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FIELD TRIP GUIDEBOOK


Pirate Island - Paint Lake by Nancy-lynne Hughes

Field Trip Guidebook FT-C1 / Open File OF2013-8

The Tanco Mine: Geological Setting, Internal Zonation and Mineralogy of a World-Class Rare Element Pegmatite Deposit

T. Martins, P. Kremer and P. Vanstone

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Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, Winnipeg

May, 2013

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SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the GAC to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. Field trip safety is a shared responsibility. The GAC has a responsibility to take all reasonable care to provide for the safety of the participants on its field trips. Participants have a responsibility to give careful attention to safety-related matters and to conduct themselves with due regard to the safety of themselves and others while on the field trips.

Field trip participants should be aware that any geological fieldwork, including field trips, can present significant safety hazards. Foreseeable hazards of a general nature include inclement weather, slips and falls on uneven terrain, falling or rolling rock, insect bites or stings, animal encounters and flying rock from hammering. **The provision and use of appropriate personal protective equipment (e.g., rain gear, sunscreen, insect repellent, safety glasses, work gloves and sturdy boots) is the responsibility of each participant.** Each field trip vehicle will be equipped with a moderate sized first-aid kit, and the lead vehicle will carry a larger, more comprehensive kit of the type used by the Manitoba Geological Survey for remote field parties.

Participants should be prepared for the possibility of inclement weather. In Manitoba, the weather in May is highly unpredictable. The average daily temperature in Winnipeg is 12°C, with record extremes of 37°C and -11°C. North-central Manitoba (Thompson) has an average daily temperature of 7°C, with record extremes of 33°C and -18°C (*Source:* Environment Canada). Consequently, participants should be prepared for a wide range of temperature and weather conditions, and should plan to dress in layers. A full rain suit and warm sweater are essential. Gloves and a warm hat could prove invaluable if it is cold and wet, and a sunhat and sunscreen might be just as essential in the heat and sun.

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary or when recommended by the field trip leader, or upon personal identification of a hazard requiring PPE use. It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

Specific Hazards

Some of the stops on this field trip may require short hikes, in some cases over rough, rocky, uneven or wet terrain. Participants should be in good physical condition and accustomed to exercise. Sturdy footwear that provides ankle support is strongly recommended. Some participants may find a hiking stick a useful aid in walking safely. Steep outcrop surfaces require special care, especially after rain. Access to bush outcrops may require traverses across muddy or boggy areas; in some cases it may be necessary to cross small streams or ditches. Field trip leaders are responsible for identifying such stops and making participants aware well in advance if waterproof footwear is required. Field trip leaders will also ensure that participants do not go into areas for which their footwear is inadequate for safety. In all cases, field trip participants must stay with the group.

Other field trip stops are located adjacent to roads, some of which may be prone to fast-moving traffic. At these stops, participants should pay careful attention to oncoming traffic, which may be distracted by the field trip group. Participants should exit vehicles on the shoulder-side of the road, stay off roads when examining or photographing outcrops, and exercise extreme caution in crossing roads.

Road cuts or rock quarries also present specific hazards, and participants MUST behave appropriately for the safety of all. Participants must be aware of the danger from falling debris and should stay well back from overhanging cliffs or steep faces. Participants must stay clear of abrupt drop-offs at all times, stay with the field trip group, and follow instructions from leaders.

Participants are asked to refrain from hammering rock. It represents a significant hazard to the individual and other participants, and is in most cases unnecessary. Many stops on this field trip include outcrop with unusual features that should be preserved for future visitors. If a genuine reason exists for collecting a sample, please inform the field trip leader, and then make sure it is done safely and with concern for others, ideally after the main group has departed the outcrop.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, the introductions for specific localities make note of any specific safety concerns. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

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Introduction

The purpose of this field trip is to provide an opportunity for scientists and pegmatite enthusiasts to visit the Tanco pegmatite in Manitoba, Canada. The Tanco pegmatite is well known amongst the pegmatite community for its impressive size, unique and diversified mineralogy, high degree of fractionation, and productivity.

The Tanco pegmatite belongs to the Bernic Lake pegmatite group, part of the Cat Lake-Winnipeg River pegmatite district as defined by Černý *et al.* (1981). This pegmatite district consists of 9 distinct pegmatite groups, which exhibit wide variations in mineralogy and degree of fractionation. The pegmatites belonging to the Bernic Lake pegmatite group in particular, of which the world famous Tanco pegmatite is most noteworthy, have been studied previously by several authors (*e.g.* Černý *et al.*, 1981; Černý *et al.*, 1996; Bannatyne, 1985; Lenton, 1979; Anderson *et al.*, 1998; Kremer, 2010; van Lichtervelde *et al.*, 2006).

This field trip guidebook aims to provide general and up to date information on Tanco, and the regional geological framework of the Bird River greenstone belt. In depth work on the regional geology can be found in Gilbert, 2006; Gilbert, 2007; Gilbert *et al.*, 2008; and detailed information on the Tanco pegmatite including history (Manitoba Science, Technology, Energy and Mines, 1988a, b, c, d; Cabot Corporation, 2012), mineralogy, geochemistry, and structure can be found in numerous previous authors' work to which we refer you (*e.g.* Černý, 1972; London, 1985; Černý, 2005; Stilling *et al.*, 2006; van Lichtervelde *et al.*, 2007; 2008; Kremer, 2010).

It is not possible to predict the underground accessibility and exposures more than half a year in advance when this field trip guidebook is being put together. Thus the specific locations to visit will depend on mining operation in May 2013.

Field trip overview and itinerary

The Tanco pegmatite is located at Bernic Lake, close to the Manitoba-Ontario border and approximately 180 km NE of Winnipeg (Figure 1). It is easily accessible from Winnipeg by the provincial road system. Directions from Winnipeg are: North on MB-59, East on MB 317 E; Northeast on MB 313, to the junction with Provincial Road 313 and then North on Provincial Road 315 (indication for Tanco Mine). The closest communities are Lac du Bonnet (60 km) and Pinawa (75 km).

To better accommodate the schedule of the Tanco mine, it was decided to overnight at a proximal location. The itinerary for this field trip is as follow:

Friday, May 24th

19:00	Departure from Winnipeg Convention Centre
21:30	Arrival at Nopiming Lodge

Saturday, May 25th

6:30-7:15	Breakfast
7:30	Departure from Nopiming Lodge
8:15	Arrival at the Tanco Mine site (UTM 15U 0325850, 5589254)
9:00	Start visit underground
12:30-13:15	Lunch
13:15-15:15	Viewing of drill core
15:30	Departure from Tanco Mine and drive back to Winnipeg
17:45	Estimated arrival time at Winnipeg Convention Centre

History of the mine

What is today known as the Tanco pegmatite was discovered during a drilling program in the late 1920's exploring for

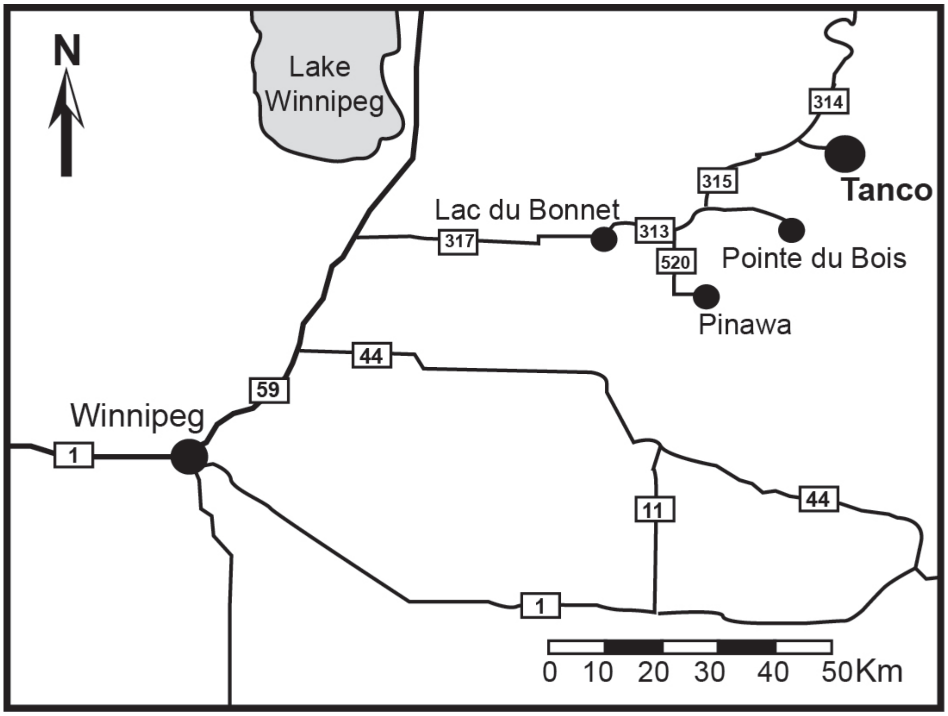

Figure 1: *Road system and geographical location of Tanco mine.*

tin. The pegmatite itself actually never outcrops and most of it is under Bernic Lake. By 1932 the Consolidated Tin Corporation, Limited (initially Jack Nutt Mines, Limited) abandoned the property and the claims eventually reverted to the Crown. From 1934 to 1940 there was minor open pit production of lithium ore from other pegmatites of the Bernic Lake pegmatite group (Buck, Pegli and Coe) and the area continued to be explored for tin.

In 1955, Montgary Petroleum Corporation Ltd. acquired the claims at Bernic Lake and drilled about 26,000 feet (almost 8 km) of drill core to explore the lithium potential of the pegmatite. Meanwhile road access started to be built as well as infrastructure to supply electricity to the mine site. By 1957, Montgary Petroleum was renamed Montgary Explorations Limited. At this time, a shaft was sunk to 334 feet (about 100 m), internal zonation of the pegmatite was defined by Hutchinson (1959) and pollucite was identified. But the year did not end well because operations were suspended for financial reasons and did not recommence until the spring of 1959.

In 1960, Chemalloy Minerals Limited (formerly Montgary Explorations Limited) carried out extensive drilling of the pegmatite to evaluate its lithium potential. Pollucite and amblygonite were mined at this time with 2 500 tons of the former being produced until 1961 when the operation was placed on care and maintenance.

It was not until 1966 that the mine once again saw some signs of life when the pegmatite was evaluated for its tantalum potential. After metallurgical testing, drilling and continuing development both at the surface and underground, the first tantalum concentrates started being produced, and the Tanco Grand Opening was held on September 8th, 1969. From this time up to 1977, the mine was also exporting pollucite to Russia.

In 1986, the commercial production of ceramic grade spodumene began and by 1988 Tanco was the major supplier for Corning Incorporated (the world leader in speciality glass and ceramics) for the production of Visionware and later Corningware. In 1993, Cabot Corporation of Boston acquired 100% interest in Tantalum Mining Corporation of Canada Limited. By 1995, construction of the plant to produce cesium formate brine had begun.

The mine has been and continues to be affected by market fluctuations driven by supply and demand as is the case for most commodities.

By 1998, the mine had milled 1 million tonnes of spodumene ore and by 2004 the mine had milled 4 million tonnes of tantalum ore. In 1999 the cesium formate plant was expanded to 700 barrels per month and in 2001, the plant underwent a further expansion in enable the manufacturing of conventional cesium chemicals.

In June 2009, tantalum operations were suspended indefinitely due to low prices. And later in the year, the same happened to the spodumene operations due to poor markets and low prices. In 2011, Tanco recommenced tantalum production and as of the present day, the operation is in production 24 hours, 7 days a week.

More detailed historic information including history of production, tonnage, and reserves of the Tanco mine throughout the years can be found in the Mineral Inventory Cards 187, 197, 209, and 213 (Manitoba Science, Technology, Energy and Mines, 1988a, b, c, d) as well as at the Cabot Corporation's website (www.cabot-corp.com).

Geological setting

The Tanco pegmatite is part of the Winnipeg River-Cat Lake pegmatite field. This vast pegmatite field has been subdivided into two pegmatite districts, and subsequently into several different pegmatite groups according to their mineralogy, geochemistry and location (Černý *et al.*, 1981). Table 1 presents a summary of the main characteristics of the different groups of pegmatites within the Cat Lake-Maskwa Lake district, and the Winnipeg River district.

The Bernic Lake pegmatite group (which includes the Tanco pegmatite) is located in the Bird River greenstone belt, which is part of the Archean Superior Province (Figure 2). The Bird River greenstone belt has been historically described as a large, synclinal keel (Trueman, 1980; Černý *et al.*, 1981); however, recent mapping by the Manitoba Geological Survey has led to a re-interpretation of the volcanostratigraphic framework of the belt (Gilbert, 2006; Gilbert, 2007; Gilbert *et al.*, 2008). The Bird River greenstone belt has been subdivided into two distinct (northern and southern) panels, both of which are composed of ca. 2.75-2.72 Ga juvenile, arc-type metavolcanic and associated metasedimentary rocks. These two panels are separated by the Booster Lake Formation (<2712 ± 17 Ma, Gilbert, 2006), a turbiditic sequence with classic Bouma-type features, penecontemporaneous with clastic sedimentary rocks of the Flanders Lake Formation (Gilbert, 2006).

Table 2 shows the sequence, age, and summarised description of the geological formations of the Bird River greenstone belt. A summary description of the rock units is presented below. The reader is referred to Gilbert (2006; 2007) and Gilbert *et al.* (2008) for detailed description of the geology of Bird River greenstone belt (Figure 3).

Southern Panel

Eaglenest Lake Formation

The Eaglenest Lake Formation is located in the southern panel of the Bird River greenstone belt along the Winnipeg River, and marks the southern margin of the supracrustal sequence (Černý *et al.*, 1981). It is a 600 m thick, south-facing sequence of greywacke-siltstone, turbiditic sediments. Rock types consist largely of crudely-bedded, steeply-dipping, poorly-sorted mafic volcaniclastic and pebbly wackes interbedded with quartzofeldspathic volcaniclastic sandstone (Trueman, 1980). The Eaglenest Lake Formation is in fault contact with the south panel MORB-type basalt (Černý *et al.*, 1981); the age relationship between the Eaglenest Lake Formation and the Southern MORB-type formation (see below) is thus uncertain.

Southern MORB-type formation

The Southern MORB-type basalt (previously referred to as the Lamprey Falls Formation) is an approximately 2.5 km

Table 1: Main pegmatite groups found in the Cat Lake-Winnipeg River pegmatite field (adapted and updated after Černý *et al.*, 1981)

Pegmatite district	Pegmatite group	Host rock/contacts	Morphology and structure	Enrichment	Other characteristics/comments
Winnipeg River	*Shatford Lake*	Sharp contacts with negligible biotization in metabasaltic rocks	Generally concordant with layering and foliation of the host rocks; exceptions dip at shallow angles or sub-horizontal	Be, Sn, Nb-Ta, Zr, REE, U, Th	Individual pegmatites are dyke-like or flat-lenticular; internal structural is highly variable; possibly NYF-type pegmatites
	Lac du Bonnet	Truncate layering and foliation of the host rocks	Dipping steeply or vertically	Li (P)	These pegmatites are not accessible at the present time
	Greer Lake	Pinching and swelling within the foliation	Concordant bodies	Be, Nb-Ta (Li)	Hydrothermal alteration or supergene weathering is virtually absent; largest dykes attain 400 m in length and 15 m in width
	Eaglenest Lake	Contacts with gneissic wall rocks are sharp	Fracture-filling bodies parallel-walled dykes without conspicuous pinch or swell undulations; locally offset by later transecting faults	Be	This group is poorly exposed. Internally, dykes are homogenous or slightly concentrically zoned; only one of the pegmatites carries beryl
	Axial Lake	Located in the body of subvolcanic Birse Lake granodiorite; sharp contacts	Concordant with the S_2 foliation; pinch and swell with attendant warping of the foliation	(Li?)	Individual bodies are flat-lenticular; internal structure is mostly irregular
	Birse Lake	Hosted by the Bernic Lake Formation; predominantly sharp contacts (only locally diffuse)	Essentially concordant to bedding, layering and foliation of host rocks; locally show offsets along joints (local en echelon patterns)	B (Be)	Shape of the pegmatites is irregular: contorted lenticular dykes predominate in the E; flat lenses and elongate dykes are typical in the W
	Rush Lake	Sharp contacts; minor biotization in metavolcanics; muscovite in metasedimentary wall rocks	Generally concordant to layering and foliation of country rocks; however some examples crosscut the foliation dipping both northward or eastward at shallow angles	Li, Rb, Cs, Be, Sn, Ta-Nb, B, P, F	Two textural and paragenetic types: very simple and generally unzoned; complex type with zoning and replacement veining
	Bernic Lake	Intrude extrusive and intrusive mafic metavolcanic rocks; boulbous and sharp contacts are observed	Varied attitudes from striking east-west to northeast, and dipping subhorizontal to near-vertical	Li, Rb, Cs, Be, Sn, Ta-Nb, B, P, F	Tanco is part of this group, together with other pegmatites with very different dimensions and rare metal enrichement
Cat Lake-Maskwa Lake	*Eagle-Irgon*	Biotite flakes occur sporadically along the contacts	Flat-lenticular with common pinch and swelll; essentially concordant, striking west-northwest to west and dipping nearly vertically	Li	Internal structure is homogeneous; variations in thickness are common; locally some pegmatites seem to be segmented along strike
	Beryl-Tourmaline	Intrudes the greenstone belt just north of Cat Lake	North striking and steeply dipping; crosscuts regional foliation at high angles	Be	Internal structure is heterogeneous and patchy; small bodies (< 15 m in length); maximum thickness ~20 cm; strong N-S lineament
	Cat Lake	Intrudes metabasaltic rocks; contacts are sharp, and locally sheared	Concordant to the foliation; dipping in near-vertical attitudes	Li, Be	Simple paragenesis; geochemically indicates moderate degree of fractionation
	Central Claim	Intrudes the Maskwa Lake quartz diorite	Sub-horizontal, tabular body ~4 m thick and extends ~850 m	Li, Be, Ta-Nb	Group represented by a single pegmatite; well zoned; primary zonation overprinted by metasomatism
	Maskwa Lake series	Contacts are generally sharp; holmquistite and biotite are found in the country rock	Pegmatites strike northeasterly, and dip subvertically; 3 diferent types: spodumene-bearing, petalite-bearing and pollucite-bearing	Li; Li, Rb; Cs, Ta-Nb (Be)	Closely-spaced swarm of pegmatites with geochemical similarities but paragenetically different.

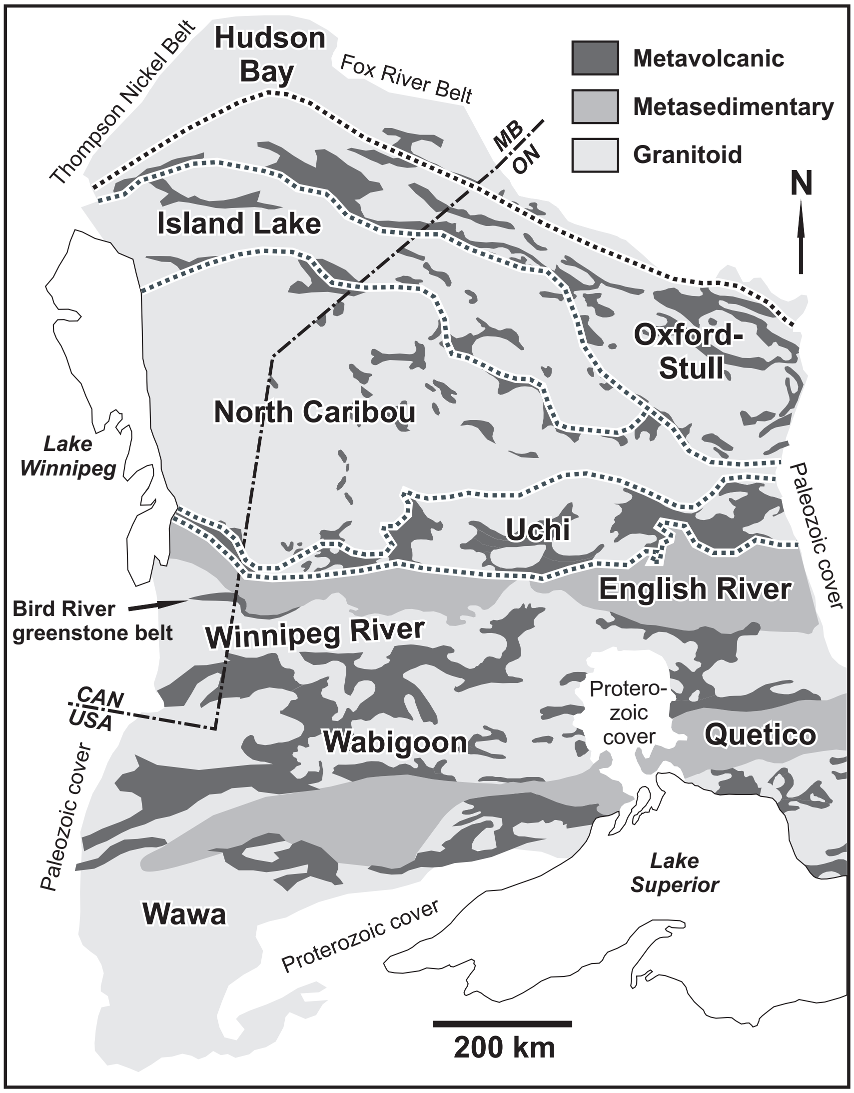

Figure 2: *Simplified geology of the northwestern Superior Province showing the location of the Bird River greenstone belt. Based on Percival* et al. *(2006) and Stott* et al. *(2010). (Abbreviations: MB- Manitoba, ON- Ontario, CAN- Canada.)*

thick, north-facing succession, composed primarily of aphyric pillowed basalt with MORB-like geochemical affinities, and related gabbro. Several units of chert-magnetite, banded iron formation occur locally within the Southern MORB-type basalt (Gilbert *et al.*, 2008). These units are up to 25 m thick and can be traced laterally for up to 500 m; they are locally associated with zones of pervasive alteration and associated pyrite-pyrrhotite-chalcopyrite mineralization.

The Southern MORB-type basalt is intruded by the sigmoidal-shaped Birse Lake granodiorite pluton. The Birse Lake granodiorite has been dated at 2723.2 ± 0.7 Ma, which represents a minimum age for volcanism. The Southern MORB-like basalt is interpreted to be derived from a juvenile mantle source associated with arc rifting, possibly penecontemporaneous with the onset of the crustal extension suggested for the overlying south panel arc-type sequence (Gilbert *et al.*, 2008).

South panel arc-type rocks

The south panel sequence consists of abundant tholeiitic, mafic to felsic volcanic rocks with geochemical profiles that are similar to modern arc rocks, but are distinct from those of arc-type rocks in the north panel. The host rocks to the pegmatites of the Bernic Lake group consist of volcanic flows and breccia of the Bernic Lake Formation as well as the Tanco gabbro, which hosts the Tanco pegmatite.

Bernic Lake Formation

The Bernic Lake Formation is approximately 2 km thick and 45 km along strike. It is composed primarily of massive to fragmental felsic and mafic to intermediate volcanic rocks, in which the mafic component increases towards the west. It is a fault-bounded sequence that occurs between the south panel MORB-type basalt to the south and the Booster Lake Formation to the north. A massive quartz- and feldspar-phyric dacite flow from the Bernic Lake Formation yielded a U-Pb age of 2724.6 ± 1 Ma (Gilbert *et al.*, 2008; Kremer, 2010). Reliable younging indicators in outcrop are rare, largely due to the effects of deformation, alteration, and recrystallization. The available data suggest the sequence is predominantly north-facing. This interpretation is supported by geochemical data from volcanic

Table 2: Geological formations of the Bird River greenstone belt (from Gilbert *et al.*, 2008)

Late intrusive rocks
Granite, pegmatite, granodiorite, tonalite, quartz diorite
Tanco pegmatite, 2640 ±7 Ma[1]; Marijane Lake pluton, 2645.6 ±1.3 Ma[2]; Lac du Bonnet Batholith, 2660 ±3 Ma[3]
Sedimentary rocks
Flanders Lake Formation, 2697 ±18 Ma[4]
Lithic arenite, polymictic conglomerate
** ***Fault, inferred*** ***
Booster Lake Formation, 2712 ±17 Ma[4]
Greywacke-siltstone turbidite, conglomerate
~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~
Intrusive rocks
MISCELLANEOUS INTRUSIONS
Gabbro, diorite, quartz-feldspar porphyry; granodiorite
Birse Lake pluton, 2723.2 ±0.7 Ma[2]; Maskwa Lake Batholith II, 2725 ±6 Ma[3]; Pointe du Bois Batholith, 2729 ±8.7 Ma[3]
Tanco gabbro, 2723.1 ±0.8 Ma[2]
Metavolcanic and metasedimentary rocks
Bernic Lake Formation 2724.6 ±1.1 Ma[2]
Basalt, andesite, dacite and rhyolite (massive to fragmental); related intrusive rocks and heterolithic volcanic fragmental rocks
Peterson Creek Formation, 2731.1 ±1 Ma[2]; 2734.6±3.1 Ma[6]
Dacite, rhyolite (massive to fragmental); felsic tuff and heterolithic felsic volcanic fragmental rocks
Diverse Arc Assemblage 2706 ±23 Ma[5]
Basalt, andesite, rhyolite, related fragmental and intrusive rocks; heterolithic volcanic fragmental rocks; greywacke-siltstone turbidite, chert, iron-formation; polymictic conglomerate (contains clasts derived from Bird River Sill)
~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~~
Intrusive rocks
Bird River Sill, 2744.7 ±5.2 Ma[3]; 2743.0±0.5 Ma[7]
Dunite, peridotite, picrite, anorthosite and gabbro
** ***Fault, inferred*** ***
Metavolcanic and metasedimentary rocks
MORB-type Volcanic rocks
Basalt (aphyric to plagioclase-phyric; locally pillowed, amygdaloidal or megacrystic); related volcanic breccia; oxide-facies iron formation
** ***Fault, inferred*** ***
Eaglenest Lake Formation
Greywacke-siltstone turbidite
Older intrusive rocks
Granodiorite, diorite (Maskwa Lake Batholith I, 2782 ±11 Ma[3], 2832.3±0.9Ma[2], 2852.8 ±1.1 Ma[2], 2844 ±12 Ma[3])

References for geochronological data: (1) Baadsgaard and Černý, 1993; (2) Gilbert *et al.*, 2008; (3) Wang, 1993; (4) Gilbert, 2006; (5) Gilbert, 2008; (6) Gilbert, unpublished data, 2007; (7) Scoates and Scotes (2013)

rocks of the Bernic Lake Formation, which become progressively more evolved northward (Gilbert *et al.*, 2008).

The Tanco gabbro

The Tanco gabbro is a gabbroic to dioritic body, on the northwest shore of Bernic Lake that is the host rock for the Tanco pegmatite. The gabbro is approximately 1.5 km wide, and extends laterally for about 3 km. It is a relatively homogenous, equigranular, medium- to coarse-grained intrusion, and contains rare pegmatitic phases (Kremer, 2010). Its margins are strongly deformed and are characterized by a well-defined, east-trending, steeply dipping foliation and local narrow, high-strain zones. A sample of pegmatitic gabbro from the northwestern shore of Bernic Lake yielded a U-Pb age of 2723.1 ± 0.8 Ma, contemporaneous with the age of volcanic rocks in the Bernic Lake Formation as well as the Birse Lake granodiorite, which intrudes the southern panel MORB-type basalt (Gilbert *et al.*, 2008; Kremer, 2010). These data suggest that the Birse Lake granodiorite, the Tanco gabbro, and volcanic rocks of the Bernic Lake Formation form a single subvolcanic to volcanic system (Kremer, 2010). Several smaller gabbro intrusions have been observed both in surface outcrop and in drill-core in the vicinity of Bernic Lake (Kremer, 2010).

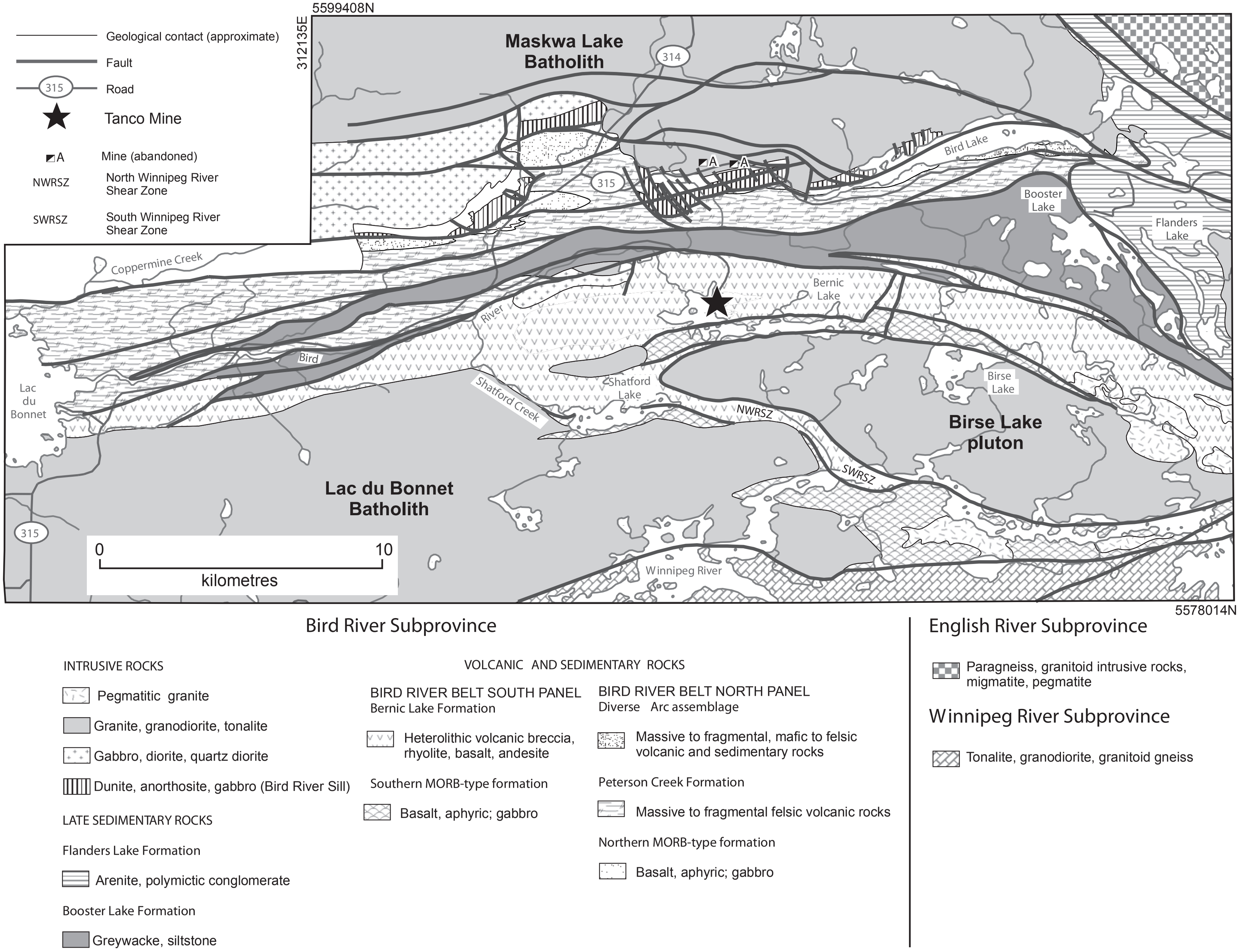

Figure 3: *Simplified geology of the Bird River greenstone belt including location of Bernic Lake and the Tanco mine. After Gilbert* et al. *(2008).*

Northern Panel

Northern MORB-type formation

The Northern MORB-type formation is 3 km wide, south facing, monoclinal sequence of pillowed basalt and, synvolcanic gabbro (locally associated with sulphide mineralization) and subordinate basalt flow-breccia and mafic tuff (Gilbert *et al.*, 2008). This formation is considered to be the oldest part of the supracrustal sequence and has an inferred maximum age of 2852.8 ± 1.1 Ma (age of the Maskwa Lake Batholith). The Northern-MORB type formation is interpreted to represent either a back-arc basin basalt, derived from a primitive, depleted mantle source, or a remnant of lithosphere from a former ocean basin (Gilbert *et al.*, 2008). The MORB-type basalt is intruded by the ca. 2743 ± 0.5 Ma Bird River Sill (Scoates and Scoates, 2013), a layered ultramafic intrusion with associated Ni-Cu deposits (at the former Maskwa–Dumbarton mines) as well as known chromite mineralization (Mealin, 2008).

North panel arc-type rocks

The north panel of arc-type rocks consists mostly of felsic to intermediate massive and fragmental volcanic rocks of cal-calkaline geochemical affinity, with minor basaltic flows and epiclastic rocks. The succession has been subdivided into the Peterson Creek Formation and the (inferred younger) volcano-sedimentary Diverse Arc assemblage (Gilbert *et al.*, 2008).

Peterson Creek Formation

The predominantly felsic volcanic and associated volcaniclastic rocks that characterize the Peterson Creek Formation extend east from the shore of Lac du Bonnet across the entire length of the belt to Bird Lake; these rocks have yielded U-Pb zircon dates of 2734.6 ±3.1 Ma (Gilbert, unpublished data, 2007) and 2731.1 ±1 Ma (Gilbert *et al.*, 2008). The main lithologies are felsic lapilli-crystal-tuff and aphyric to quartz- and feldspar-phyric dacite and rhyolite flows that locally grade into autoclastic breccia (Gilbert, 2007). The formation is widest (up to 3 km) in the western part of the Bird River belt, where the felsic volcanic rocks are apparently overlain by oxide-facies iron formation and an upper, 400 m sequence of intercalated turbidite, massive andesite, felsic volcanic breccia and tuff.

Diverse Arc Assemblage

The Diverse Arc assemblage, located south of the Northern MORB-type formation, has an estimated thickness of approximately 750 m (Gilbert, 2007). This assemblage consists of turbidite, and exhalative chert deposits, massive intermediate and felsic flows, as well as heterolithic tuff and volcanic breccia. Much of the clastic detritus has been redeposited as debris flows. This highly diverse sequence is overlain by a distinctive layer of polymictic conglomerate (~75 m thick) that is interpreted as the uppermost part of the Diverse Arc succession (Gilbert, *pers. comm., 2013.*). The conglomerate is unsorted and consist mainly of basalt and gabbro cobbles, with subordinate rhyolite, turbidite and chert clasts. Occasional clasts of anorthositic gabbro are lithologically identical to parts of the Bird River Sill and suggest that uplift and erosion of the underlying rocks, possibly related to extensional faulting, culminated in the unroofing and erosion of the sill, which subsequently shed gabbroic detritus into the adjacent sedimentary basin. The Diverse Arc assemblage is inferred to be in fault contact with the structurally underlying MORB-type basalt to the north. The Diverse Arc assemblage is interpreted to overlie the Peterson Creek Formation to the south along a conformable or disconformable contact (Gilbert *et al.*, 2008).

Sedimentary Rocks

Booster Lake Formation

The east trending, fault-bounded Booster Lake Formation, located at the structural boundary between the north and south panels of the Bird River greenstone belt, consists of a dominantly greywacke-mudstone turbidite sequence (Černý *et al.*, 1981; Gilbert, 2005) that extends laterally for approximately 44 km, (Gilbert, 2006; 2007). This formation displays many features of a classic Bouma sequence, such as graded bedding, rip-ups, and flame- and scour-structures that are abundant and provide reliable top determinations throughout much of the formation (Černý *et al.*, 1981; Gilbert, 2005). The maximum age of the Booster Lake Formation is best constrained by the youngest detrital zircon, which yielded a subconcordant age of 2712 ± 17 Ma (Gilbert, 2006).

Flanders Lake Formation

The Flanders Lake Formation occurs in the northeastern part of the Bird River greenstone belt, and delineates a major west- to northwest-trending anticline that refolds earlier fold structures identified in the Booster Lake Formation (Gilbert, 2007). The fluvial-alluvial deposits of the Flanders Lake Formation consist of cross-bedded, arkosic to pebbly sandstone, polymictic conglomerate, and their gneissic equivalents. The regional map pattern shows an angular relationship between the Flanders Lake Formation and the volcanic and sedimentary rocks of the Peterson Creek, Bernic Lake, and Booster Lake formations, suggesting an unconformable and/or faulted contact. Detrital zircon analyses indicate a maximum age of deposition of 2697 ± 18 Ma (Gilbert, 2006).

Structural Geology

Four episodes of deformation affect the Bernic Lake area that surrounds the Tanco pegmatite (defined by Kremer and Lin, 2006; Kremer, 2010). The deformational history and associated structural elements of the Bernic Lake area are summarized in Table 3.

Relationship of the Bernic Lake pegmatite group to structural elements

Pegmatite groups in the Cat Lake – Winnipeg River pegmatite field (including the Bernic Lake pegmatite group) show strong spatial associations with large, belt-scale D_2 fault structures that often mark structural boundaries between adjacent

Table 3: Summary of deformation history of the Bernic Lake area (after Kremer and Lin, 2006 and Kremer, 2010).

Deformation Event	Structural Generation	Associated Structural Elements	Inferred Shortening Axes
D_1	G_1	Rarely preserved isoclinal folds (F_1)	???
D_2	G_2	Penetrative flattening foliation (S_2)	NNE-SSW
		Down-dip stretching lineation (L_2)	
		Upright tight to isoclinal folds (F_2)	
		Formation-bounding (south-side-up) shear zones	
D_3	G_3	Spaced fracture cleavage (S_3)	NNW-SSE
		Reactivation of formation-bouding shear zones	
	G_4	Conjugate fracture set	NNW-SSE
D_4	G_5	Late, brittle overprint	

tectonostratigraphic formations, suggesting that these structures are important controls on the localization of pegmatitic melt.

East of Bernic Lake, pegmatites are emplaced in highly deformed metavolcanic rocks within or adjacent to the North Bernic Lake shear zone, which separates the Bernic Lake Formation from the Southern MORB-type Formation. These pegmatites crosscut the shear fabric (S_2), however still show evidence of ductile deformation in the form of folding and boudinage (Kremer and Lin, 2006; Kremer, 2010). This style of emplacement is in contrast to the Tanco pegmatite, which is hosted along a prominent conjugate fracture set within the Tanco gabbro. The Tanco pegmatite, however, also overprints D_2 fabric elements; the S_2 foliation and L_2 lineations in rafts of gabbro encapsulated in the pegmatite are rotated. Both shear-hosted and fracture-hosted pegmatites are crosscut by late, brittle fractures attributed to D_4 deformation.

According to mapping by Duguet *et al.* (2005; 2006), pulses of granitic magmatism throughout the belt are coeval with G_3 deformation. In the northeastern corner of the belt, this is most evident by the emplacement of the Marijane granite in the nose of a large F_3 fold structure. The Marijane granite has been dated (U-Pb on monazite) and yielded an age of 2645.6 ± 1.3 Ma, which is interpreted as the age of regional D_3 deformation (Duguet *et al.*, 2006; Gilbert *et al.*, 2008). Pegmatites from the Bernic Lake pegmatite group (both the Tanco pegmatite and a shear-hosted pegmatite from east of Bernic Lake) have also been dated, and returned interpreted emplacement ages of 2641 ± 3 Ma (Camacho *et al.*, 2012) and 2647.4 ± 1.0 Ma respectively (Gilbert *et al.*, 2008; Kremer, 2010), suggesting that pegmatite emplacement is synchronous with a belt-scale *ca.* 2650-2640 Ma tectonomagmatic event.

On the basis of lithological and structural mapping bolstered by detailed U-Pb analyses, a syn-D_3 model that incorporates the different styles of emplacement observed in the Bernic Lake pegmatite group has been proposed (Kremer, 2010). In mafic metavolcanic rocks, a prominent spaced S_3 cleavage consistently overprints the ubiquitous S_2 foliation. Along the north Bernic Lake shear zone, the S_2 foliation is reactivated as shear (C-) planes during (renewed) south-side-up dextral shearing, and in the Tanco gabbro, the response to D_3 strain is the formation of a conjugate fracture set. The different emplacement styles and spatial distributions observed in the pegmatites are therefore likely related to the heterogeneity in structural responses to D_3 strain by their respective host rocks. The reactivation of the north Bernic Lake shear zone would have created pathways through which granitic melt formed at depth could have ascended. In some instances (shear-hosted pegmatites) emplacement and crystallization occurred in low-strain dilational zones within the north Bernic Lake shear zone, and these pegmatites record increments of D_3 strain. In the case of the Tanco pegmatite, melt escaped along the adjacent fracture set(s) developed in the Tanco gabbro, which were “wrenched” open by movement along shear zones which bound the northern and southern margins of the gabbro. The difference in response to D_3 strain (from ductile G_3 structures to brittle G_4 structures) of the various lithologies is indicative of an emplacement depth of the Bernic Lake pegmatite group at or near the brittle-ductile transition.

The Tanco pegmatite

The Tanco pegmatite is a subhorizontal, essentially undeformed, bilobate, saddle-shaped body. The pegmatite is about 1520 m long, 1060 m wide, and up to ~100 m thick, thinning toward the edges. The volume of the pegmatite is ~21,850,000 m^3, the mass is ~57,430,000 tonnes, and its average density is 2.63 g/cm^3 (Stilling *et al.,* 2006). It occurs mostly under Bernic Lake, southeastern Manitoba and it is most known by drill core and underground mining exposures. This highly fractionated pegmatite of the lithium-cesium-tantalum (LCT) family has an extensive mineralogy (more than 100 listed minerals) and it is zoned (consists of nine internal zones). The outer zones are concentric, whereas the layered inner zones are segmented and locally complex in shape.

The Tanco pegmatite has fascinated renowned geoscientists, the entire pegmatite community and mineral collectors around the world. It is a big, highly complex and fractionated body that has been the target of scientific research since the 1970’s. The most recent general review on Tanco pegmatite was done by Černý in 2005. Since then, new data has been published on bulk rock geochemistry (Stilling *et al.*, 2006), new mineral discoveries (Cooper *et al.*, 2009), mineral and mineralization studies (*e.g.* van Lichtervelde *et al.*, 2006; 2007; 2008) and structural studies (Kremer and Lin, 2006; Kremer 2010).

Zoning of the Tanco pegmatite

The Tanco pegmatite is a classic example of a complexly zoned pegmatite (Figure 4a). In the various zones it is possible to find the different mineral associations including the ones of economic interest: Ta, Li, and Cs. The mineralogy and petrography of the different zones has been described in detail by several authors (*e.g.* Černý, 2005; Černý *et al.*, 1996; 1998; Stilling *et al.*, 2006). A description of the zonation of the Tanco pegmatite is given in Table 4 which summarizes the mineralogy, texture and geochemistry that can be found for of each zone. Figure 4b and 4c illustrate the wall zone and its albite-quartz assemblage, and tantalum mineralization from the 511 zone, respectively.

Mineralogy

Mineralogy from Tanco is very extensive with more than 100 minerals listed in the literature (*e.g.* Černý *et al.,* 1996; 1998). Tanco has also yielded holotypes of four new minerals: černýte (Kissin *et al,.* 1978), tancoite (Ramik *et al,.* 1980), diomignite (London *et al.,* 1987), titanowodginite (Ercit *et al.,* 1992), Ercitite (Fransolet *et al.,* 2000), Groatite (Cooper *et al.,* 2009). An updated listing of the mineral occurrences at Tanco can be found in Table 5. Detailed descriptions of the different minerals, including mineral geochemistry and evolution, can be found in the above mentioned publications and several others (*e.g.* Černý *et al.*, 1996; 1998; Černý, 2005).

Geochemistry

The Tanco pegmatite is a mineralized, peraluminous pegmatite body, belonging to the LCT family, Rare-Element-Li subclass, complex type, subtype petalite (updated classification by Černý and Ercit, 2005). The most recent work on bulk geochemistry of Tanco was published by Stilling *et al.* (2006). In their work a 3D computer model representation of the pegmatite was used to help with the calculation of volumes and compositions of individual zones and of the whole pegmatite. The work was based on 102 km of 1355 drill-hole intersections, underground observations, measured and estimated mineral modes of the zones, zone-specific compositions and mineral densities, and ore grades.

The bulk mode of Tanco is close to a muscovite granite, with the exception of 8 wt.% petalite, 2.8 wt.% lithian micas, and 1 wt.% primary spodumene. The contents of all other accessory silicates and phosphates are only in tenths of a wt.%, and minerals of the high-field-strength elements account for mere hundredths to thousandths of a wt.% each. Accordingly, the bulk chemical composition of the pegmatite corresponds to that of a peraluminous, moderately silicic, high-phosphorus, Na>K granite, with enrichment in Li, Rb, Cs and F; moderate contents of Tl, Be, B, Ga, Sn, Nb and Ta, and remarkable depletion in Fe, Mn, Mg, Ca, Ba, Sc, Ti and Zr. A very high degree of fractionation is shown for the bulk pegmatite by the values K/Rb 4.7, K/Cs 9.3, Rb/Cs 2.0, Rb/Tl 137, Fe/Mn 0.63, Mg/Li 0.02, Al/Ga 917, Zr/Hf 2.6, Zr/Sn 0.21 and Nb/Ta 0.19 (Stilling *et al.*, 2006).

The LCT mineralization at Tanco

Tanco was at one time a major producer of spodumene concentrates, however, spodumene ore is not currently being mined and these products are no longer produced at the mine. Cesium is extracted from the pollucite and then through a number of chemical reactions, is combined to form cesium formate (see details and references in the Economic aspects section below).

The Tanco Mine is the sole tantalum minerals producer in Canada. Given the recent increasing emphasis on sourcing this product outside of conflict areas (*e.g.* Democratic Republic of Congo) understanding the tantalum mineralization of the Tanco pegmatite is of high importance. Recent studies in this area by van Lichtervelde and co-authors gave an insight on the origins for tantalum mineralization in the Tanco pegmatite (van Lichtervelde *et al.* 2006; 2007; 2008).

Van Lichervelde *et al.* (2006) found that the role of metagabbro rafts (part of Tanco's pegmatite country rock) has no evident chemical influence on the crystallisation of columbite-group minerals in the pegmatite. Abnormally high concentrations of tantalum are spatially associated with metagabbro rafts in the mine but their influence on the tantalum mineralization is more physical than chemical. The authors concluded that these rafts might have separated distinct pegmatite cells that have evolved independently of the whole pegmatite body.

Textural and geochemical studies of the Nb-Ta oxides from the Tanco Lower pegmatite provided evidence for the tantalum mineralization being of magmatic origin. Interaction of fluids is not discarded but only given an indirect role in delivering minor elements such as Fe, Mn or Ca (van Lichtervelde *et al.* 2007).

Economic aspects (economic mineralogy, mining, milling, products and uses)

Most of the information regarding economic aspects of Tanco presented in this guidebook is based on information compiled by Tanco mine geologists and other personnel (Vanstone *et al.* 2005).

Mining

The Tanco pegmatite is situated about 60 m below Bernic Lake, and is accessible from surface either via a shaft or via a 400 m ramp with 20% decline.

Mining is carried out using the room and pillar method (Figure 4d) mainly because the mine is shallow (which contributes to lower inherent ground stresses and generally stable ground conditions) and its diverse mineralogy. The initial pillar design was to have 16 m square pillars, with mining rooms also at 16 m wide. As mining progressed, ongoing rock mechanics studies showed that the rooms could be increased to 22 m, without excessively loading the pillars. Pillar reduction has now been done successfully throughout the mine.

Two-boom hydraulic jumbos perform all drilling for drifts, slashes, benches and arches. During the initial top slice development, the roof is carefully arched, utilizing smooth blasting techniques. The roof arches allow residual ground stresses to be redirected to the post pillars. Rock bolting is rarely required

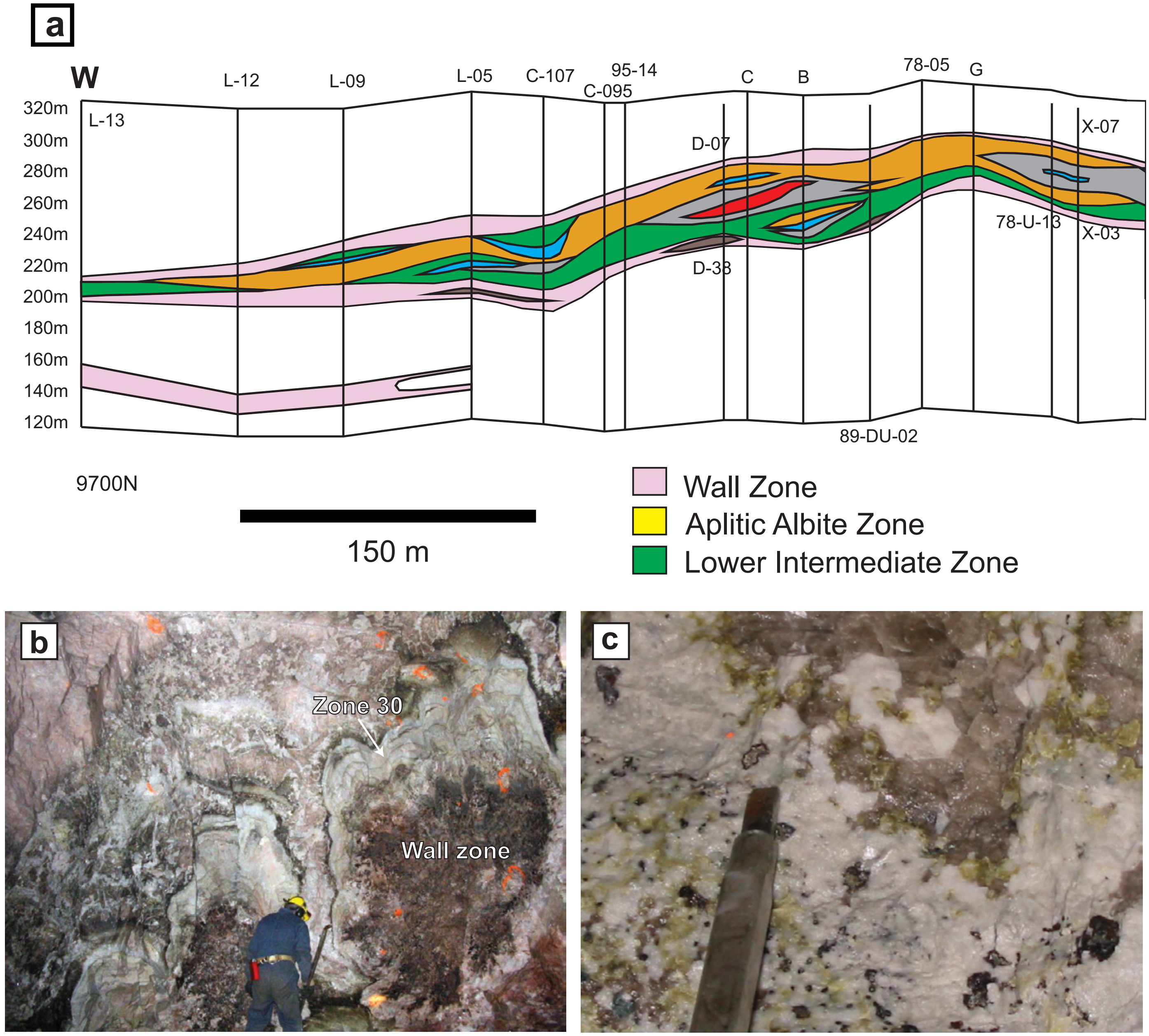

***Figure 4:** Cross section of the pegmatite and underground photos at Tanco mine (with permission of Cabot Corporation). **a)** East-West fence section 9700 N through the Tanco pegmatite (looking North) showing its complex internal zoning (modified from Černý, 2005); **b)** Wall zone in contact with a saccharoidal albite-quartz assemblage (located in the Beryl Pit area near the base of Zone 30). The darker patches in the lower portion of the picture (in front of and behind the person) are Wall Zone (Zone 20). A layer of banded pale blue saccharoidal albite (Zone 30) is draped over the Wall Zone. This albite is in contact with quartz (the smokey fringe on the albite-quartz contact is consistent with tantalum minerals collecting on this contact). The green colour which is most noticeable in the left part of the photo is due to the presence of the green lithian mica; **c)** Tantalum mineralization in an albite-beryl-mica assemblage from the high-grade tantalum 511-Zone (Beryl Pit area); the scaling bar chisel end is 25.5 cm.*

because ground stress in the Tanco mine is considered low, relative to other hard rock mines.

At Tanco, the roof of mature mine workings may often average 20 m above the working levels below, and in places, may reach >30 m. These high backs are carefully monitored throughout mining operations, utilizing custom designed aerial lift devices (referred to as Giraffes, Figure 4e). Where suited, mining is carried out, utilizing a single boom Simba long-hole drill. The longhole method was the primary method by which the oversized pillars were reduced. The broken ore is transported utilizing different sizes load-haul-dumps, mobile, front-end loader units, and a 20 ton truck to various ore-passes, which are located throughout the mine.

The ore is broken on grizzlies (metal grates at the top of the ore pass), utilizing either mobile or stationary hydraulic rock breakers. The ore is then passed to an underlying tramming

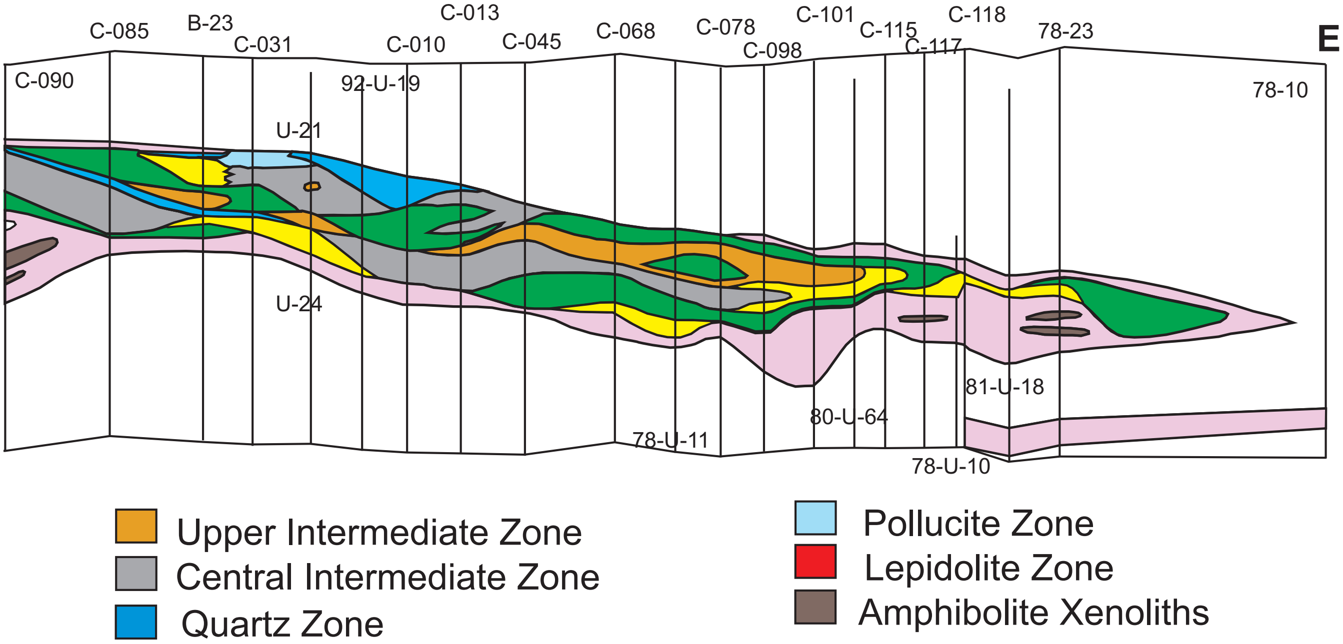

***Figure 4 (continued): d)** Scooptram close to one of the spodumene zone pillars illustrating the room and pillar method used at Tanco; **e)** Custom designed aerial lifts.*

level where it is transported to the shaft by a train of 4 ton, Granby style, side dump ore cars, and hoisted to surface coarse ore bins via 4 ton Kimberly style skips.

Tantalum and spodumene ores are stored in one of two loading pockets and skipped on a daily basis up the two-compartment shaft, into dedicated surface coarse ore bins. The mine however, must produce and provide three distinct ores to the mill. To overcome the limitation of the system, one loading pocket and associated coarse ore bin is emptied weekly and an appropriate tonnage of pollucite ore is batched through.

Mine ventilation air is downcast from surface through one of two vent raises, one being, in part, the Jack Nutt shaft from 1929/30 and the other, a 1.8 m diameter bore-hole raise. The exhaust mine air up-casts through the access decline. Total fresh air volume exceeds 5300 m^3 per minute and is appropriate for the operation of Tanco’s fleet of diesel mining equipment.

Table 4: Zoning of the Tanco pegmatite (from Černý, 2005)

Zone	Main constituents	Characteristics subordinate (accessory) and rare minerals	Textural and structural characteristics	Geochemistry important major & minor elements
Exomorphic unit	Biotite, tourmaline, holmquistite	Arsenopyrite	Fine-grained reaction rims and diffuse veins	K, Li, B (P, F)
(10) Border zone	Albite, quartz	Tourmaline, apatite, (biotite), beryl, triphylite	Fine-grained layers	Na, (B, P, Be, Li)
(20) Wall zone	Albite, quartz	Beryl, (tourmaline), muscovite, Li-muscovite, microcline-perthite	Medium-grained, with giant K-feldspar crystals	K, Na, (Li, Be, F)
(30) Aplitic albite zone	Albite, quartz, (muscovite)	Muscovite, Ta-oxides, beryl, (apatite, tourmaline, cassiterite), ilmenite, zircon, sulfides	Fine-grained undulating layers, fracture fillings, rounded blebs, diffuse veins	Na, (Be, Ta, Sn, Zr, Hf, Ti)
(40) Lower intermediate zone	Microcline-perthite, albite, quartz, spodumene, amblygonite	Li-muscovite, lithiophilite, lepidolite, petalite, Ta-oxides	Medium- to coarse- grained; heterogeneous	K, Na, Li, P, F, (Ta)
(50) Upper intermediate zone	Spodumene, quartz, amblygonite	Microcline-perthite, pollucite, lithiophilite, (albite, Li-muscovite), petalite, eucryptite, Ta-oxides	Giant crystal size of major and most of the subordinate minerals	Li, P, F, (K, Na, Cs, Ta)
(60) Central intermediate zone	Microcline-perthite, quartz, albite, muscovite	Beryl, (Ta-oxides), zircon, ilmenite, spodumene, sulfides, lithiophilite, apatite, cassiterite	Medium- to coarse-grained	K, (Na, Be, Ta, Sn, Zr, Hf, Ti)
(70) Quartz zone	Quartz	Spodumene, amblygonite	Monomineralic	Si, (Li)
(80) Pollucite zone	Pollucite	Quartz, spodumene, petalite, muscovite, lepidolite, albite, microcline, apatite	Almost monomineralic	Cs, (Li)
(90) Lepidolite zone	Li-muscovite, lepidolite, microcline-perthite	Albite, quartz, beryl, (Ta-oxides, cassiterite), zircon	Fine-grained	Li, K, Rb, F, (Na, Be, Ta, Sn, Zr, Hf, Ga)

A fleet of personnel carriers and service trucks supports mining operations. Tanco maintains all of its mine equipment at its own on-site facilities.

Mineral processing

Due to land constraints, the concentrator is constructed on a peninsula formed by two bays on Bernic Lake. The building is multi-floored, with equipment on a total of six levels. The major items of concentration equipment are on two levels, with feed preparation equipment, filters and driers, on the upper levels, with pumps on the lower levels.

The first stage of processing is crushing, where the coarse ore from underground (<300 mm in size) is broken down to <12 mm in size. The tantalum, spodumene and pollucite ores are crushed into separate fine-ore, storage bins. The new dry grinding plant supplies ground pollucite for the cesium formate plant.

Different processes concentrate each ore. Tantalum is processed by gravity concentration, a process that makes use of the fact that tantalum minerals are much heavier than the waste minerals. Spodumene, on the other hand, is primarily processed by flotation, which makes use of the different physical and chemical characteristics of the surfaces of the various minerals. Pollucite is ground and then subjected to acid leaching and other chemical processing to produce cesium chemicals.

Tantalum

The major uses for tantalum are in the electronics industry (*e.g.* cell phones, computers, DVD players) and for cutting tools. High quality capacitors are the major single use for tantalum. Europe is the major consumer of tantalum carbide used in production of hardmetal alloys for cutting tools. Other tantalum alloys are important constituents of aero engines, and for acid resistant pipes and tanks used in the chemical industry. One very important use of tantalum is in the medical industry: Ta "pins" are used for hip-joint replacements, for example, as it is the only metal that is not rejected by the body.

Tantalum processing

There are three main elements in the gravity concentration of Tanco's minerals: liberation of the values from the gangue or waste rock; feed preparation of the ground product into different size fractions; and concentration of the different fractions. At Tanco, the plant is split effectively into four fractions: grinding/spiral circuit, coarse sand circuit, fine sand circuit and slime circuit.

Fine ore is first ground to pass 2 mm. The <2 mm product passes to the spirals, which recover the coarse, free, tantalum minerals, which may otherwise have been ground too fine for effective recovery. The spiral tailing is sized at 0.30 mm by a Linatex hydrosizer with the underflow recirculating to the main grinding mill.

Table 5: Mineral occurrences at Tanco (updated from Černý, 2005 and taking into account the current IMA-CNMMN nomenclature)

Native elements	
Lead	Pb
Bismuth	Bi
Arsenic	As
Copper (?)	Cu
Antimony	(Sb>Bi)
Stibarsen	SbAs

Sulfides and sulfosalts	
Galena	PbS
Sphalerite	(Zn,Cd)S
Hawleyite	(Cd,Zn)S
Pyrrhotite	$Fe_{1-x}S$
Pyrite	FeS_2
Marcasite	FeS_2
Arsenopyrite	FeAsS
Stibnite	Sb_2O_3
Molybdnite	MoS_2
Cosalite	$PbBiS_2$
Gladite	$CuPbBi_5S_9$
Pekoite	$CuPbBi_{11}S_{18}$
Gustavite	$Pb_5Ag_3Bi_{11}S_{24}$
Tetrahedrite	$(Cu,Fe,Ag)_{12}Sb_3S_{13}$
Freibergite	$(Ag,Cu,Fe)_{12}Sb_3S_{13}$
Bournonite	$PbCuSbS_3$
Dyscrasite	Ag_3Sb
Pyrargyrite	Ag_3SbS_3
Miargyrite	$AgSbS_2$
Cubanite	$CuFe_2S_3$
Chalcopyrite	$CuFeS_2$
Stannite	Cu_2FeSnS_4
Kësterite	Cu_2ZnSnS_4
Černýite	Cu_2CdSnS_4

Halides	
Fluorite	CaF_2

Oxides	
Cassiterite	SnO_2
Rutile	$(Ti,Fe,Ta,Nb)O_2$
Tantite	Ta_2O_5
Tapiolite-(Fe)	$Fe^{2+}Ta_2O_6$
Columbite-(Fe)	$Fe^{2+}Nb_2O_6$
Columbite-(Mn)	$Mn^{2+}Nb_2O_6$
Tantalite-(Mn)	$Mn^{2+}Ta_2O_6$
Wodginite	$Mn(Sn>Ta,Ti,Fe)(Ta>Nb)_2O_8$
Ferrowodginite	$(Fe>Mn)(Sn>Ta,Ti.Fe)(Ta>Nb)_2O_8$
Titanowodginite	$(Mn>Fe)(Ti>Sn,Ta,Fe)(Ta>Nb)_2O_8$

Phosphates	
Fluorapatite	$(Ca,Mn)_5(PO_4)_3(F)$
Carbonate-hydroxylapatite	$Ca_5(PO_4,CO_3)_3(OH)$ (after Burke, 2008)
Lithiophosphate	Li_3PO_4
Lithiophilite	$Li(Mn>Fe)PO_4$
Amblygonite	$LiAlPO_4(F,OH)$
Montebrasite	$LiAlPO_4(OH,F)$
Tancoite	$LiNa_2HAl(PO_4)_2(OH)$
Whitlockite	$Ca_3(PO_4)_2$
Fairfieldite	$Ca_2(Mn,Fe)(PO_4)_2.2H_2O$
Collinsite	$Ca_2(Mg,Fe)(PO_4)_2.2H_2O$
Crandallite	$CaAl_3H(PO_4)_2(OH)_6$
Overite	$Ca_3Al_3(PO_4)_8(OH)_6.15H_2O$
Dorfmanite	$Na_2HPO_4.2H_2O$
Ercitite	$NaMnPO_4(OH).2H_2O$
Switzerite	$(Mn,Fe)_3(PO_4)_2.7H_2O$
Groatite	$NaCaMn^{2+}_2 (PO_4) [PO_3(OH)]_2$

Carbonates	
Calcite	$CaCO_3$
Rhodochrosite	$MnCO_3$
Dolomite	$CaMg(CO_3)_2$
Zabuyelite	Li_2CO_3

Sulfates	
Baryte	$BaSO_4$

Borates	
Diomignite	$Li_2B_4O_7$

Silicates	
Quartz	SiO_2
Albite	$Na(AlSi_3O_8)$
Microcline	$K(AlSi_3O_8)$
Sanidine (Adularia)	$K(AlSi_3O_8)$
Rb-feldspar	$(Rb>K)(AlSi_3O_8)$
Biotite*	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$
Lithian muscovite	$K(Al,Li)_2(Al,Si)_4O_{10}(OH,F)_2$
Lepidolite*	$(K,Rb)(Li,Al)_2(Al,Si)_4O_{10}(OH,F)_2$
Illite*	$(K,H_2O)Al_2(AlSi_3O_{10})(OH,H_2O)_2$
Montmorillonite	$(Na,Ca)(Mg,Al)_2(Si_4O_{10})(OH)_2.n(H_2O)$
Cookeite	$LiAl_4(AlSi_3O_{10})(OH)_8$
Eucryptite	$LiAl(SiO_4)$
Spodumene	$LiAl(Si_2O_6)$
Petalite	$Li(AlSi_4O_{10})$
Foitite	$\square Fe^{2+}_2AlAl_6(Si_6O_{18})(BO_3)_3(OH)_4$
Schorl	$NaFe^{2+}_3Al_6(Si_6O_{18})(BO_3)_3(OH)_4$
Elbaite	$NaLi_{1.5}Al_{1.5}Al_6(Si_6O_{18})(BO_3)_3(OH)_4$

Table 5 (continued): Mineral occurrences at Tanco (updated from Černý, 2005 and taking into account the current IMA-CNMMN nomenclature)

Oxides (continued)		Silicates (continued)	
Ferrotitanowodginite	$(Fe>Mn)(Ti>Sn,Ta,Fe)(Ta>Nb)_2O_8$	Rossmanite	$\square LiAl_2Al_6(Si_6O_{18})(BO_3)_3(OH)_4$
Lithiowodginite	$LiTaTa_2O_8$	Feruvite	$CaFe^{2+}{}_3Al_5Mg(Si_6O_{18})(BO_3)_3(OH)_4$
Simpsonite	$Al_4Ta_3O_{13}(OH)$	Dravite	$NaMg_3Al_6(Si_6O_{18})(BO_3)_3(OH)_4$
Stibiotantalite (?)	$SbTaO_4$	Beryl	$Be_3Al_2(Si_6O_{18})$
Microlite *renamed fluorcalciomicrolite or oxycalciomicrolite*	$(Na,Ca)_2Ta_2O_6(O,OH,F)$ (see Atencio *et al.*, 2010 for details)	Topaz	$Al_2SiO_4(F>OH)_2$
Uranmicrolite (after Atencio *et al.* 2010)	$(Na,Ca,U)_2Ta_2O_6(O,OH,F)$	Pollucite	$(Cs,Na)(AlSi_2O_6).nH_2O$
Cesstibtantite *renamed Hydroxykenomicrolite*	$(Sb,Na)_2Ta_2(O,OH)_6(OH,Cs)_1$ (after Atencio *et al.* 2010)	*Cesian analcime*	$(Na,Cs)(AlSi_2O_6).nH_2O$
Calciotantite	$CaTa_4O_{11}$	Holmquistite	$Li_2Mg_3Al_2(Si_8O_{22})(OH)_2$
Rankamaite-Sosedkoite	$(Na,K)_{3-x}Al(Ta,Nb)_{10}(O,OH)_{30}$	Zircon	$(Zr,Hf)(SiO_4)$
Ilmenite	$(Fe,Mn)TiO_3$	Thorite	$ThSiO_4$
Uraninite	UO_2	Coffinite (?)	$U(SiO_4.(OH)_4)$
Manganite	$MnO(OH)$	Garnet (?)*	$(Mn,Fe)_3Al_2Si_3O_{12}$

* Refers to a series name
Mineral names in italic: not approved by IMA
□ represents a vacancy

Effective feed preparation is essential for satisfactory separation on shaking tables, and this is carried out with cyclones, followed by Bartles-Stokes hydrosizers. The hydrosizers contain four spigots and an overflow. The spigot products, or sand fractions, are distributed to further banks of spirals. These spirals each produce a low-grade concentrate, a recirculated middling, and a tailings product. Falcon concentrators scavenge the fine sand tailings products. When installed, this centrifugal separator was one of the newest concentration devices available, confirming Tanco's commitment to "leading edge technology" in the pursuit of performance.

Rougher concentrates from all sections are collected in a storage tank from which the cleaner section is fed at constant flowrate and density. Classification in cyclones and a hydrosizer sizes feed to four cleaner tables, which produce a fine, 35% Ta_2O_5 concentrate, a recirculated middling, and a tailing.

Overflows from the various cylcones along with the Stokes hydrosizer overflow constitute the feed to the ultrafines circuit. These are thickened in another bank of cyclones and treated on a Mozley MultiGravity Separator. This separator produces a rougher concentrate, upgraded on Bartles CrossBelts.

Overall recovery of tantalum ranges from 69-72%. During the summer months accumulated tailings can be processed along with the ore; the same flowsheet being used. Recovery from the tailing portion of the feed is of the order of 30%, upgrading the feed from 0.05% to 30% Ta_2O_5. The specifications of a typical tantalum concentrate produced at Tanco are >28 wt.% of Ta_2O_5.

Tanco's tantalum concentrates are shipped to the Global Advanced Metals facility in Boyertown, Pennsylvania for conversion to the metal or tantalum compounds.

Spodumene

Spodumene can be used either as a feedstock for the production of lithium carbonate and metal, or directly, in its mineral form, in the glass and ceramics industries. Since the development of the "salars" in the USA and Chile, most lithium carbonate is recovered from these sources, and limited spodumene is used for chemical production.

Lithia is a very powerful flux, especially when used in conjunction with potash and soda feldspars. In ceramics, lithium lowers thermal expansion and decreases the firing temperature. Glasses containing lithia are much more fluid in the molten state than those containing proportionate amounts of sodium or potassium. Lower viscosity and faster melting can be utilized to improve glass quality in terms of fewer defects such as unmelted or partially melted raw material grains, and more rapid removal of small bubbles. Lower viscosity can permit the glassmaker to run a forming machinery at a higher rate, or create more elaborate products such as some perfume bottles. In frits and glazes, lithia is used to reduce the viscosity and thereby increase the fluidity of the coatings. This reduces maturing times and lowers firing temperatures. Small amounts of lithia also increase gloss.

Spodumene processing

After crushing to <12 mm, the heavy medium Triflo circuit rejects the feldspar from the <12 mm >0.5 mm range. Ferrosilicon and magnetite as a 70:30 mixture are used with a feed density of 2.74 kg/l and effective density of separation of 2.65 kg/l. The <0.5 mm fraction continues to the grinding circuit.

The sink product and the <0.5 mm fraction are ground in closed circuit with a 2 mm primary screen and a Linatex hydrosizer with an approximate cut point of 150 µm. Rougher and cleaner spirals recover coarse free tantalum within the grinding circuit. A 5 foot (~1.5 m), low intensity drum magnet removes ground steel produced during the grinding process.

The grinding circuit product is scavenged for tantalum by two Falcon concentrators. Tantalum from the Falcon concentrators is upgraded on a Double Deck Holman Table with the tailings and middlings returning to the grinding circuit. Coarse tantalum from the cleaner spiral is also upgraded on a single Holman Table. The tantalum recovered from the spodumene circuit is a valuable by-product.

Prior to the amblygonite flotation stage, in order to control phosphate levels, the pulp is deslimed by single stage cycloning. Due to the nugget-like appearance of the amblygonite, close control of this flotation stage must be maintained. Starvation quantities of collector are used based on feed tonnage and previous tails assays. Starch is used as a depressant for spodumene at pH 9.2. A spodumene-phosphate by-product called Montebrasite is produced to meet market requirements. This concentrate is subjected to wet high intensity magnetic separation to remove weakly magnetic iron materials. This concentrate is pumped to a belt filter and propane fired rotary drier. The dried concentrate goes to a storage bin prior to bagging or bulk shipping to meet the customers' requirements.

Mica is then removed with a single flotation stage. This step assists in the removal of K_2O from the final concentrate product. The mica flotation tailings are two stage cycloned to remove starch. Two conditioning stages for automatic pH control and collector addition are carried out prior to rougher flotation.

Final product handling is carried out utilizing air slides and dense phase pneumatic pumping to storage bins. The final product can be shipped to the customer in 25 kg, 1,000 kg bags, or bulk, via road or rail. The concentrate is sold to markets worldwide. Water used within the circuits is either fresh (from Bernic Lake) or re-cycled pond overflow depending on the section of the plant.

Clients can accept different levels of impurities, depending on their specific use of the material. Customers specify tight impurity levels for the use of spodumene concentrates in the glass and ceramics industries, and the process for the production of these concentrates is based on removal of contaminant minerals.

Cesium

Tanco produces cesium products from pollucite. It is estimated that the pegmatite held about 75% of the world's known reserves of this mineral. Cesium can be used in magneto-hydrodynamic power generation, in aerospace applications, optoelectronics, in DNA separation and as a catalyst in chemical applications. It is also used as a calibrated drilling lubricant for high temperature, high pressure oil wells (cesium formate). The main use for the pollucite mined at Tanco is in the manufacture of cesium formate brine.

Cesium formate is a clear, water soluble fluid with a specific gravity of 2.3 g/cm^3 and a viscosity similar to water. It is used in the oil drilling industry as a drilling fluid, where the properties of low viscosity, high specific gravity and complete solution confer significant benefits over traditional solids based drilling fluids in deep wells greater than 4,575 m (Benton and Turner, 2000).

Use of cesium formate eliminates formation damage, particularly skin formation while drilling through the reservoir. This results in improved hydrocarbon flows to the well giving better daily production from the well, in addition to enhanced recoveries from the reservoir in the long term allowing more hydrocarbons to be extracted from the well before well stimulation techniques become necessary (Brangetto *et al.*, 2007).

From an occupational health and safety perspective, there are considerable benefits to the use of cesium formate. It has low toxicity for mammals with a pH between 10 – 11. Skin contact is not desirable, but if occurs, has no immediate consequences. The low environmental toxicity of cesium formate makes it the fluid of choice in areas where environmental sensitivities are particularly acute (Gilbert and Pessala, 2009).

Cesium Formate Plant

The cesium formate pilot plant was designed, built and commissioned in 1996/97 in response to a potential market for formate brines. The focus of plant production was aimed at the oil and gas industries' demand for a high-density, solids free drilling fluids. The plant was designed to readily incorporate process changes and modifications enabling it to produce a wide variety of cesium-based products, thus allowing Tanco and Cabot Corporation to rapidly respond to these future markets. The original plant was designed to produce 500 barrels/month of 2.3 g/cm^3 specific gravity cesium formate. In 1999, expansion of the plant allowed for the production of 700 barrels/month. In 2001, the plant underwent a further expansion in order to accommodate the manufacturing of conventional cesium chemicals (Vanstone *et al.*, 2005).

Since Bernic Lake is a headwater lake and therefore very susceptible to environmental damage, the plant design minimizes environmental impacts on the surrounding area. All areas of the plant are contained to capture any spilled material, and wastes are stored in a lined disposal cell, which eliminates the discharges to the lake.

Cesium Formate Manufacture

Pollucite ore is mined from the Tanco mine along with the spodumene and tantalum ores. The ore is crushed to <12 mm, and then dry ground in a ball mill to a powder form. Utilizing a series of acid/base reactions, the cesium is extracted from the pollucite ore and converted to a high-density, cesium formate solution. The final product is shipped by container to Aberdeen, Scotland and Bergen, Norway for use by the drilling industry in the North Sea, and to Houston, Texas for use in the Gulf of Mexico.

Markets

Cesium chemicals are currently used primarily in catalyst and chemical synthesis applications. While current worldwide demand for fine cesium chemicals is approximately 700,000 pounds a year, it is expected that new applications in the oil, gas and chemical industries for these products will increase in demand by more than ten-fold.

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References

Anderson, S.D., Černý, P., Halden, N.M., Chapman, R. and Uher, P. 1998: The Yitt-B pegmatite swarm at Bernic Lake, Southeastern Manitoba: a geochemical and paragenetic anomaly; Canadian Mineralogist, v. 36, p. 283-301.

Atencio, D., Andrade, M.B., Christy, A.G., Gieré, R. and Kartashov, P.M. 2010: The pyrochlore supergroup of minerals: nomenclature; Canadian Mineralogist, v. 48, p. 673-698.

Baadsgaard, H. and Černý, P. 1993: Geochronological studies in the Winnipeg River pegmatite populations, southeastern Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, v. 18, p. A5.

Bannatyne, B.B. 1985: Industrial minerals in rare-element pegmatites of Manitoba; Manitoba Energy and Mines, Geological Services, Economic Geology Report ER84-1, 96 p.

Benton, W. and Turner, J. 2000: Cesium formate fluid succeeds in North Sea HPHT field trials; Drilling Contractor, p. 38-41.

Brangetto, M., Pasturel, C., Gregoire, M., Ligertwood, J., Downs, J., Harris, M. and Turner, J. 2007: Caesium formate brines used as workover, suspension fluids in HPHT field development; Drilling Contractor, p.109-111.

Burke, E.A.J. 2008: Tidying up mineral names: an IMA-CNMNC scheme for suffixes, hyphens and diacritical marksm; The Mineralogical Record v.39, p. 131-135.

Cabot Corporation 2012 <http://www.cabot-corp.com/wcm/download/en-us/sp/TANCO1.pdf> (accessed October 4th, 2012).

Camacho, A., Baadsgaard, H., Davis, D.W., and Černý, P. 2012: Radiogenic isotope systematic of the Tanco and Silverleaf granite pegmatites, Winnipeg River pegmatite district, Manitoba; Canadian Mineralogist, v. 50, p. 1775-1792.

Černý, P. 1972: The Tanco pegmatite at Bernic Lake, Manitoba. VII. Eucryptite; Canadian Mineralogist, v. 11, p. 708-713.

Černý, P. 2005: The Tanco rare-element pegmatite deposit, Manitoba: Regional context, internal anatomy, and global comparisons; *in* Linnen, R.L., and Samson, I.M., *eds*., Rare-Element Geochemistry and Mineral Deposits: Geological Association of Canada, GAC Short Course Notes 17, p. 127-158.

Černý, P. and Ercit, S. 2005: The classification of granitic pegmatites revisited; Canadian Mineralogist, v. 43, p. 2005-2026.

Černý, P., Ercit, T. and Vanstone, P. 1996: Petrology and mineralization of the Tanco rare-element pegmatite, Southeastern Manitoba (Field Trip A3). Geological Association of Canada – Mineralogical Association of Canada, 63 p.

Černý, P., Ercit, T. and Vanstone, P. 1998: Mineralogy and Petrology of the Tanco rare-element pegmatite deposit, Southeastern Manitoba (Field trip Guidebook B6); International Mineralogical Association. 17th General Meeting, Toronto, 74 p.

Černý, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, B.J. 1981: The Cat Lake-Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Energy and Mines, Manitoba Resources Division, Economic Geology Report ER80-1, 215 p.

Cooper, M.A., Hawthorne, F.C., Ball, N.A., Ramik R.A. and Roberts, A.C. 2009: Groatite, Na Ca Mn^{2+}_2 (PO_4) $[PO_3(OH)]_2$, a new mineral species of the alluaudite from the Tanco pegmatite, Bernic Lake, Manitoba, Canada: description and crystal structure; Canadian Mineralogist, v. 47, p. 1225-1235.

Duguet, M., Lin, S., Gilbert, H.P., and Corkery, M.T. 2005: Preliminary results of geological mapping and structural analysis of the Bird River greenstone belt, southeastern Manitoba (NTS 52L5 and 6): *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p.117–124.

Duguet, M., Gilbert, H.P., Corkery, M.T. and Lin, S. 2006: Geology and structure of the Bird River Belt, southeastern Manitoba (NTS 52L5 and 6); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 170–183.

Ercit, T.S., Hawthorne, F.C. and Černý, P. 1992: The wodginite group. I. Structural crystallography. Canadian Mineralogist v. 30, 597-611.

Fransolet, A.-M., Cooper, M.A., Černý, P., Hawthorne, F.C., Chapman, R. and Grice, J.D. 2000: The Tanco pegmatite at Bernic Lake, southeastern Manitoba. XV. Ercitite, $Na,Mn^{3+}PO_4(OH)(H_2O)_2$, a new phosphate mineral species, Canadian Mineralogist v. 38, p.893-898.

Gilbert, H.P. 2005: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6N); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 125-139.

Gilbert, H.P. 2006: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 184–205.

Gilbert, H.P. 2007: Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 129–143.

Gilbert, H.P., 2008: Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 121–138.

Gilbert, H.P., Davis, W.D., Duguet, M., Kremer, P.D., Mealin, C.A. and MacDonald J. 2008: Geology of the Bird River Belt, southeastern Manitoba (parts of NTS 52L5, 6); Geoscientific Map MAP2008-1.

Gilbert, Y. and Pessala, P. 2009: Cesium formate and Zinc bromide: Comparative Hazard Assessment and HSE Profiles; Gaia Consulting OY, 48 p.

Hutchinson, R.W. 1959: Geology of the Montgary Pegmatite [Manitoba]. Economic Geology, v. 54, p. 1525-1542.

Kissin, S.A., Owens, D.R. and Roberts, W.L. 1978: Černýite, a copper - cadmium - tin sulfide with the stannite structure; Canadian Mineralogist, v. 16, p. 139-146.

Kremer, P.D. and Lin, S. 2006: Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 206–213.

Kremer, P.D. 2010: Structural geology and geochronology of the Bernic Lake area in the Bird River greenstone belt, Manitoba: Evidence for syn-deformational emplacement of the Bernic Lake pegmatite group; M.Sc. thesis, University of Waterloo 91pp.

Lenton, P.G. 1979: Mineralogy and petrology of the Buck Claim lithium pegmatite, Bernic Lake, Southeastern Manitoba; M.Sc. thesis, University of Manitoba, 164 p.

London, D. 1985: Origin and significance of inclusions in quartz: a cautionary example from the Tanco pegmatite; Manitoba, Economic Geology, v. 80, p. 1988-1995.

London, D., Zolensky, M.E. and Roedder, E. 1987: Diomignite: natural $Li_2B_4O_7$ from the Tanco pegmatite, Bernic Lake, Manitoba; Canadian Mineralogist, v. 25, p. 173-180.

Manitoba Science, Technology, Energy and Mines, 1988a Mineral Inventory File No. 187; <http://www.manitoba.ca/iem/mrd/mined/minfacts/mbhistory/mininv/187.htm> (accessed October 4th 2012).

Manitoba Science, Technology, Energy and Mines, 1988b Mineral Inventory File No. 197; <http://www.manitoba.ca/iem/mrd/mined/minfacts/mbhistory/mininv/197.htm> (accessed October 4th 2012).

Manitoba Science, Technology, Energy and Mines, 1988c Mineral Inventory File No. 209; <http://www2.gov.mb.ca/dbtw-wpd/exec/dbtwpub.dll?AC=GET_RECORD&XC=/dbtw-wpd/exec/dbtwpub.dll&BU=http%3A%2F%2Fwww2.gov.mb.ca%2FItmcat%2Fweb%2Fminsearch.html&TN=MINERA~1&SN=AUTO23126&SE=1941&RN=10&MR=0&TR=0&TX=1000&ES=1&CS=2&XP=&RF=Web%3A+Brief&EF=Basic+Record+Form&DF=Viewing+PrintingWeb&RL=1&EL=1&DL=1&NP=3&ID=&MF=&MQ=&TI=0&DT=&ST=0&IR=206&NR=0&NB=0&SV=0&SS=1&BG=&FG=&QS=mininventorytest&OEX=ISO-8859-1&OEH=ISO-8859-1> (accessed October 4th 2012).

Manitoba Science, Technology, Energy and Mines, 1988d Mineral Inventory File No. 213; <http://www.manitoba.ca/iem/mrd/mined/minfacts/mbhistory/mininv/213.htm> (accessed October 4th 2012).

Mealin, C.A. 2008: Geology, geochemistry and Cr-Ni-Cu-PGE mineralization of the Bird River sill: evidence for a multiple intrusion model; MSc thesis, University of Waterloo, Waterloo, Ontario, 155 p.

Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006: Tectonic evolution of the western Superior Province from NATMAP and LITHOPROBE studies; Canadian Journal of Earth Sciences, v. 43, p. 1085–1117.

Ramik, R.A., Sturman, B.D., Dunn, P.J. and Povarennykh, A.S. 1980: Tancoite, a new lithium sodium aluminum phosphate from the Tanco pegmatite, Bernic Lake, Manitoba, Canadian Mineralogist, v.18, p. 185-190.

Scoates, J.S. and Scoates, R.F.J 2013: Age of the Bird River Sill, southeastern Manitoba, Canada, with implications for the secular variation of layered intrusion-hosted stratiform chromite mineralization; Economic Geology, v. 108, 13 p.

Stilling, A., Černý, P. and Vanstone, P.J. 2006: The Tanco pegmatite at Bernic Lake, Manitoba. XVI. zonal and bulk composition and their petrogenetic significance; Canadian Mineralogist, v. 44, p. 599-623.

Stott, G.M., Corkery, M.T., Percival, J.A., Simard, M. and Goutier, J. 2010: Project units 98-006 and 98-007. A revised terrane subdivision of the Superior Province; in Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p. 20-1 - 20-10.

Trueman, D.L. 1980: Stratigraphy, structure and metamorphic petrology of the Archean greenstone belt at Bird River, Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 150 p.

van Lichtervelde, M., Linnen, R.L., Salvi, S. and Didier, B. 2006: Evaluating the role of metagabbro rafts on tantalum mineralization in the Tanco pegmatite; Manitoba; Canadian Mineralogist v. 44, p. 625-644.

van Lichtervelde, M., Salvi, S., Béziat, D. and Linnen, R.L. 2007: Textural Features and Chemical Evolution in Tantalum Oxides: Magmatic Versus Hydrothermal Origins for Ta Mineralization in the Tanco Lower Pegmatite, Manitoba, Canada; Economic Geology, v. 102, p. 257-276.

van Lichtervelde, M., Grégoire, M., Linnen, R.L., Béziat, D. and Salvi, S. 2008: Trace element geochemistry by laser ablation ICP-MS of micas associated with Ta mineralization in the Tanco pegmatite, Manitoba, Canada; Contributions to Mineralogy and Petrology, v. 155,p. 791-806.

Vanstone, P., Young, S., Galeschuk, C., Simard, R. and Gibb, A. 2005: The Tanco Rare-element pegmatite, Southeastern Manitoba; Tantalum Mining Corporation of Canada Limited, 22p.

Wang, X. 1993: U-Pb zircon geochronology study of the Bird River greenstone belt, southeastern Manitoba; M.Sc. thesis, University of Windsor, Windsor, Ontario, 96 p.