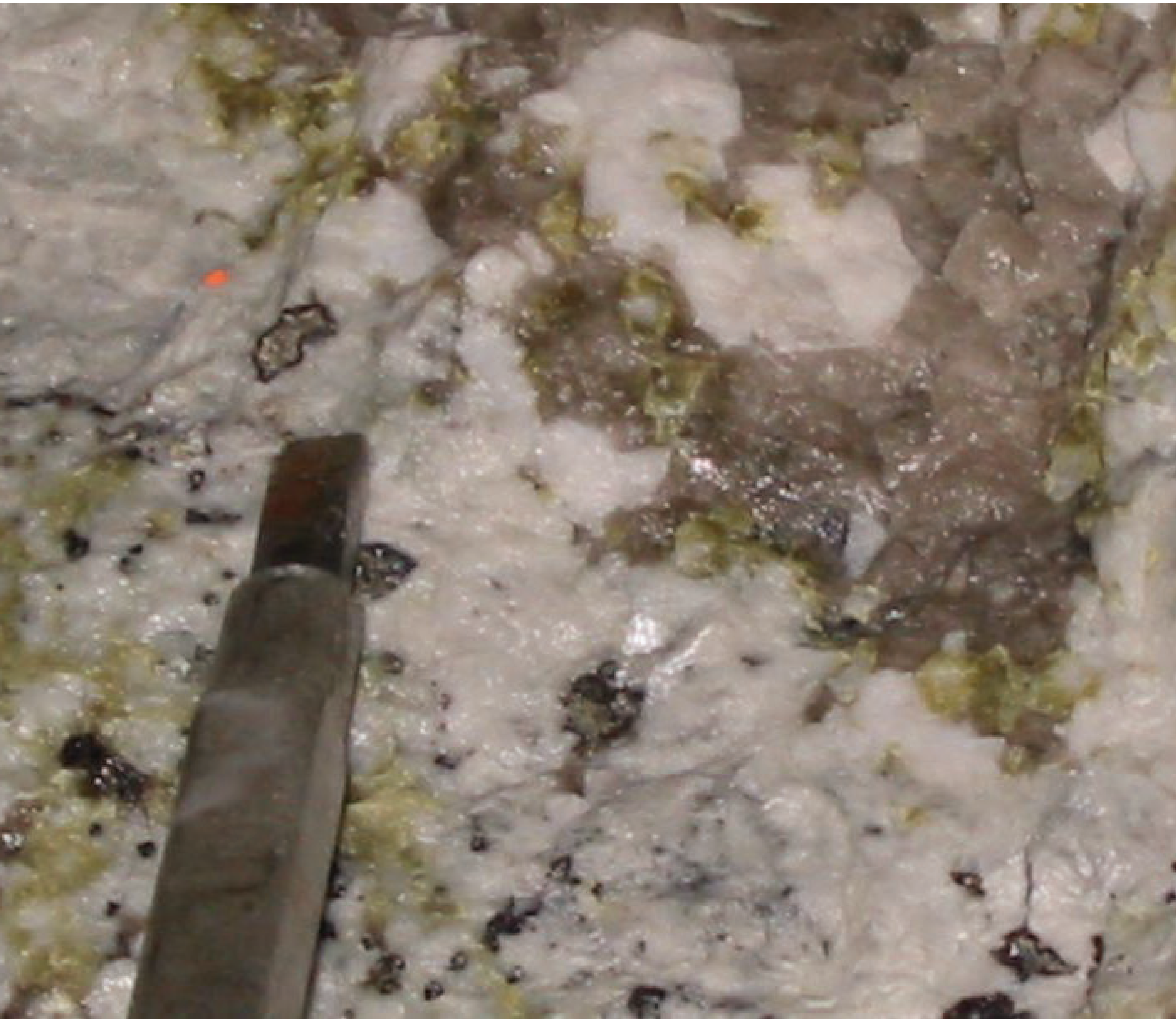
# Open File OF2024-3

The Tanco pegmatite: geological setting, internal zonation, mineralogy and mining of a world-class rare element pegmatite deposit



Manitoba

**Open File OF2024-3**

# The Tanco pegmatite: geological setting, internal zonation, mineralogy and mining of a world-class rare-element pegmatite deposit

**by T. Martins, C. Breasley, L. Groat, R. Linnen, C. Deveau and S. Rankmore**
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**Front cover photos:**

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.

## Abstract

The Archean Tanco pegmatite, located in southeastern Manitoba, Canada, is a world-class deposit known for its lithium, tantalum and cesium mineralization. The pegmatite is part of the Bernic Lake group of pegmatites which are located in the southern limb of the Bird River greenstone belt. Over the years, the Tanco pegmatite has been mined for tantalum and cesium and is now currently mined for lithium concentrate primarily from spodumene.

The pegmatite is bilobate and 1520 m long, 1060 m wide and up to ~100 m thick. U-Pb geochronology produced a crystallization age of the Tanco pegmatite at 2641 ±3 Ma and 2647.4 ±1.0 Ma. More than 100 minerals have been identified at the Tanco mine including multiple new mineral discoveries such as černýite, tancoite and groatite. It has historically been divided into nine major mineralized zones, with zone 50 containing the highest concentration of spodumene, zones 30 and 60 hosting tantalum, and zone 80 being the primary cesium-bearing zone.

Mining is carried out using the room and pillar method at Tanco due to the diverse mineralogy and shallow nature of the mine. Ore is broken down and transported from underground to the surface where it is separated for mineral processing. The Tanco processing plant is built across six levels due to land limitations on the Bernic Lake peninsula, with concentration equipment on the middle floors and preparation, filtration and pumping systems distributed across the upper and lower levels.

This guidebook offers a detailed overview of the Tanco pegmatite's geological history, internal zonation, mineralization, mining and mineral processing methods, highlighting its unique mineralogy, complexity and significant scientific contributions to the understanding of pegmatites.



## Résumé

La pegmatite archéenne de Tanco, située dans le sud-est du Manitoba, au Canada, est un gisement de classe mondiale connu pour ses minéralisations de lithium, de tantale et de césium. Cette pegmatite fait partie du groupe de pegmatites du lac Bernic, situé dans la partie sud de la ceinture de roches vertes de la rivière Bird. Au fil des ans, on a exploité la pegmatite de Tanco pour le tantale et le césium. Actuellement, on l'exploite pour le concentré de lithium, principalement contenu dans du spodumène.

La pegmatite est bilobée et mesure 1 520 m de longueur, 1 060 m de largeur et jusqu'à ~100 m d'épaisseur. La géochronologie U-Pb a donné un âge de cristallisation de la pegmatite de Tanco de 2 641 ±3 Ma et 2 647,4 ±1,0 Ma. Plus de 100 minéraux ont été identifiés à la mine de Tanco, y compris de multiples nouveaux minéraux tels que la černýite, la tancoite et la groatite. La mine est traditionnellement divisée en neuf zones minéralisées principales. La zone 50 contient la plus forte concentration de spodumène, les zones 30 et 60 contiennent du tantale et la zone 80 est la principale zone contenant du césium.

À Tanco, l'exploitation minière est réalisée par la méthode des chambres et piliers en raison de la diversité minéralogique et de la faible profondeur de la mine. Le minerai est fragmenté et transporté du sous-sol à la surface où il est séparé pour le traitement des minéraux. L'usine de traitement de Tanco est construite sur six niveaux en raison des contraintes de terrain sur la péninsule du lac Bernic. Les équipements de concentration se trouvent aux étages intermédiaires et les systèmes de préparation, de filtration et de pompage sont répartis entre les niveaux supérieurs et inférieurs.

Le présent guide offre une vue d'ensemble détaillée de l'histoire géologique de la pegmatite de Tanco, de sa zonalité interne, de sa minéralisation et de ses méthodes d'exploitation minière et de traitement des minéraux. Le guide met l'accent sur la singularité minéralogique de cette pegmatite ainsi que sur sa complexité et ses importantes contributions scientifiques à la compréhension des pegmatites.

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## Introduction

The content of this Open File was initially presented as a guidebook for visitors attending a field trip to the Tanco mine during GAC-MAC-PEG 2024.

The pegmatite is located at the Tanco Mine at Bernic Lake, close to the Manitoba-Ontario border and approximately 180 km northeast of Winnipeg. It belongs to the Bernic Lake pegmatite group, part of the Cat Lake–Winnipeg River pegmatite field as defined by Černý et al. (1981). This pegmatite field consists of nine distinct pegmatite groups which exhibit wide variations in mineralogy and degrees of fractionation. The pegmatites belonging to the Bernic Lake pegmatite group, of which the world famous Tanco pegmatite is most noteworthy, have been studied previously by several authors (e.g., Lenton, 1979; Cerný et al., 1981, 1996; Bannatyne, 1985; Anderson et al., 1998; van Lichtervelde et al., 2006; Kremer, 2010).

This Open File aims to provide general and up-to-date information on the Tanco pegmatite since the last field trip guidebook by Martins et al. (2013), and the regional geological framework of the Bird River greenstone belt (Figure 1). Detailed information on the history of the mine can be found in Manitoba Science, Technology, Energy and Mines (1988) and Tantalum Mining Corp. of Canada Ltd. (2024). In-depth work on the regional geology can be found in Gilbert (2005, 2006, 2007) and Gilbert et al. (2008). Papers on the mineralogy, geochemistry and structure include Černý (1972), London (1985), Černý (2005), Stilling et al. (2006), van Lichtervelde et al. (2007, 2008) and Kremer (2010).

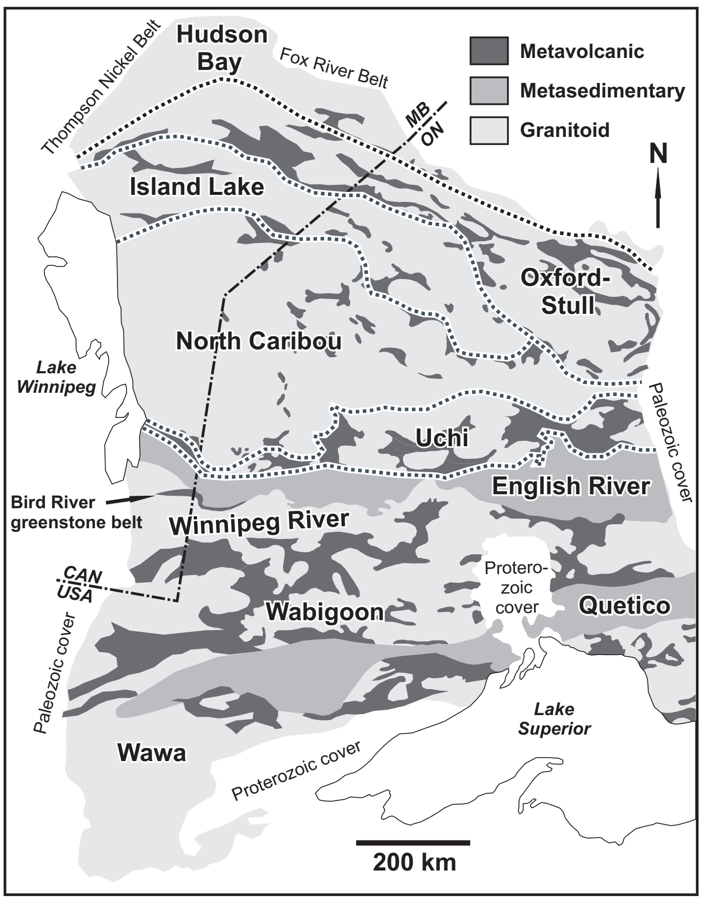


***Figure 1:*** *Simplified geology of the northwestern Superior Province showing the location of the Bird River greenstone belt. Based on Percival et al., (2006) and Stott et al., (2010). Abbreviations: CAN, Canada; MB, Manitoba; ON, Ontario; U.S., United States.*

## History of the mine

The Tanco pegmatite was discovered in the late 1920s during a tin-focused drill program by Jack Nutt Mines Ltd. The pegmatite was a "blind discovery" because it does not outcrop, and the bulk of it is under Bernic Lake (Figure 2). A mill was constructed to produce tin concentrates, but in the end, the low quantities of tin ore extracted meant the operation was unfeasible. Diamond-drilling of the pegmatite body revealed spodumene but there was little interest in lithium at the time. By 1932, the renamed Consolidated Tin Corporation Ltd. had abandoned the property with the claims reverting to the Crown. From 1934 to 1940 there was minor open-pit production of lithium ore from other nearby pegmatites of the Bernic Lake pegmatite group (Buck, Pegli, and Coe) and tin exploration continued in the area.

In 1955, Montgary Petroleum Corporation Ltd. acquired the claims at Bernic Lake and drilled about 26,000 feet (almost 8 km) of core to explore the lithium potential of the pegmatite. Meanwhile, the construction of a road as well as infrastructure to supply electricity to the mine site began. By 1957, Montgary Petroleum, renamed Montgary Explorations Ltd. sunk a shaft to 334 feet (about 100 m). The internal zonation of the pegmatite was defined by Hutchinson (1959), and pollucite (Cs ore) was identified. Operations were suspended for financial reasons and did not recommence until the spring of 1959.

In 1960, Chemalloy Minerals Ltd. (formerly Montgary Explorations Ltd.) carried out extensive drilling of the pegmatite to evaluate its lithium potential. Pollucite and amblygonite were mined with 2,500 tons of pollucite and amblygonite being produced by 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. A concerted program of metallurgical testing, drilling and mine development both at the surface and underground resulted in the first tantalum concentrates being produced. The Tanco Grand Opening was held on September 8, 1969 and from this time to 1977, the mine actively extracted tantalum and also exported pollucite to Russia.

The commercial production of ceramic-grade spodumene began in 1986, and by 1988 Tanco was the major supplier for Corning Incorporated. This extremely pure spodumene was important for the production of Visions cookware and later CorningWare. In 1993, Cabot Corporation acquired a 100% interest in Tantalum Mining Corporation of Canada Ltd. and by 1995 construction of a plant to produce cesium formate brine had begun.

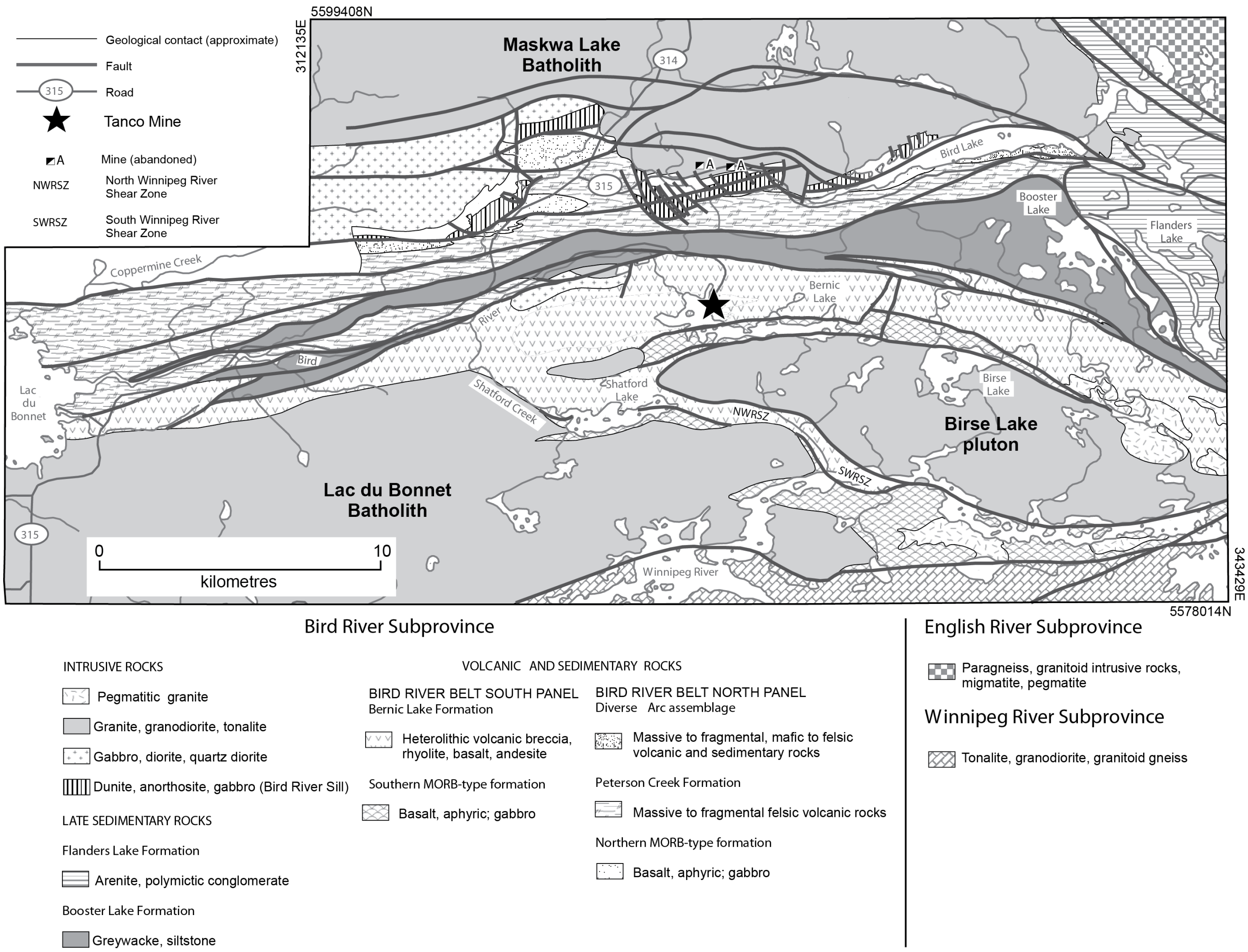


***Figure 2:*** *Simplified geology of the Bird River greenstone belt including location of Bernic Lake and the Tanco mine (after Gilbert et al., 2008). Abbreviation: MORB, mid-ocean–ridge basalt.*

Market fluctuations driven by supply and demand for each of the commodities produced by the mine has continually affected the focus of the operation and the production levels. By 1998, the mine had milled one million tonnes of spodumene ore and by 2004, four million tonnes of tantalum ore. The cesium formate plant was expanded in 1999 to 700 barrels per month, and in 2001 the plant underwent a further expansion to enable the manufacturing of conventional cesium chemicals. Tantalum operations were suspended indefinitely due to low prices in June 2009. The same happened to the spodumene operations later in 2009 due to poor markets and low prices. In 2011, Tanco recommenced tantalum production and this continued until March 15, 2013.

In 2021, the mine was acquired by Sinomine Resource Group Co., Ltd. who were looking to take advantage of the opportunities in a surging lithium market. Sinomine renovated and restored the spodumene processing system with spodumene ore production resuming in 2021. The company expects to reach a yearly production of 30,000 t of 5.5% $Li_2O$. The company has recently applied for an extension of the mill capacity to support higher production.

## Geological setting

The Tanco pegmatite is part of the Winnipeg River–Cat Lake pegmatite field (Černý et al., 1981). 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 pegmatite groups within the Cat Lake–Maskwa Lake and Winnipeg River districts.

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 1). The Bird River greenstone belt has historically been described as a large, synclinal keel (Trueman, 1980; Černý et al., 1981); however, mapping by the Manitoba Geological Survey has led to a re-interpretation of the volcanostratigraphic framework of the belt (Figure 2; Gilbert,

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

| Pegmatite district | Pegmatite group | Host rock/contacts | Morphology and structure | Enrichment | Other characteristics/comments |
|---|---|---|---|---|---|
| | *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, rare-earth elements, 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) | Individual pegmatites are typically oriented N-S. |
| | *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 |
| **Winnipeg River** | *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 S2 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 échelon patterns) | B (Be) | Shape of the pegmatites is irregular: contorted lenticular dykes predominate in the east; flat lenses and elongate dykes are typical in the west |
| | *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 enrichment |
| | *Eagle-Irgon* | Biotite flakes occur sporadically along the contacts | Flat-lenticular with common pinch and swell; 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 north-south lineament |
| **Cat Lake–Maskwa Lake** | *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 different 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 |

2006, 2007; Gilbert et al., 2008). Gilbert (2008) subdivided the southern part of the Bird River greenstone belt 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 metavolcanic panels are separated by the fault-bounded enclave of 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 summarized 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 the Bird River greenstone belt.

**Table 2:** Geological formations of the Bird River greenstone belt (based on 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 ±0.9 Ma[2], 2852.8 ±1.1 Ma[2], 2844 ±12 Ma[3]) |

Abbreviation: MORB, mid-ocean–ridge basalt.
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 Scoates (2013).

## *Structural geology*

Four episodes of deformation affect the Bernic Lake area (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.

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 tectonostratigraphic formations. This association suggests that the structures have a strong control 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. The shear zone separates the Bernic Lake formation from the southern mid-ocean–ridge basalt-type formation to the south. These pegmatites crosscut the shear fabric ($S_2$); however, they 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. However, the Tanco pegmatite also overprints $D_2$ fabric elements. The $S_2$ foliation and $L_2$ lineation in

**Table 3:** Summary of the 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 | |

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 $D_3$ deformation. In the northeastern corner of the belt, this is most evident in the emplacement of the Marijane granite in the nose of a large $F_3$ fold structure. The Marijane granite yielded a U-Pb monazite 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 returned intrusive 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. A syn-$D_3$ model that incorporates the different styles of emplacement observed in the Bernic Lake pegmatite group has been proposed on the basis of lithological and structural mapping, bolstered by detailed U-Pb analyses (Kremer, 2010). A prominent spaced $S_3$ cleavage consistently overprints the ubiquitous $S_2$ foliation in mafic metavolcanic rocks. 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 $D_3$ structures to brittle $D_4$ 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, bi-lobate, 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 has been estimated as ~21,850,000 $m^3$, the mass as ~57,430,000 tonnes, and the average density as 2.63 $g/cm^3$ (Stilling et al., 2006). It occurs mostly under Bernic Lake and has only been examined by drill-core and underground mining exposures.

The Tanco pegmatite has fascinated 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 1970s. The most recent general review on the Tanco pegmatite is Černý (2005). Subsequently, 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; Brown et al., 2017), 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 3). It is possible to find different combinations of mineral associations in each of the different zones including those containing elements of economic interest: Ta, Li and Cs. Nine major pegmatite discrete zones and subzones are described. The outer zones are concentric, whereas the inner zones are layered segments that are locally complex in shape. The mineralogy and petrography of the different zones have been described in detail by several authors (e.g., Černý, 2005; Černý

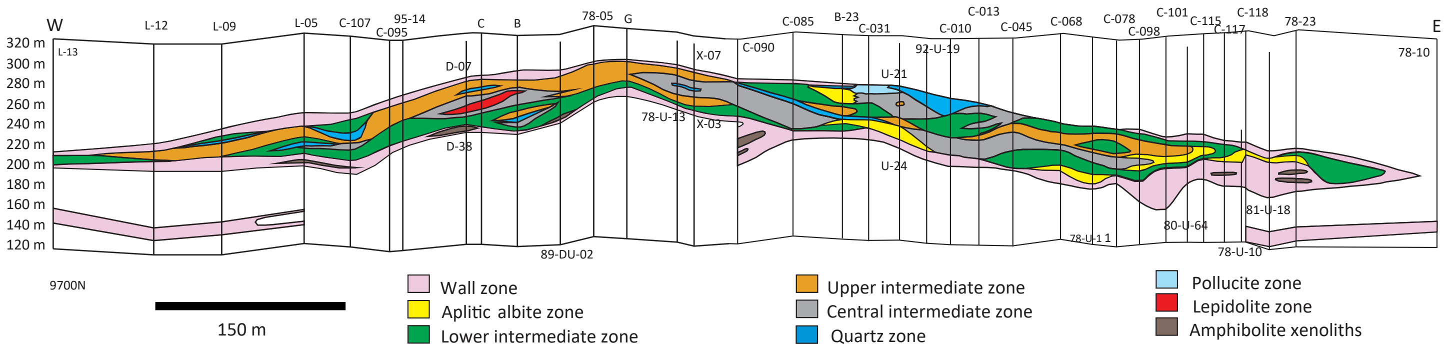


***Figure 3:** Cross-section of the pegmatite and underground photos at Tanco mine of the west-east fence section 9700 through the Tanco pegmatite (looking north) showing its complex internal zoning (modified from Černý, 2005).*

et al., 1996, 1998; Stilling et al., 2006). This Open File presents an overview of the literature and historic core logging scheme used by the Tanco mine geologists, including the description presented by Breasley et al. (2022).

**Zone 05**: Host rock – The host rock is generally called 'amphibolite', but locally it is much more diverse and composition can vary. The amphibolite host rock at Tanco comprises 54% Fe-hornblende, 37% plagioclase (An38), 4% ilmenite, 1% apatite, and 4% quartz with minor epidote, biotite, chlorite and almandine (Morgan and London, 1987). It was subjected to multiple metasomatic events during crystallization of the Tanco pegmatite (Morgan and London, 1987).

**Zone 10**: Border zone – The border zone is a fine-grained contact zone with amphibolite, representing the portion of the Tanco pegmatite that crystallized first. It is comprised of a very thin band of quartz and albite, which locally penetrates the host rock. This zone is less than 30 cm thick and is the least geochemically evolved section of the pegmatite (Stilling et al*.,* 2006).

**Zone 20**: Wall zone – The wall zone consists of simple pegmatite that is roughly representative of the bulk composition of the Tanco pegmatite (Figure 4a). The zone is composed predominantly of megacrystic microcline-perthite, quartz, albite, and curvilamellar lithian muscovite. Minor components include beryl, tourmaline, muscovite, and perthite. Some notable features of this zone include red perthite, exocontact tourmaline as crystals oriented perpendicular to the country rock contact, and white beryl. This zone hosts giant K-feldspar phenocrysts in medium-grained groundmass. Aplitic bands are commonly found in the footwall of the wall zone. This zone is up to 35 m thick in the footwall (Černý, 2005).

**Zone 22**: Simple pegmatites – Isolated blebs of pegmatite that are simple in mineralogy and not enriched in metals. This zone is commonly found above and below the main mineralized Tanco body within the country rock.

**Zone 30**: Aplitic albite zone – This zone consists of albite, quartz and muscovite, and minor Ta oxides, beryl, apatite, tourmaline, cassiterite, ilmenite, zircon and sulphides. This zone is generally pale blue-white and contains dark brown/black clots of remobilized tantalum/niobium-bearing minerals. The blue colour is attributed to micro-scale blades of albite. This zone is of particular interest due to its distinctive textures that include multiple undulatory layered growths and fracture infill structures. The banded nature represents progressive crystallization fronts. Zone 30 is >16 m thick in some areas. Other interesting features of this zone include the presence of a 'beryl fringe' at contact zones with other units (Stilling et al., 2006) and the typical association with tantalum and niobium mineralization (Figure 4b). Some spatial associations of this zone include ragged lenses of mineralization in the eastern area of the pegmatite, where zone 30 rocks are found beside the wall zone and grading locally into zone 60 (Černý et al., 1998). In the western side of the Tanco deposit, zone 30 is found throughout zone 60 and in contact with zones 40 and 20 (Černý et al., 1996).

**Zone 36**: Aplitic albite zone – Muscovite and quartz after microcline (MQM) zone. Zone 36 consists of intercalations of zone 30 aplite and zone 60 MQM secondary alteration. The zone 30 aplite occurs in greater abundance than the zone 60 MQM. MQM is typically green/white with coarser crystalline growth than the massive blue albite. This zone often contains beryl and is commonly associated with tantalum mineralization.

**Zone 40**: Lower intermediate zone (mixed zone) – This zone is internally highly variable and is often used to describe chaotic zones in historic drillcore. Common components include microcline-perthite, albite, quartz, spodumene (with up to 2 m spodumene and quartz intergrowth [SQUI] crystals) and amblygonite. Minor components include Li muscovite, lithiophilite, lepidolite, petalite, and tantalum oxides. This zone can be distinguished from zone 50 (see below) by the notable abundance of feldspars. Zone 40 is medium- to coarse-grained, remarkably heterogeneous, and can be up to 25 m in thickness. Radial fans of albite and mica commonly surround the feldspar minerals (Černý et al., 1996).

**Zone 45**: Low-grade spodumene zone – This zone is part of the mixed zone but is more enriched in SQUI. It contains higher sodium contents than zone 50, and blue-white aplite bands and patches are common. Thin section analysis reveals a highly complex internal mineralogy indicative of high-temperature metosamatic processes, including relatively high-temperature/pressure spodumene textures. However, multiple generations of aplite

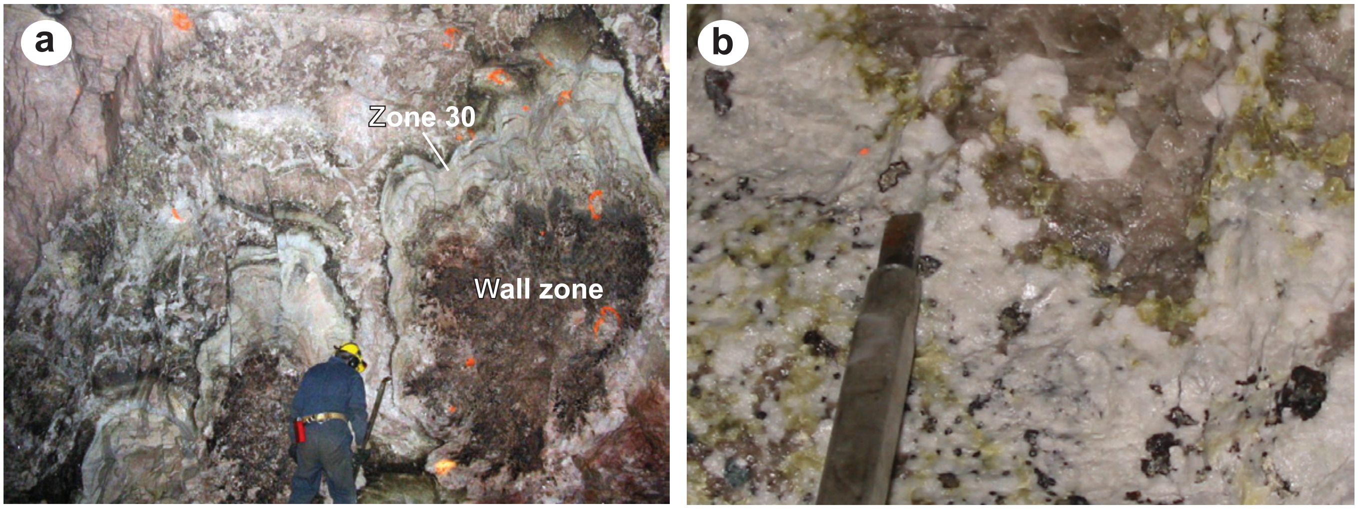


***Figure 4:** Underground photos of the Tanco mine (with permission of Sinomine). **a)** Wall zone in contact with a saccharoidal albite-quartz assemblage (located in the Beryl Pit area near the base of Zone 30). The darker patches in the lower portion of the picture (in front of and behind the person) are wall zone (Zone 20). A layer of banded pale blue saccharoidal albite (Zone 30) is drapped over the wall zone. This albite is in contact with quartz (the smoky 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; **b)** 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.*

are found at Tanco, therefore it is unknown whether the aplite in zone 45 is genetically linked to zone 30.

**Zone 50**: Upper intermediate zone (spodumene zone) – Major components include giant crystals of spodumene and quartz (in multiple co-existent textural forms) and amblygonite. Minor components include microcline-perthite, pollucite, lithiophilite, petalite, eucryptite, Ta oxides, albite and Li muscovite. Historic logs suggest the presence of minor quartz pods, triphylite, and apatite. This zone is up to 24 m thick, and generally has a gradational contact with zone 40. The lack of albite and mica differentiates this zone from zone 40. Vugs are commonly found in this zone (Černý et al., 1996), which is the most enriched in Li and is known for containing the largest spodumene crystals within the Tanco deposit.

**Zone 60**: Central intermediate zone (MQM zone) – This zone is hypothesised to be entirely metasomatic (Černý, 2005; van Lichtervelde et al., 2007). The zone displays a variety of colours including greens, yellows, and browns. It is the main zone of Ta mineralization, and commonly contains mixtures of zones 30 and 90. Major components include microcline-perthite, quartz, albite and muscovite. Minor components include beryl, Ta oxides, zircon, ilmenite, spodumene, sulphides, lithiophilite, apatite and cassiterite. This zone is medium- to coarse-grained. It is up to 45 m thick with notably sharp contacts, which occasionally grade into zones 30 and 90 (Černý et al., 1996).

**Zone 70**: Quartz zone – Zone 70 comprises massive monomineralic quartz lenses. It is difficult to distinguish in drillcore from quartz pods present in other zones and can contain minor amblygonite and spodumene. A distinctive feature of this zone is that it is often surrounded by a potassium feldspar cap which contains crystals of SQUI-oriented normal to the contact. Zone 70 represents a highly evolved pegmatitic 'core' and is found in the eastern side of the Tanco deposit. Pink quartz from this zone may contain minor petalite (Stilling et al., 2006).

**Zone 80**: Pollucite zone – This zone is almost entirely comprised of monomineralic pollucite. Minor components include quartz, spodumene, petalite, muscovite, lepidolite, albite, microcline and apatite. This zone is geochemically similar to zone 50 and is gradational between them, although it is large enough in scale to be defined as a new unit. It hosts a remarkable 75% pure pollucite unit that is commonly crosscut by late veins of lepidolite, quartz and feldspar. The late-stage alteration of pollucite to adularia and clay minerals gives it the classic 'tapioca' texture, a useful identification tool. This zone comprises several lens-like bodies found above zone 50. The largest segment of this zone is found in the east of the deposit (Černý et al., 1996).

**Zone 58**: Low-grade pollucite zone – This zone is found surrounding zone 80. Common components include pollucite mixed with SQUI, potassium feldspar, quartz, amblygonite and petalite.

**Zone 90**: Lepidolite zone – This zone is hypothesized to have formed via metasomatism, with purple lithian muscovite having replaced primary feldspar. Microlite is the dominant Ta mineral and is found intermixed with MQM alteration in this zone. Thin section microscopy and scanning electron imaging show that the microlites have strong internal zonation. Dominant minerals include Li muscovite, lepidolite and microcline-perthite. Minor components include albite, quartz, beryl, Ta oxides, cassiterite and zircon. This zone is <18 m thick and is composed predominantly of fine-grained micas. It is economically important due to high concentrations of rubidium and cesium micas, and tantalum and niobium oxides. This zone forms two major bodies which trend east-west along with multiple smaller bodies found within zone 60 (Černý et al., 1996).

**Zone 99**: K-spar zone – This zone is typically comprised of massive potassium feldspar crystals and contains minor amblygonite-montebrasite.

### *Mineralogy*

The mineralogy of Tanco is very diverse with more than 100 minerals listed in the literature (e.g., Černý et al., 1996, 1998). Tanco has yielded four holotypes of new minerals: černýite (Kissin et al., 1978), tancoite (Ramik et al., 1980), diomignite (London et al., 1987), titanowodginite (Ercit et al., 1992), ercitite (Fransolet et al., 2000), and groatite (Cooper et al., 2009). An updated listing of the mineral occurrences at Tanco can be found in Table 4. 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 Li-Cs-Ta (LCT) family, rare-element–Li subclass, complex type, subtype petalite (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 3-D 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 includes information from 102 km of drillcore in 1355 drillholes, 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 following 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).

### *Mining*

The Tanco pegmatite is situated about 60 m below Bernic Lake and is accessible from surface either via a shaft or a 400 m ramp with 20% decline (Figure 5).

Mining is carried out using the room and pillar method (Figure 6a) 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 16 m in width. 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 been completed successfully throughout the mine.

Two-boom hydraulic jumbos perform all drilling for drifts, slashes, benches and arches. During initial top-slice development, the roof is carefully arched, utilizing smooth blasting techniques. Rock bolting is rarely required because ground stress in the Tanco mine is considered low, relative to other hard rock mines. The roof arches allow residual ground stresses to be redirected to the post pillars.

The roof of mature mine workings at Tanco average 20 m above the working levels, 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 6b). Where suited, mining is carried out, utilizing a single boom Simba longhole drill. "Longhole drilling was the primary method by which the oversized pillars were reduced. The broken ore is transported utilizing different sized 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 level where it is transported to the shaft by a train of 4 ton Granby-style side dump ore cars. Tantalum and spodumene ores are stored in one of two loading pockets and skipped on a daily basis up the two-compartment shaft via 4 ton Kimberly-style skips into dedicated surface coarse ore bins. The mine, however, must produce and provide three distinct ores to the mill: Li, Ta and Cs (when the three ores are in production). 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 air ventilation 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 borehole 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. 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*

There are limitations on usable land because the mine is situated on a peninsula at Bernic Lake. Therefore, the processing 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, and 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.

Different processes are used to concentrate each product. Tantalum is processed by gravity concentration, a process that uses the density of tantalum minerals which are much heavier

**Table 4:** 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) | $Mn^{2+}$Nb2O6 |
| Tantalite-(Mn) | $Mn^{2+}Ta_2O_6$ |

| **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 | $Li(Mn>Fe)PO_4$ |
| Triphylite | $Li(Fe>Mn)PO_4$ |
| 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 | $LiAl(Si_2O_6)$ |

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

**Table 4 (continued):** Mineral occurrences at Tanco (updated from Černý 2005 and taking into account the current IMA-CNMMN nomenclature).

| **Oxides** | | **Silicates** | |
|---|---|---|---|
| Wodginite | $Mn(Sn>Ta,Ti,Fe)(Ta>Nb)_2O_8$ | Petalite | $Li(AlSi_4O_{10})$ |
| Ferrowodginite | $(Fe>Mn)(Sn>Ta,Ti.Fe)(Ta>Nb)_2O_8$ | Foitite | □$Fe^{2+}_2AlAl_6(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Titanowodginite | $(Mn>Fe)(Ti>Sn,Ta,Fe)(Ta>Nb)_2O_8$ | Schorl | $NaFe^{2+}_3Al_6(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Ferrotitanowodginite | $(Fe>Mn)(Ti>Sn,Ta,Fe)(Ta>Nb)_2O_8$ | Elbaite | $NaLi_{1.5}Al_{1.5}Al_6(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Lithiowodginite | $LiTaTa_2O_8$ | Rossmanite | □$LiAl_2Al_6(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Simpsonite | $Al_4Ta_3O_{13}(OH)$ | Feruvite | $CaFe^{2+}_3Al_5Mg(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Stibiotantalite (?) | $SbTaO_4$ | Dravite | $NaMg_3Al_6(Si_6O_{18})(BO_3)_3(OH)_4$ |
| Microlite *renamed fluorcalciomicrolite or oxycalciomicrolite* | $(Na,Ca)_2Ta_2O_6(O,OH,F)$ (see Atencio et al., 2010 for details) | Beryl | $Be_3Al_2(Si_6O_{18})$ |
| *Uranmicrolite* (after Atencio et al., 2010) | $(Na,Ca,U)_2Ta_2O_6(O,OH,F)$ | Topaz | $Al_2SiO_4(F>OH)_2$ |
| Cesstibtantite *renamed Hydroxykenomicrolite* | $(Sb,Na)_2Ta_2(O,OH)_6(OH,Cs)_1$ (after Atencio et al., 2010) | Pollucite | $(Cs,Na)(AlSi_2O_6).nH_2O$ |
| Calciotantite | $CaTa_4O_{11}$ | *Cesian analcime* | $(Na,Cs)(AlSi_2O_6).nH_2O$ |
| Rankamaite-Sosedkoite | $(Na,K)_{3-x}Al(Ta,Nb)_{10}(O,OH)_{30}$ | Holmquistite | $Li_2Mg_3Al_2(Si_8O_{22})(OH)_2$ |
| Ilmenite | $(Fe,Mn)TiO_3$ | Zircon | $(Zr,Hf)(SiO_4)$ |
| Uraninite | $UO_2$ | Thorite | $ThSiO_4$ |
| Manganite | $MnO(OH)$ | Coffinite (?) | $U(SiO_4.(OH)_4)$ |
| | | Garnet (?)* | $(Mn,Fe)_3Al_2Si_3O_{12}$ |

Abbreviation: IMA-CNMMN, International Mineralogical Association-The Commission on New Minerals and Mineral Name
*Refers to a series name
Mineral names in italic: not approved by the IMA
□ represents a vacancy

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.

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.

## *Tantalum*

The major uses for tantalum are in the electronics industry (e.g., cell phones, computers) and for cutting tools. High quality capacitors are the major single application for tantalum. Other tantalum alloys are important constituents of aircraft engines, and for acid-resistant pipes and tanks used in the chemical industry. In addition, medical applications are also of importance (e.g., used for hip-joint replacements and dental implants).

The Tanco mine has been the sole Ta producer in Canada but Ta is not currently in production at the mine. Given an increasing emphasis on sourcing this product outside of conflict areas (e.g.*,* Democratic Republic of the Congo) it is expected that Ta will be produced at Tanco in coming years.

Textural and geochemical studies of the Nb-Ta oxides from the Tanco pegmatite provided evidence for the tantalum mineralization being of magmatic origin. Interaction of fluids may have only had an indirect role in delivering minor elements such as Fe, Mn or Ca (van Lichtervelde et al., 2007). Van Lichtervelde et al. (2006) found that enclosed metagabbro rafts (part of the pegmatite country rock) had no evident chemical influence on the crystallisation of columbite-group minerals in the pegmatite. Abnormally high concentrations of Ta are spatially associated with metagabbro rafts in the mine but the influence of rafts on the Ta mineralization is more physical than chemical. The authors concluded that these rafts might have separated distinct pegmatite cells that then evolved independently of the whole pegmatite body.

### Tantalum processing

There are three main elements in the gravity concentration of minerals from Tanco: liberation of the minerals 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 three fractions: grinding/spiral circuit, fine sand circuit, and slime circuit. The circuit is configured so that free tantalum-bearing minerals are recovered ahead of primary grinding from feed material less than 2 mm in size by spirals. The grinding circuit is then closed at 0.30 mm by a Linatex hydrosizer with the underflow recirculating to the main grinding mill.

The fine sand product from the grinding circuit is dewatered by cyclones and then classified by Bartles-Stokes hydrosizers

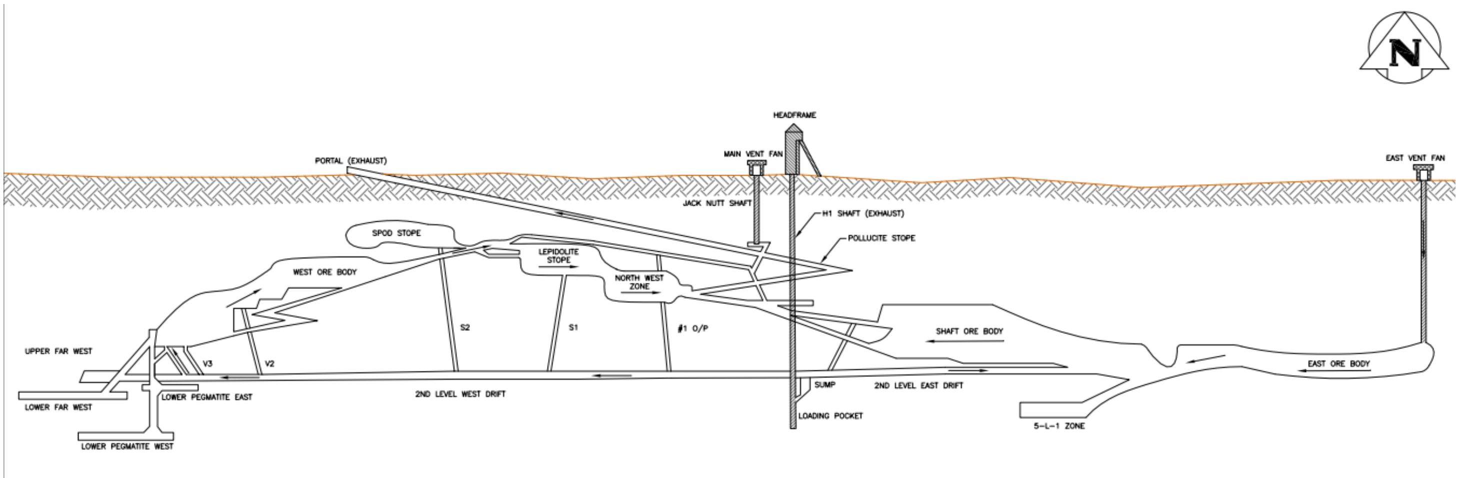


***Figure 5:*** *Idealized mine cross-section looking southwest (Tetratech, 2013).*



***Figure 6:*** *Underground photos at the Tanco mine (with permission of Sinomine):* ***a)*** *scooptram close to one of the spodumene zone pillars illustrating the room and pillar method used at Tanco;* ***b)*** *custom designed aerial lifts.*

into five separate size fractions which are essential for satisfactory separation using conventional gravity equipment. The first three coarsest size fractions from the Bartles-Stokes hydrosizer are treated by spirals for tantalum recovery. A fourth finer size fraction exceeds recoverable sizes on spirals, and is treated by Holman shaking tables. The fifth size fraction, which are slimes, report to the slime circuit. The spirals each produce a low-grade concentrate, a recirculated middling, and a tailings product. Falcon continuous concentrators (Sepro) scavenge the fine-sand tailings products. When this system was installed, this 300 g-force centrifugal separator was one of the most advanced 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, which feeds the cleaner section at a constant flow rate and density. The creation of size fractions which feed four cleaner tables is achieved by the use of hydrocyclones and a Dorr-Oliver hydrosizer. The cleaner tables produce a fine 35% $Ta_2O_5$ concentrate, where table middlings and tailings are recirculated back to the circuit for reprocessing.

Overflows from the various cyclones along with the Bartles-Stokes hydrosizer overflow constitute the feed to the ultrafines circuit. These are thickened in another bank of 2" high-pressure cyclones and treated by a flotation process. Tantalum flotation concentrate then reports to a 450 g-force Falcon centrifuge

(UF600) which was developed at Tanco specifically for treating a tantalum flotation product.

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 on 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. % $Ta_2O_5$.

### *Cesium*

Tanco produces cesium products from pollucite. Cesium can be used in magneto-hydrodynamic power generation, in aerospace applications, opto-electronics, in DNA separation, and as a catalyst in chemical applications. Cesium formate is a clear, water-soluble fluid with a specific gravity of 2.3 g/cm$^3$ and a viscosity similar to water. The main use for the pollucite mined at Tanco is in the manufacture of cesium formate brine, a calibrated drilling lubricant for high-temperature, high-pressure oil wells. It is used where the properties of low viscosity, high specific gravity, and complete solution confer significant benefits over traditional solids-based drilling fluids in wells deeper than 4575 m (Benton and Turner, 2000).

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 plant was designed to readily incorporate process changes and modifications enabling it to produce a wide variety of cesium-based products, thus allowing Tanco 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).

### *Lithium*

Spodumene can be used either as a feedstock to produce lithium carbonate, hydroxide and metal, or directly, in its mineral form, in the glass and ceramics industries. Global estimates in early 2024 by the United States Geological Survey (USGS) for end-use markets suggests that 80% of lithium production is used in batteries. Currently, LCT pegmatites account for the majority of the world’s lithium production according to data from the USGS (2024).

The Li aluminosilicate relationships at Tanco can be explained by a reaction path that shows the nature of primary Li crystallization (London, 1986, 1990; Černý et al., 1998). The hypothesized crystallization path shows an initial primary petalite phase that crystallized from a hydrous granitic melt. As the melt cooled, it crossed the petalite-spodumene reaction boundary, where the bulk of petalite reacted to form SQUI. The crystallization path then shows a period of primary spodumene growth, followed by a transition to primary eucryptite growth as the spodumene-eucryptite reaction boundary is crossed at 270 °C and 1.8 kbar (Figure 7). Extensive re-equilibration of spodumene to eucryptite did not occur, which is believed to be due to the presence of exsolved $CO_2$ liquid and lack of hydrous fluids, which could catalyse reactions (Černý and London, 1983). Černý and Ferguson (1972) found that the SQUI at Tanco had a similar bulk composi-

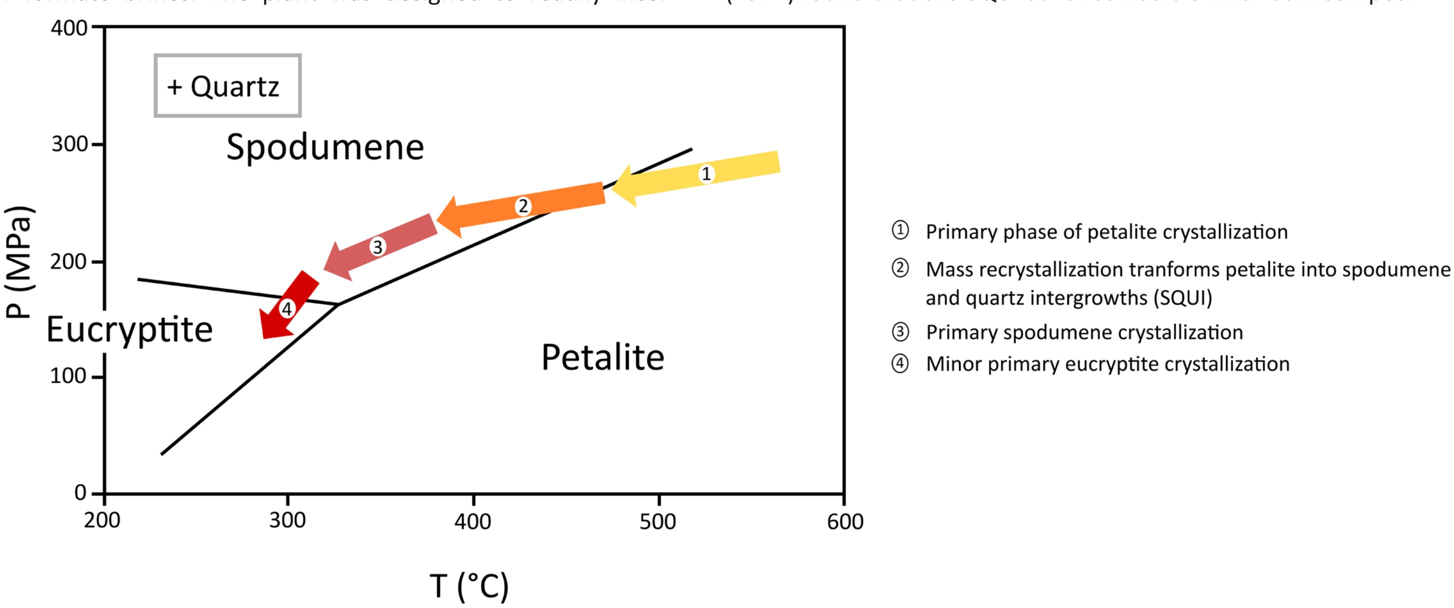


***Figure 7:*** *Li silicate phase diagram showing the proposed crystallization path of the Tanco pegmatite (adapted from London, 2008). Abbreviation: MPA, megapascals.*

tion to the petalite and therefore concluded that all spodumene and quartz intergrowths at Tanco resulted from the breakdown of petalite. The variable coarseness of SQUI, reduction in volume during recrystallization (18.6%), and subsequent silica migration is hypothesized to explain deviations from the petalite composition (Černý and Ferguson, 1972).

Recent research has shown the occurrence of three distinct textural and geochemical types of spodumene and quartz intergrowths within zones 45 and 50 (Breasley et al., 2022). These types include:

1. A classic SQUI variety which shows elongated spodumene and quartz laths which are intimately intergrown and have a dominant singular orientation (Figure 8).

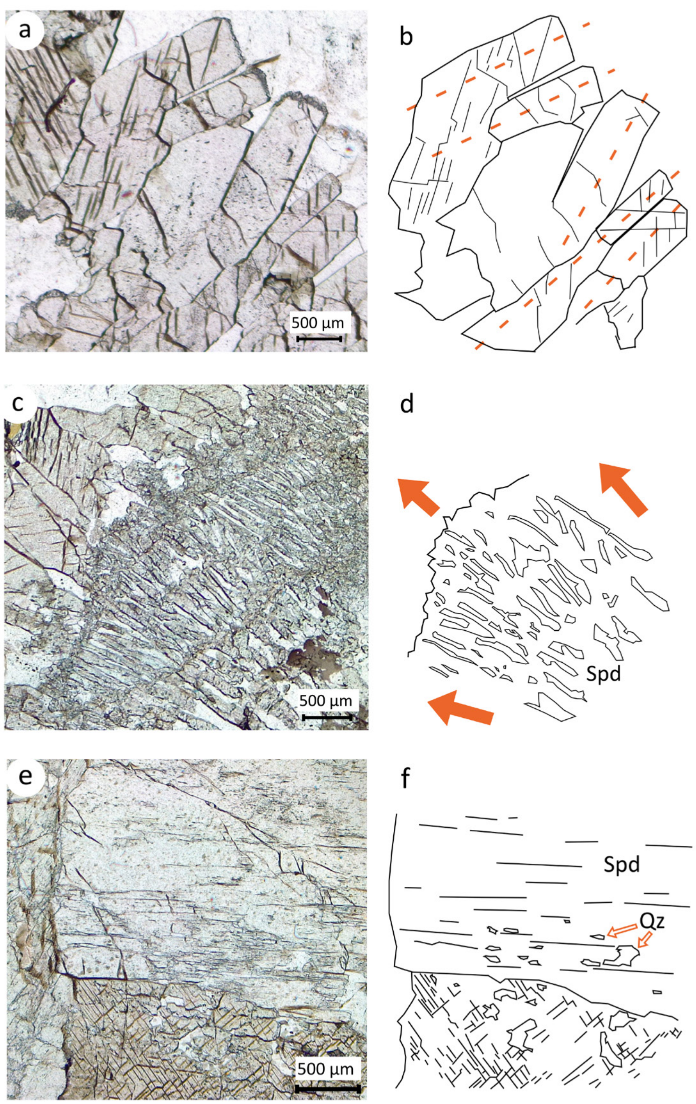


*__Figure 8:__ Microphotographs of spodumene crystals. __a)__ plain polarized light (PPL) image of classic SQUI; __b)__ digitization of representative classic SQUI showing strong crystallographic orientation of growth (orange dashed line); __c)__ PPL image of micro SQUI; __d)__ digitization of representative micro SQUI showing oriented symplectic growth (orange arrows); __e)__ PPL image of equant SQUI; __f)__ digitization of representative equant SQUI showing interlocking boundaries with surrounding crystals (after Breasley et al., 2022). Abbreviations: Qz, quartz; Spd, spodumene.*

The modal composition is highly variable with a range of spodumene to quartz ratios in thin sections. Classic green SQUI occurs proximal to gabbroic rafts and wall-rock which formed green spodumene crystals due to Fe contamination. Skeletal petalite parental crystals which are believed to have broken down into classic SQUI sometimes create bounding structures for oriented SQUI growth observed in hand sample and previously noted in the literature (Černý and Ferguson, 1972). A second variety exists termed micro SQUI

2. A second variety which is milky white, massive and microcrystalline in hand sample. This SQUI variety represents symplectic intergrowths of internally mottled spodumene (with abundant inclusions of quartz, zircon and mica) and quartz. The characteristic habit forms localized radial elongated fans of symplectite (100–600 µm) and commonly very fine intergrowths with no obvious elongated crystals of spodumene (<20–50 µm). Internal textures of micro SQUI are highly variable, and contacts with classic SQUI can be both sharp and gradational. In thin section, the micro SQUI texture is interpreted to represent fluid flow pathways with micro crystalline re-precipitation of minerals. Micro SQUI is a challenge for mineral processing as the very fine-scale intergrowths are remarkably hard and lead to issues with grinding and poor recovery during froth floatation (Breasley et al., 2023).

3. The third variety is termed macro SQUI (3) which shows angular crystal boundaries where spodumene and quartz are not intimately intergrown. Spodumene crystals grew contemporaneously with quartz, and crystals are in planar contact. The spodumene contains micro inclusions of quartz, eucryptite and mica that lack preferred orientation.

**Spodumene processing**

After crushing to <12 mm, the 2.0 mm fraction is removed ahead of the dense medium separation circuit Triflo, which rejects feldspars utilizing a Condor 300 (Sepro). A 70:30 mixture of ferrosilicon and magnetite is used to create a medium with an effective density of separation of 2.65 kg/l. The <2.0 mm fraction continues to the grinding circuit (Figure 9).

The sink product and the <2.0 mm fraction are ground in a closed circuit with a Linatex hydrosizer to produce a grinding circuit product of 95% passing 212 µm. A 5 foot (~1.5 m), low-intensity drum magnet within the grinding circuit removes ground steel produced during the grinding process.

Prior to 2009, the processing at Tanco was required to produce spodumene concentrates with $Li_2O$ values exceeding 7.0% $Li_2O$, along with specifications for $P_2O_5$, $K_2O$ and $Fe_2O_3$. These specifications were all well below 0.5%. This required a process with multiple spodumene cleaning flotation stages, an amblygonite flotation stage for the removal of $P_2O_5$, a mica removal stage

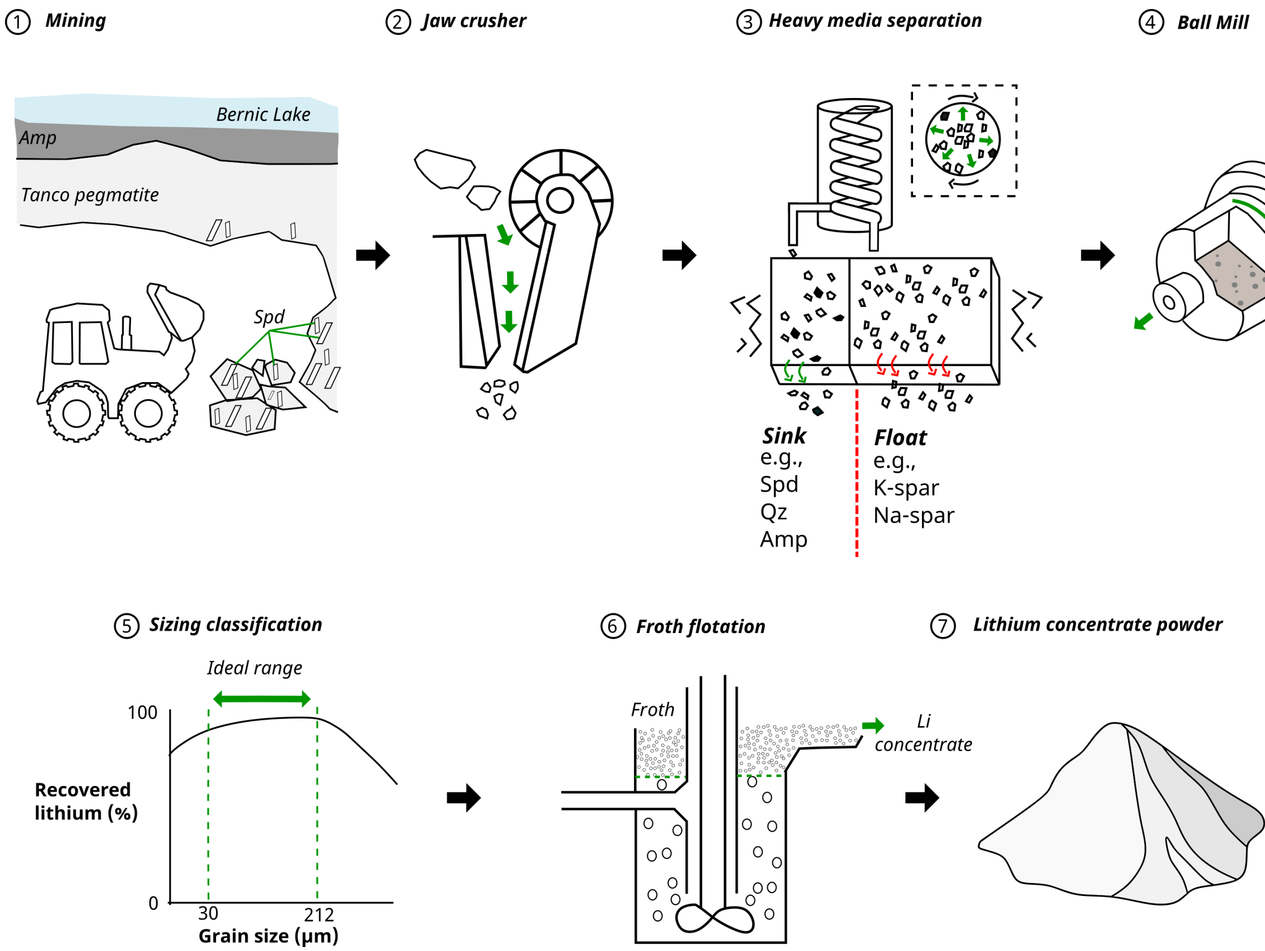


***Figure 9:*** *Schematic showing the process of mining and mineral processing of spodumene ore:* ***1)*** *Spodumene is blasted and retrieved from underground;* ***2)*** *material is reduced in size using a jaw crusher;* ***3)*** *rock chips go through heavy media separator (internal process shown in dashed box) separating sinks (>2.65 g/cm³) from floats (<2.65 g/cm³);* ***4)*** *rock chips are ground down into powder using a ball mill;* ***5)*** *grains are separated based on size;* ***6)*** *powder undergoes froth flotation;* ***7)*** *lithium concentrate powder is recovered;* ***viii)*** *lithium concentrate is transported to a chemical processing plant. Modified from Breasley et al. (2023). Abbreviations: Amp, amphibolite; K-spar, potassium feldspar; Na-spar, plagioclase; Qz, quartz; Spd, spodumene.*

for controlling $K_2O$, and selective mining combined with the use of wet high-intensity magnetics for controlling $Fe_2O_3$. The product was then filtered using a horizontal belt filter, and then dried by a propane-fired rotary drier so that it could be shipped dry by railcar.

The current spodumene product at Tanco now has a lithium specification closer to 5.5% $Li_2O$, with relaxed specifications for the elements which previously required tight control. This has allowed the Tanco spodumene flotation process to be drastically simplified as the requirements only consider the lithium grades. The process consists of a rougher flotation and a scavenger flotation. The scavenger flotation retreats the rougher flotation rejects. There is also a cleaner flotation stage to upgrade the material recovered by the scavenger flotation stage. Flotation concentrate is then filtered to a moisture of approximately 10%, and then shipped from site in bulk using highway trucks. Tantalum is currently not being recovered from the spodumene ore fed to the mill as it was in the past. This has further simplified the spodumene process as it existed pre-2009 at Tanco.

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