractionation, instrumental mass discrimination, and time-dependant elemental fractionation. Analytical reproducibility (GJ-1 reference standard) of $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ratios is usually better than 0.7%. No matrix dependent U/Pb fraction has been observed. The chemical procedures to separate U and Pb for TIMS analysis were adapted from Romer & Wright (1992) and Romer & Smeds (1994). U and Pb were measured in multi-collector mode on a MM354 (University of Toronto) and a Thermo-Finnigan Triton (BGR). Isoplot (Ludwig 2003) was

Table 1: Mean concentrations and estimated frequencies of minerals in coltan ore concentrates from pegmatite provinces in Africa as determined by MLA.

	defined critical concentration (in %)	DR Congo / Kibaran	mean	DR Congo / Eburnean	mean	Rwanda	mean	Mozambique	mean	Ethiopia	mean	Nigeria	mean
Bi-Tantalite	0.2		<0.01		<0.01		<0.01	xx	0.55		<0.01		<0.01
Cassiterite	1.0	xx	7.36		<0.01	xxx	16.80		<0.01		<0.01	xxx	7.80
Epidote	0.5		0.05		<0.01		<0.01		2.81		<0.01		<0.01
Fe-Columbite	5.0	xx	19.70	xx	4.82	xx	9.15		0.06		0.22	xxx	56.50
Fe-Tantalite	5.0	x	5.33	xxx	26.80	xx	10.90		0.14		0.10		0.29
Haematite	1.0	x	6.09		<0.01	x	4.69	xx	8.46	x	6.19	xx	2.05
Ilmenite	1.0	xx	4.53	xx	0.90		0.89	x	5.25		0.68	xxx	25.00
Microlite	0.5		0.04		0.03	(x)	2.95	xxx	8.68		0.14		<0.01
Mn-Columbite	5.0	xxx	18.30	xxx	20.00	xxx	15.30		0.97	xx	9.84		0.25
Mn-Tantalite	5.0	xxx	20.90	xxx	28.00	xxx	18.70	x	17.50	xxx	67.80		0.09
Monazite	0.2	x	0.27		<0.01		0.13	xx	6.56		0.03	xx	0.60
Rutile	0.5		0.43	xx	5.46		0.44		0.30		0.05		0.28
Scheelite	0.2		<0.01		<0.01		<0.01		<0.01		<0.01		<0.01
Tapiolite	1.0	x	4.81	xxx	11.40	(x)	2.77		0.06		<0.01		<0.01
U-Microlite	0.2		0.02		0.01	(x)	0.87	xxx	0.61	x	1.22		<0.01
Wodginite	0.5	(x)	1.64		<0.01	x	2.00		0.06		0.17		0.02
Zircon	0.2		0.27		0.05	xx	1.56	xx	0.44	x	0.23	xxx	1.36
Number of samples		20		2		30		7		5		2	

Legend: Fraction of samples with higher concentrations of a mineral than the defined critical concentration for the respective mineral phase: xxx - ~75-100% ; xx - about 50-75%; x - about 25-50%; (x) - individual samples with high concentations of the mineral occur

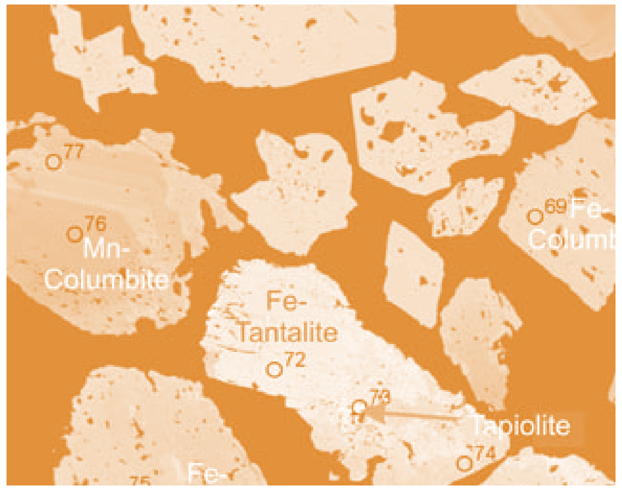

Figure 3: Back-scatter electron image of a columbite-tantalite concentrate from Rwanda displaying heterogeneous chemical composition shown by different grey values. Numbers refer to EPMA spots.

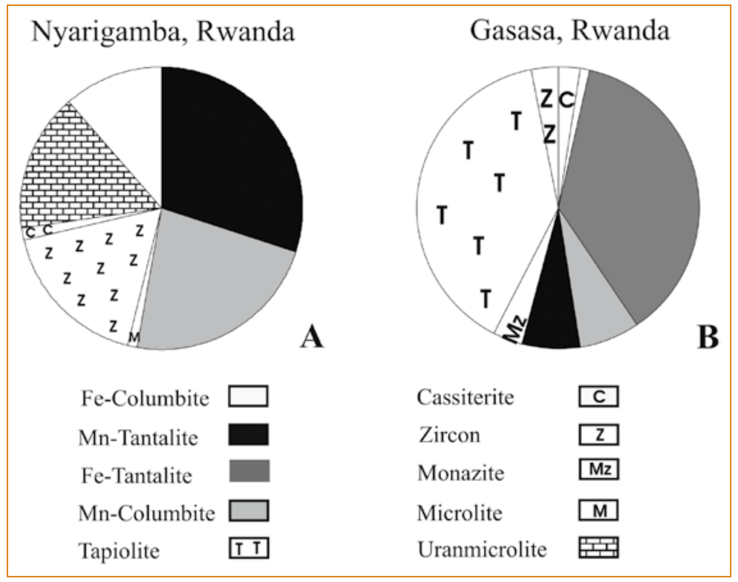

Figure 4: Modal concentration of minerals in coltan concentrates from Nyarigamba and Gasasa (Rwanda) as determined by MLA.

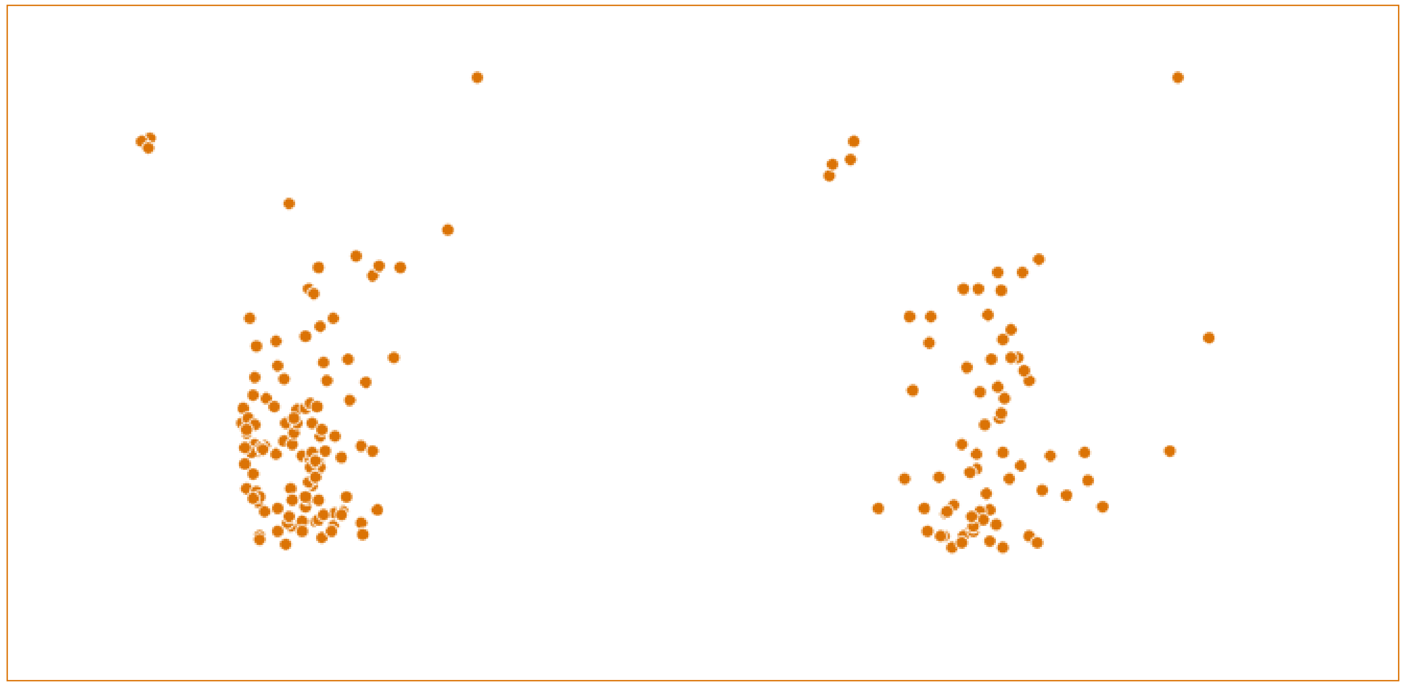

Figure 5: Variation in Mn-Fe and Ta-Nb ratios in single CGM and tapiolite grains from coltan concentrates of Kibaran-age pegmatites in Rwanda and the DR Congo; EPMA.

used for graphical presentation of U-Pb isotope data and age calculation.

Results

Mineralogical composition of the coltan concentrates

Coltan concentrates are usually dominated by CGM, but may also carry abundant additional accessory phases. These include pyrochlore-group minerals, tapiolite, wodginite, stibiotantalite, bismutotantalite, cassiterite, as well as silicate, phosphate and further oxide phases. Some of these minerals are characteristic of certain deposits (i.e., the Manono deposit in the Kibaran pegmatite province of the DRC), mining districts (i.e., the Gatumba district in the Kibaran pegmatite province of Rwanda), or pegmatite provinces (i.e., the Alto Ligonha Province, Mozambique). A fully quantitative set of data for each concentrate is part of a fingerprint to the location sampled. This includes mineral associations and their relative concentrations, grain sizes, and their intergrowth relationships (Fig. 3). Mean concentrations of ore minerals and accessory phases in coltan concentrates as well as their frequencies within African pegmatite provinces are summarized in Table 1 and illustrated in Fig. 4. The frequency of a mineral in a tantalum pegmatite province was evaluated by comparing the concentrates with a defined critical concentration, which was set to ~30% of the mean concentration of this mineral in all concentrates.

The detection of significant amounts of minerals typical of a deposit, district or province provides valuable hints to the origin of a concentrate. Bismutotantalite was so far only found in samples from Mozambique, wodginite frequently occurs only at locations in Rwanda and tapiolite seems to be indicative of concentrates from the DRC (especially from deposits with Eburnean ages - see below) and from Rwanda (Fig. 4b). The relative frequency of ferro- or manganocolumbites and/or -tantalites also

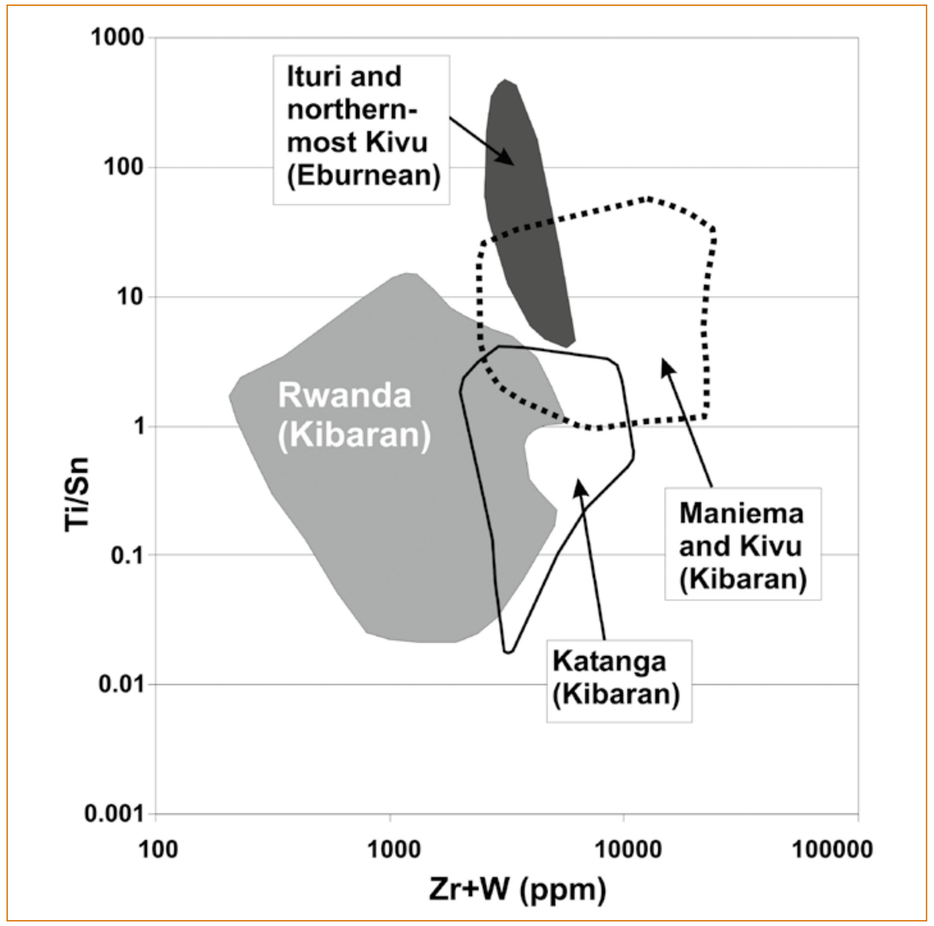

Figure 6: Ti/Sn versus Zr+W plot for samples from the Kivu and adjacent areas in the DR Congo and Rwanda. Laser ablation ICP-MS and magnetic sector ICP-MS and ICP-OES data both plot into the same fields for the respective provinces.

varies considerably (Table 1). Finally, the presence or absence of cassiterite, ilmenite and other minerals may give additional hints for identification of the origin (e.g. zircon, Fig. 4a).

Major and trace elements

The columbite group minerals (CGM) have the general formula AB_2O_6, in which the A position is dominated by Fe^{2+} und Mn^{2+} and, to a lesser extent, is occupied by Mg^{2+} and trivalent cations. The B position is dominated by Nb^{5+} und Ta^{5+}, but may also be occupied by Ti^{4+} und Sn^{4+}. The mechanisms of incorporation of trace elements (e.g. Ti, Sc, U, W, REE) into the CGM structure and the percentage of the substitutions relative to the total cations are described in a number of papers (e.g. Černý & Ercit, 1989; Ercit, 1994; Romer et al., 1996; Mulja et al., 1996; Wise et al., 1998). Coupled substitutions of $3M^{4+}$ for $M^{2+} + 2M^{5+}$, other mechanisms involving trivalent cations as well as the influence of the local redox conditions during CGM crystallization are discussed to explain cation incorporation (e.g. U^{4+} vs U^{6+}; Romer et al., 1996). For the crystal chemistry of other Nb and Ta minerals the reader is referred to Černý & Ercit (1989), Ercit et al. (1992) and Černý et al. (2004).

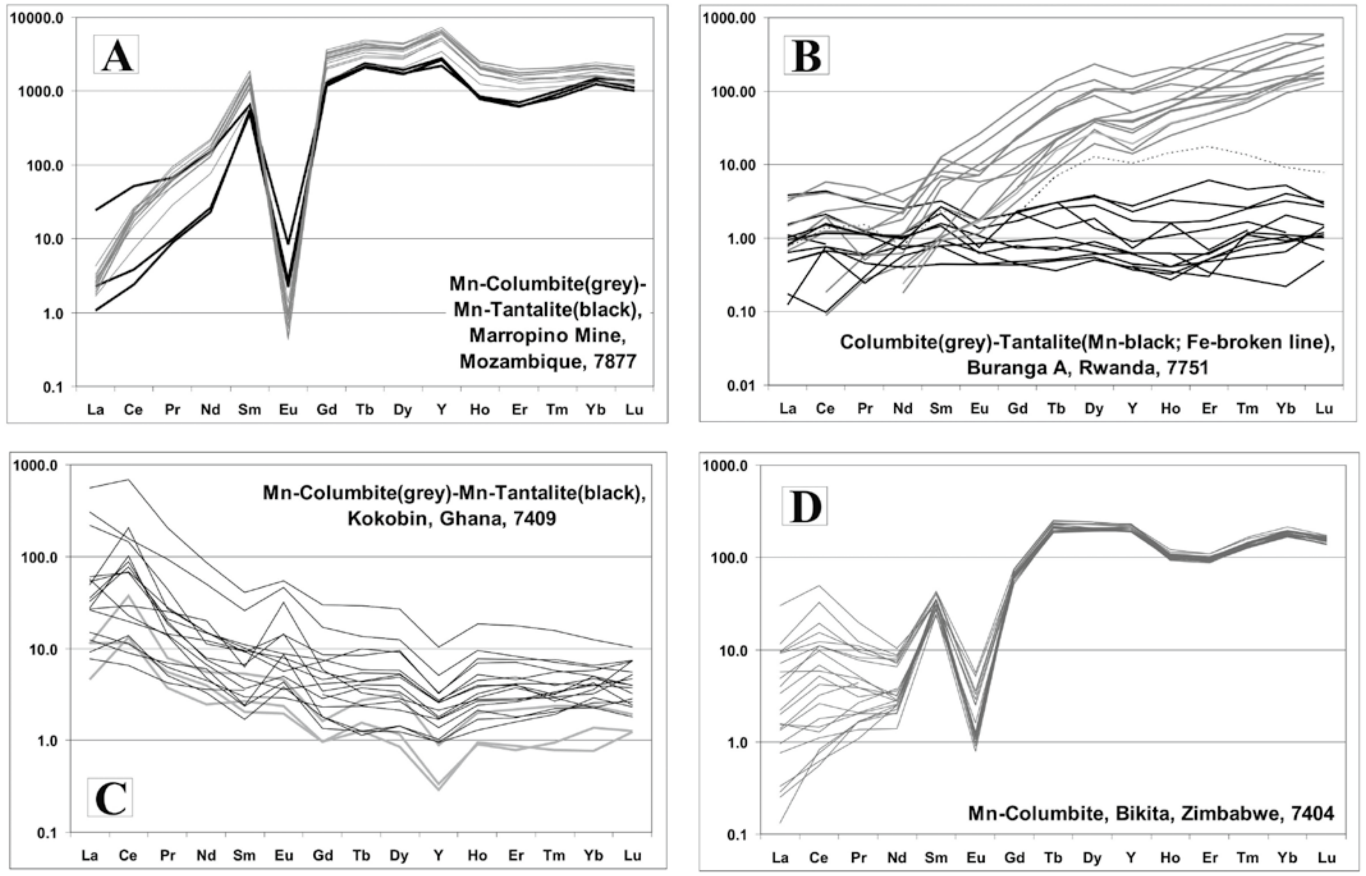

Figure 7: Concentrations of Y and REE in columbite-tantalite from ore concentrates. (A) Marropino (Mozambique), (B) Buranga (Rwanda), (C) Kokobin (Ghana) and (D) Bikita (Zimbabwe). LA ICP-MS data.

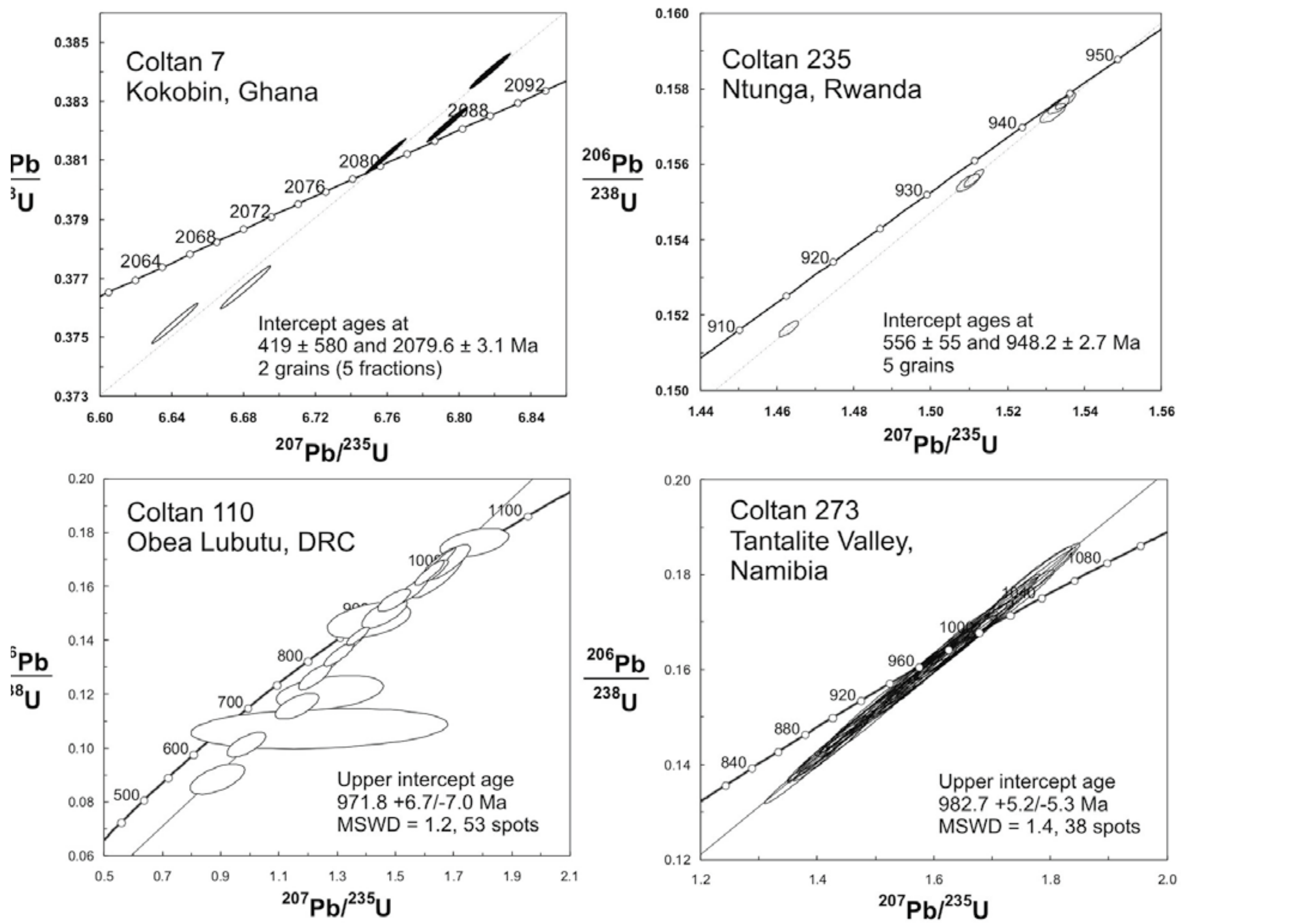

Figure 8: TIMS data for columbite-tantalite from Ghana and Rwanda; BGR laboratory (upper diagrams), and LA ICP-MS data for columbite-tantalite from Namibia and the DRC (lower diagrams).

In addition, mineral chemistry reflects intrinsic parameters of ore-forming processes, source, and host rock relationships. Fractionation and contamination in the pegmatite melt are recorded in chemical zoning (Fig. 3) and trace element patterns of the grains. The classical approach using microprobe analyses (EPMA) of the major elements permits a rough classification of the pegmatite type (Černý, 1989, 1992) but may also be used for further discrimination of deposits and districts. As an example, variations in Mn-Fe (XMn = 100*Mn/(Mn+Fe)) and Ta-Nb (XTa = 100*Ta/(Ta+Nb)) ratios in four coltan concentrates are shown in Figure 5. The overall compositional range within the concentrates is large, and follows distinct trends.

About 35 trace elements (including the rare earth elements) are determined by LA ICP-MS and/or ICP-MS. The concentrations of several trace elements (e.g. Mg, Sc, Ti, W, Hf) correlate well with those of the major elements within the studied minerals (Fe, Mn, Nb, Ta). Good correlations between trace elements are often present on a deposit or district scale. A number of trace elements and element ratios appear to be useful for differentiation of ore districts within larger pegmatite provinces (e.g. Bi, Ti, W, Zr, Zr/Hf, Ti/Sn; Fig. 6).

The chondrite-normalized REE distribution patterns vary significantly depending on the type of Ta-bearing mineral phases (columbite, tantalite, microlite) and in part also their major element compositions (e.g. the Fe and Mn concentrations in tantalites; Fig. 7b). Furthermore, ore concentrates from different pegmatite provinces can be separated using a number of criteria. Whereas some locations are characterized by low REE concentrations (e.g. Kenticha, Ethiopia), others are highly enriched, especially

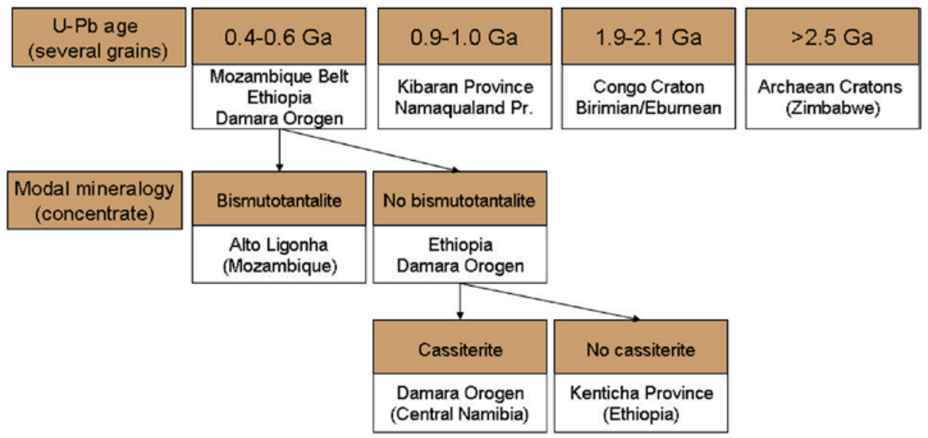

Figure 9: Flow chart exemplifying the discrimination of tantalum provinces from Africa based on age and modal mineralogy.

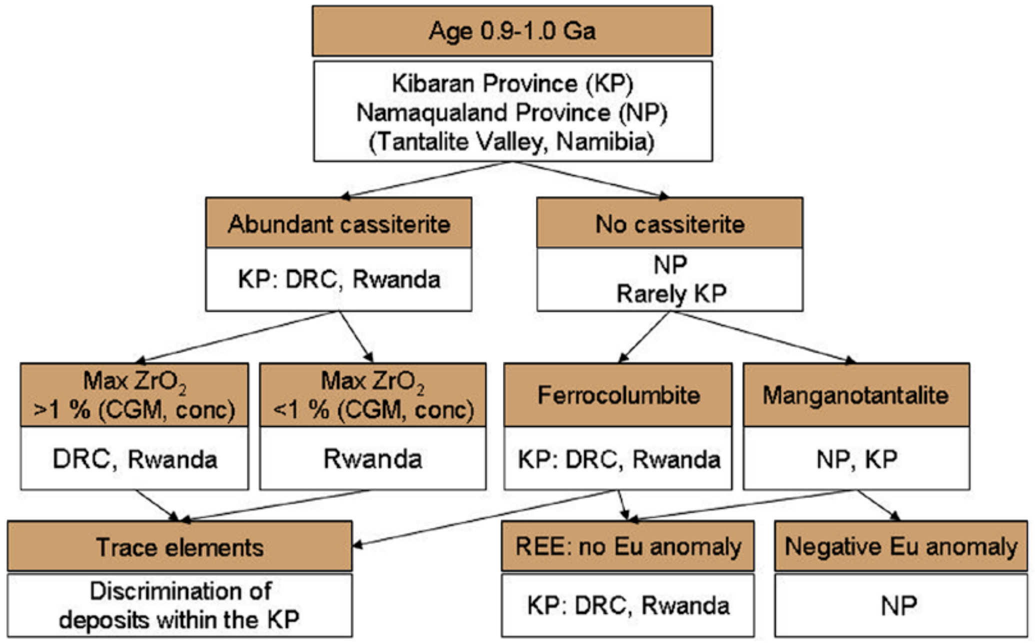

Figure 10: Flow chart exemplifying the discrimination of tantalum concentrates (0.9-1.0 Ga old) from central and southern Africa. CGM = columbite-group minerals; conc = concentrate.

in the MREE and/or HREE (Fig. 7a,b). Samples with Kibaran ages (Kivu province in the DRC and Rwanda) either show flat patterns for most tantalites (especially the manganotantalites; Fig. 7b), rising values from the LREE to the HREE (columbites; Fig. 7b) or trough-like patterns (not shown). Another important criterion for discrimination is the presence or absence and intensity of a Eu anomaly, which is negative in most cases (e.g. strongly negative for the concentrates from the Alto Ligonha Pegmatite Province in Mozambique (Fig. 7a) and from Zimbabwe (Fig. 7d)).

U-Pb dating

Relatively high concentrations of U, and low to very low amounts of common Pb in columbite-tantalite facilitate the application of the U-Pb system to date columbite-tantalite (Romer & Wright, 1992; Romer & Smeds, 1994). The results of TIMS and LA ICP-MS analyses in three different laboratories are consistent and prove that columbite-tantalite from Africa mostly yields reliable, concordant to slightly discordant ages (Fig. 8). In the concentrates analyzed so far from Africa, four age populations are evident: Archaean (>2.5 Ga), Palaeoproterozoic (2.1-1.9 Ga), early Neoproterozoic (1.0-0.9 Ga); late Neoproterozoic to early Palaeozoic (Pan-African; ca. 0.6-0.4 Ga). Multiple LA ICP-MS measurements and TIMS analysis of different fragments of submilligram size, both applied to single crystals, reveal isotopic homogeneity on the microscale. Age inheritance is not evident. Therefore, different age groups in mixed concentrates can be distinguished. The ages obtained for columbite-tantalite from Rwanda, Burundi and the DRC closely match a U-Pb emplacement age at 0.96 Ga obtained for slightly discordant columbite from the Kivuvu and Ruhembe pegmatites in Burundi (Romer & Lehmann, 1995), and are in general accordance with alternative ages of late Kibaran so-called "G4" tin granites.

Discussion

Without doubt, there are regional and local variations in the composition of coltan. These are due to differences in geological age and mineralogical and chemical composition of host pegmatites and their derivative heavy mineral concentrates. Zoned CGM crystals perfectly mimic the chemical evolution of pegmatitic melts (Lahti, 1987) and thus can be used as monitors of the fractionation stage of the source rocks. This allows distinction of locations even in districts and provinces of similar geological ages, similar host rocks or similar parent melt compositions. Each tantalum deposit has its unique characteristics. Therefore, a fingerprint of samples of suspect or unknown origin should be possible when a large and high-quality analytical data base is available.

Distinction of multiple sources would also be possible, if a complete fingerprint of the end members exists in the data base. U-Pb dating of several grains from a concentrate reveals if the CGM are cogenetic or are derived from different ore provinces. The investigation of special zoning patterns, as well as of trace elements within single CGM will also enable a decision on the presence of one or several populations.

In summary, the methods discussed in this paper are useful to fingerprint the origin of coltan. However, it takes appreciable analytical efforts and time to completely characterize a concentrate. In the future, methods will be developed that allow fast screening based on modal mineralogy and trace element and/or isotope geochemistry. We shall briefly discuss two possible applications of the method:

(1) Derivation of an unknown sample from an African tantalum province.

U-Pb ages of several grains in a concentrate point to one of four age groups that have been previously discussed. Further discrimination, i.e. between pegmatites of Pan-African age in the Alto Ligonha Province of Mozambique, the central Damara orogen (Namibia) and southern Ethiopia is possible using modal mineralogy (Fig. 9) or mineral composition.

(2) Regional discrimination within an identified age group.

Discriminating single deposits (pegmatites) within an age group is possible using combined information, but may be time-consuming, depending on the degree of required certainty. Based on modal mineralogy, and major and trace element data of CGM, a distinction of tantalum concentrates from Kibaran pegmatites within the DRC and Rwanda, and those of the Namaqualand Province in Namibia and South Africa, is demonstrated in Figure 10. Both yield identical geological ages (0.9-1.0 Ga). CGM in Kibaran pegmatites lack Eu anomalies, whereas those in Namaqualand pegmatites have prominent negative Eu anomalies, concomitant with a lack of cassiterite. Within the Kibaran, tantalum concentrates derived from areas west of the western branch of the East-African rift zone (Kivu, Maniema and Katanga provinces of the DRC) are distinguished by generally higher trace element concentrations (i.e., Zr, Hf, W, Sn) from those east of the rift in Rwanda and Burundi. The use of major and trace element information would enable discrimination of all deposits and occurrences studied so far.

Minerals are traded on an open global market. However, the public is increasingly aware of "clean" products, which are mined in an environmentally sound and socially tolerable way in countries which accept the rules of good governance. This is true especially for minerals imported from conflict areas. The worldwide implementation and acceptance of the "Kimberley Process" for diamonds prove that the international community is no longer willing to accept materials from conflict areas or materials produced under criminal circumstances. The analytical fingerprint of "coltan" may assist in the establishment of a control instrument in an envisaged certification of the production and trade chain of coltan. Modified techniques may be applied to other ores as well. Our working group will provide analytical fingerprinting methods for coltan ores, also in the framework of the project "Certified Trade Chains in the Minerals Sector" (CTC) recently in development at the BGR. It is of vital interest to the mining industry and promoted by political initiatives ("market transparency") to introduce and use the certification instruments now becoming available.

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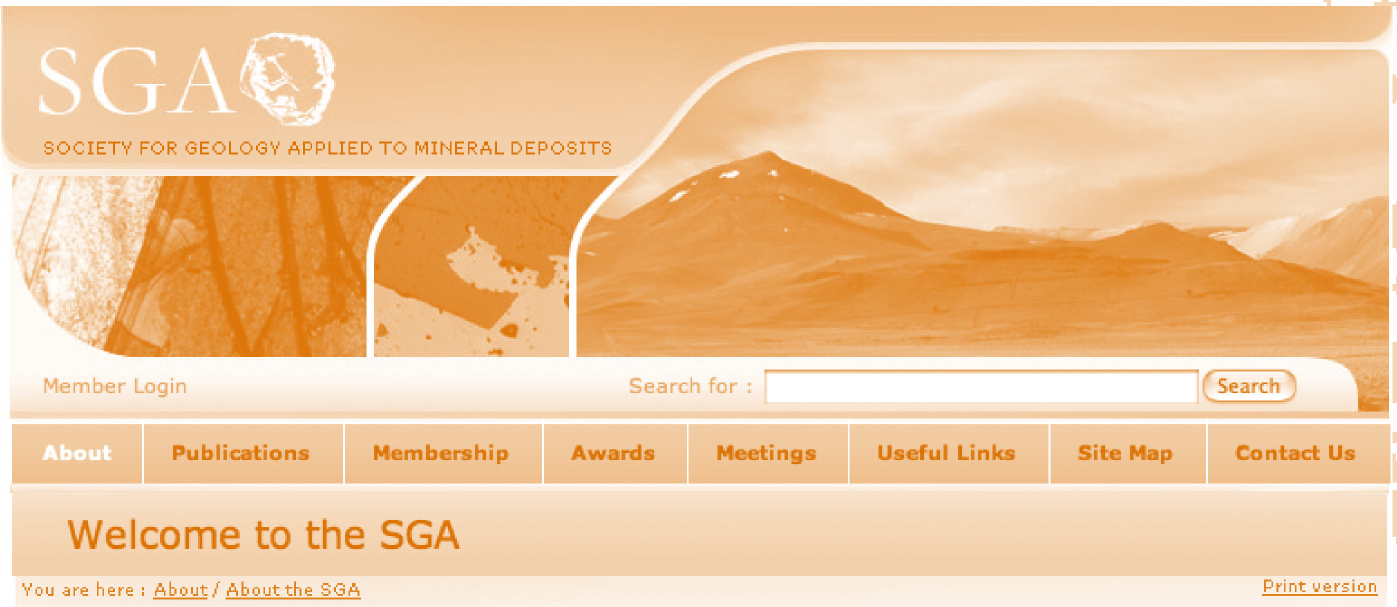
The SGA website

Georges Beaudoin, Chief Editor SGA website
Université Laval, Québec,Canada, georges.beaudoin@ggl.ulaval.ca

http://www.e-sga.org



>>> FORTHCOMING EVENTS <<<

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2008

June 29 – July 4
GORDON CONFERENCE ON GEOCHEMISTRY ON MINERAL DEPOSITS. Il Ciocco, Italy. www.grc.org/conferences.aspx?id=0000113, www.grc.org/sites.aspx?id=10&tab=0

July 5-9
SEG-GSSA 2008 incorporating GeoForum 2008: Resurgence on Economic Geology and the Minerals Industry in Africa: Joint Conference of The Geological Society of South Africa (GSSA) and Society of Economic Geologists (SEG). Misty Hills, Johannesburg, South Africa. E-mail info@seg-gssa2008.org, www.seg-gssa2008.org

July 13-18
18TH GOLDSCHMIDT 2008: From Sea to Sky. Vancouver, BC, Canada. http://www.goldschmidt2008.org

July 20-25
AUSTRALIAN EARTH SCIENCES CONVENTION 2008. Perth, Australia. http://www.gsa.org.au/events/calendar.html

August 5-14
33RD INTERNATIONAL GEOLOGICAL CONGRESS (IGC 2008): The Nordic Countries, Geoscience World Congress 2008, Oslo, Norway - Contact address: A. Solheim; e-mail: as@ngi.no; websites: www.ngu.no, www.33igc.org

August 6-8
III INTERNATIONAL CONFERENCE ON MINING INNOVATION-MININ 2008. Santiago, Chile. http://www.minin2008.com

August 18-22
GEOCHEMISTRY OF THE EARTH'S SURFACE 8: Joint Meeting of the IAGC, MinSoc and the Natural Hisory Museum. London, UK. http://www.minersoc.org/GES8.htm

August 18-24
IAVCEI 2008 General Assembly, Reykjavik, Iceland. E-mail armh@hi.is, http://www.iavcei.org/IAVCEI08_GA_ICELAND_CIRCULAR1.pdf

***August 18-29**
XXVII UNESCO-SEG-SGA Latin American Metallogeny Course, La Paz, Bolivia - Contact address: http://www.unige.ch/sciences/terre/mineral/seminars/lapaz08/lapaz08.html

***August 31-September 3**
AUSTRALASIAN INSTITUTE OF MINING AND METALLURGY, NEW ZEALAND BRANCH ANNUAL CONFERENCE. Wellington, New Zealand. Contact: http://www.ausimm.co.nz

***September 2-4**
7th ISAG, International Symposium on Andean Geodynamics, Nice, France - Contact: Jean-Yves Collot, UMR Géosciences Azur, Observatoire Océanologique, La Darse, B.P. 48, 06235 Villefranche-sur-Mer Cedex, France, phone: +33 (0)4 93 76 37 63; fax: +33 (0)4 93 76 37 66; e-mail: isag08@geoazur.unice.fr; website: http://www-geoazur.unice.fr/ISAG08/index.php

September 8-10
9th INTERNATIONAL CONGRESS FOR APPLIED MINERALOGY. Brisbane, Australia. http://www.icam2008.com/home/asp

September 8-14
MAGADAN GOLD FORUM: International Convention on "Gold of the North Pacific Rim". Magadan, Russia. http://gold-forum.neisri.ru

September 14-18
URANIUM MINING AND HYDROGEOLOGY V. Freiberg, Germany. http://www.geo.tu-freiberg.de/umh/index.htm

September 14-20
ANNUAL MEETING, ASSOCIATION OF ENVIRONMENTAL & ENGINEERING GEOLOGISTS (AEG). New Orleans, Louisiana, USA. http://www.aegweb.org/i4a/pages/index.cfm?pageid=3312

September 21-25
AIPG Annual Meeting and 3rd International Professional Geology Conference (American Association of Petroleum Geologists, American Institute of Professional Geologists). Flagstaff, Arizona, USA. William J. Siok, CPG, Executive Director AIPG, E-mail wsiok@aipg.org, http://www.aipg.org

September 23-28
THE XXIV INTERNATIONAL MINERAL PROCESSING CONGRESS (IMPC 2008). Beijing, China - Contact address: e-mail: impc2008@impc2008.org; website: http://www.impc2008.org/english/welcom.htm

October 5-8
GEOLOGICAL SOCIETY OF AMERICA 120TH ANNUAL MEETING, Houston, TX, USA - Contact address: GSA Meetings Department, P.O. Box 9140, Boulder, CO 80301-9140, USA; phone: +1 303 447 2020; fax: +1 303 447 0648; e-mail: meetings@geosociety.org; website: http://www.geosociety.org/meetings/index.htm

***October 17**
Terry Leach Symposium 2008: Th eapplication of Petrology to geological models in mineral exploration, Kirribilli Club, Milsons Point, Sydney, Australia - Contact: http://www.smedg.org.au

November 9-14
Society of Exploration Geophysicists (SEG) International Exposition, 78th Annual Meeting. Las Vegas, Nevada, USA. E-mail meetings@seg.org, http://www.seg.org/

December 1-5
EIGHTH INTERNATIONAL GEOSTATISTICS CONGRESS - GEOSTATS 2008. Santiago, Chile. E-mail info@geostats2008.com, http://www.geostats2008.com

December 15- 19
AMERICAN GEOPHYSICAL UNION FALL MEETING, San Francisco, CA, USA - Contact address: E. Terry, AGU Meetings Department, 2000 Florida Avenue, NW, Washington, DC 20009 USA; phone: +1 202 777 7335; fax: +1 202 328 0566; e-mail: meetinginfo@agu.org; website: http://www.agu.org/meetings

2009

May 24-27
GEOLOGICAL ASSOCIATION OF CANADA AND THE MINERALOGICAL ASSOCIATION OF CANADA (Joint Meeting), (GAC-MAC). Toronto, Canada. http://www.halifax2005.ca/

August 17-20
10TH BIENNIAL SGA MEETING. Townsville, Australia. http://www.e-sga.org/, www.ees.jcu.edu.au/SGA2009

August - September
7TH INTERNATIONAL MINING GEOLOGY CONFERENCE 2009. Queenstown, New Zealand. The AusIMM Events Department, Phone +61 3 9662 3166, Fax +61 3 9662 3662, E-mail concerence@ausimm.com.au, www.ausimm.com

August 30 – September 4
18TH INTERNATIONAL MASS SPECTROMETRY CONFERENCE. Bremen, Germany. http://www.imsc-bremen-2009.de/

September 3-7
AN INTERNATIONAL CONFERENCE ON THE CAMBRIAN EXPLOSION. Banff, Alberta, Canada. http://www.geology.utoronto.ca/facultycaron/Walcott2009.htm

October 5-9
INTERNATIONAL SYMPOSIUM ON THE

GEOLOGY OF THE BLACK SEA REGION II. Ankara, Turkey. E-mail uiab@mta.gov.tr, Phone-Fax +90-312-287 91 93 , http://www.mta.gov.tr/

October 18-21
GEOLOGICAL SOCIETY OF AMERICA, 121ST ANNUAL MEETING, Portland, Oregon, USA - Contact address: GSA Meetings Dept., P.O. Box 9140, Boulder, CO 80301-9140, USA; phone: +1 303 447 2020; fax: +1 303 447 1133; e-mail: meetings@geosociety.org; website: http://www.geosociety.org/meetings/index.htm

October 25-30
SOCIETY OF EXPLORATION GEOPHYSICISTS (SEG) INTERNATIONAL EXPOSITION & 79TH ANNUAL MEETING, Houston, Texas, USA - Contact address: e-mail: meetings@seg.org

2010

GEOLOGICAL ASSOCIATION OF CANADA AND THE MINERALOGICAL ASSOCIATION OF CANADA (Joint Meeting), (GAC-MAC): GeoCanada 2010, Calgary, Canada - Contact address: website: http://www.halifax2005.ca/

August 22-27
20th GENERAL MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION. Budapest, Hungary. http://www.univie.ac.at/Mineralogie/IMA_2010/

October 31-November 3
GEOLOGICAL SOCIETY OF AMERICA: 122ND ANNUAL MEETING, Denver, Colorado, USA - Contact address: GSA Meetings Department, P.O. Box 9140, Boulder, CO 80301-9140, USA; phone: +1 303 447 2020; fax: +1 303 447 0648; e-mail: meetings@geosociety.org; website: http://www.geosociety.org/meetings/index.htm

2011

May 25-27
GAC/MAC Annual Meeting. Ottawa, Canada. http://www.gac.ca/ANNMEET/annmeet.html

September 18-23
SOCIETY OF EXPLORATION GEOPHYSICISTS (SEG) International Exhibition and 81st Annual Meeting, San Antonio, Texas, USA. http://www.seg.org/meetings/, E-mail meetings@seg.org

October 9-12
GEOLOGICAL SOCIETY OF AMERICA: 123rd Annual Meeting. Minneapolis, Minnesota, USA. GSA Meetings Department, P.O. Box 9140, Boulder, CO 80301-9140, USA. Phone +1 303 447 2020, Fax: +1 303 447 0648, E-mail meetings@geosociety.org, http://www.geosociety.org/meetings/index.htm

SMEDG and AIG

TERRY LEACH SYMPOSIUM 2008

SMEDG and AIG are organising a one day symposium, to be held at the Kirribilli Club, Milsons Point, Sydney, Australia, on Friday, 17th October 2008, to honour Terry Leach's contribution to mineral exploration.

The Application of Petrology to ~Geological Models in Mineral Exploration~

Terry's clients and colleagues will present exploration case histories reflecting on the contributions he made to specific exploration and mining projects.

For more information and proposed speakers see **www.smedg.org.au**

There will be opportunities to mount Trade Displays and to sponsor the Symposium at various levels. Contact details on the SMEDG website

XXVII Latin American Metallogeny Course

August 18-29, 2008 - La Paz, Bolivia

Metallogenesis and Mineral Deposits of the Central Andes and the Precambrian of Bolivia

The 2008 edition of UNESCO-SEG-SGA Latin American Course on Metallogeny will be held at the Universidad Privada Boliviana (La Paz, Bolivia) from 18th to 29th August, 2008. The course is sponsored by the UNESCO, SEG, SGA and several mining companies and local institutions. The course is aimed at academic, mineral exploration, government and graduate student geologists, and provides an opportunity to update their skills and knowledge on mineral deposits with leading researchers in the field. The course comprises two parts. Part 1, a series of lectures which provide participants with a review on the geochemistry of hydrothermal processes (Mark Reed, University of Oregon), an update on the use of fluid inclusions (Larryn Diamond, University of Bern) and new applications of radiogenic isotopes and geochronology in the study of mineral deposits (Fernando Barra, University of Arizona). Following lectures will focus on the geology and genesis of Sn/W and diamond deposits (Bernd Lehmann, Technical University of Clausthal), Skarns and IOCG (Fernando Tornos, Instituto Geologico Minero de España), epithermal (Antonio Arribas, Newmont Mining Corp.) and orogenic gold deposits (Larryn Diamond). A full day of lectures is devoted to mineral deposits in Bolivia and entirely presented by local (national) instructors. Part 2 consists of mine visits to several deposit-types of Bolivia and will give an opportunity for students to apply and further discuss the concepts learned during the lectures.

More information about the course, the detailed program and application form are posted in the website http://www.unige.ch/sciences/terre/mineral/seminars/lapaz08/lapaz08.html

10th Biennial SGA Conference 2009, Townsville, Australia 17–20 August 2009

Jupiters Hotel and Casino and the Townsville Entertainment and Convention Centre

In conjunction with the Society for Geology Applied to Mineral Deposits, EGRU is delighted to invite all their members and others interested in economic geology to participate in the 2009 conference to be held in Townsville. This will be the next in the series of biennial international SGA meetings, the most recent of which in Athens, Beijing and Dublin have each attracted more than 500 participants.

Location of Townsville, home of the 10th Biennial SGA meeting in northern Queensland, Australia. Some of the more important mineral deposits in the region are shown along with proposed fieldtrip locations in Australia and New Zealand. 1.Base metal deposits of the Mount Isa region; 2. IOCG and Broken Hill-type deposits of the Cloncurry district 3. North Queensland gold and base metal deposits; 4. Environmental management of tropical North Queensland mine sites; 5. Iron ore deposits of the Hamersley district; 6.Archaean nickel deposits of Western Australia; 7. Archaean gold deposits of Western Australia; 8. Epithermal gold deposits and active hot springs in North Island, New Zealand; 9. Volcanology, alteration and VHMS deposits: A Tasmanian Perspective ; 10. Porphyry and epithermal systems of New South Wales.

Important updates soon on http://www.e-sga.org/ http://www.ees.jcu.edu.au/SGA2009/

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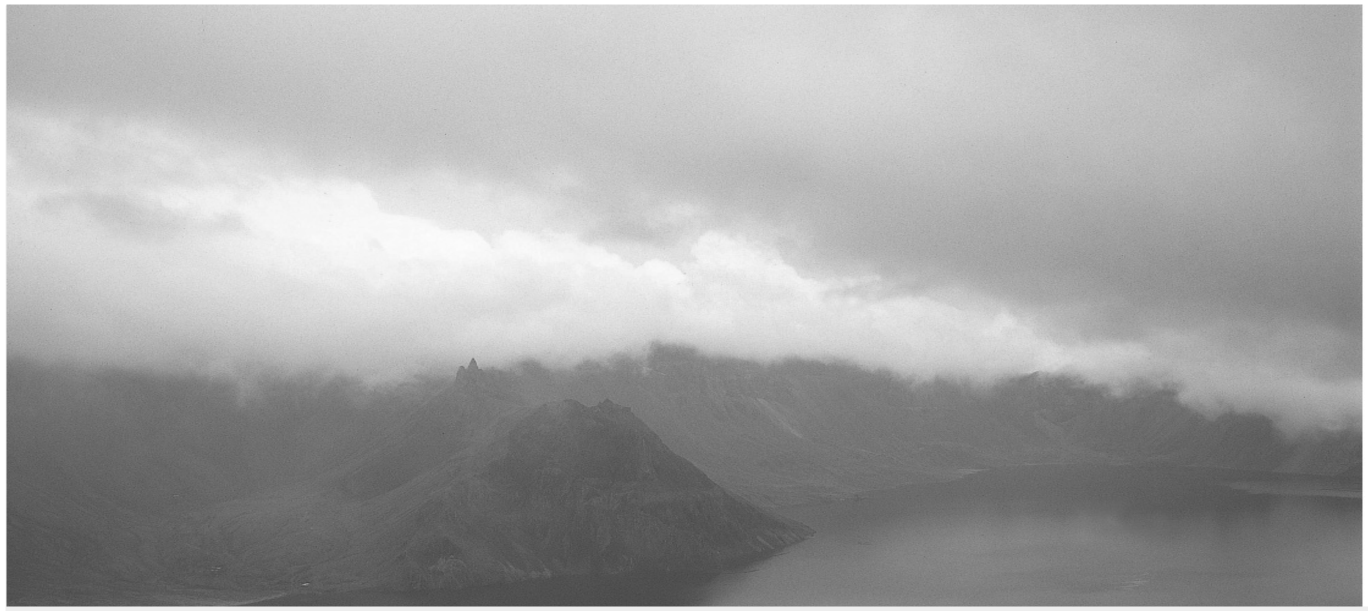

Mathematical Methods for Engineers and Geoscientists

O. Waelder, Technical University Dresden, Germany

This book introduces and explains classical and modern mathematical procedures as applied to the real problems confronting engineers and geoscientists. Written in a manner that is understandable for students across the breadth of their studies, it lays out the foundations for mastering difficult and sometimes confusing mathematical methods. Arithmetic examples and figures fully support this approach, while all important mathematical techniques are detailed. Derived from the author's long experience teaching courses in applied mathematics, it is based on the lectures, exercises and lessons she has used in her classes. Also, the explanations and discussions in the book are inspired by the most frequently-asked questions of students, graduates and professionals.

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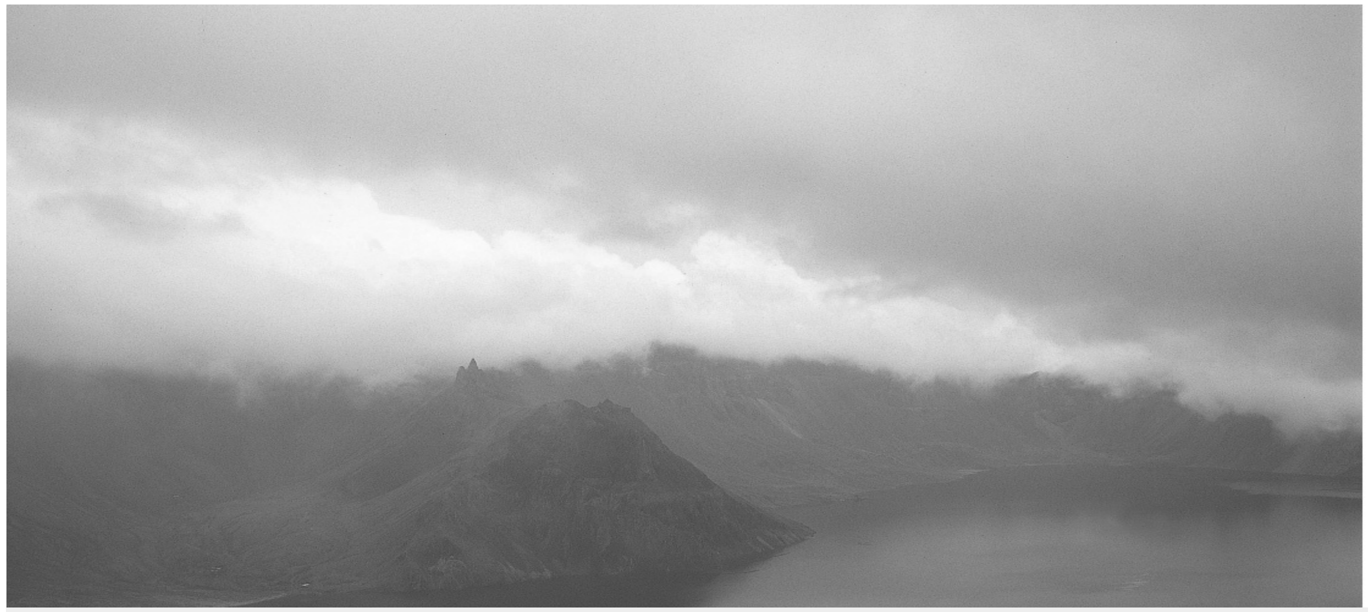

Geological Atlas of Africa

With Notes on Stratigraphy, Tectonics, Economic Geology, Geohazards, Geosites and Geoscientific Education of Each Country

T. Schlüter, UNESCO Nairobi, Kenya

This is the first attempt to summarise the geology of Africa by presenting it in an atlas and to synthesise the stratigraphy, tectonics, economic geology, geohazards, geosites and geoscientific education of each country and territory of the continent. Furthermore, the digitised geological maps (on the attached CD-ROM) are correlated and harmonised according to the current stratigraphic time table. The atlas aims to contribute to capacity building in African Earth Sciences and to initiate research and economic opportunities by providing a database of basic geological background information.

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Name	Place	Date	Signature
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