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Investigating textural and geochemical relations of lithium mineralization in the Tanco pegmatite, southeastern Manitoba (part of NTS 52L6)

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In Brief:

- Samples of the Tanco pegmatite were taken from underground mining faces showing different spodumene textures
- Spodumene at the Tanco pegmatite can be classified into four textural groups which show complex internal geochemical zonation highlighted by cathodoluminescence imaging and LA-ICP-MS
- Future analysis will include using micro-CT to quantify the variable proportions of spodumene and quartz ratios within intergrowths

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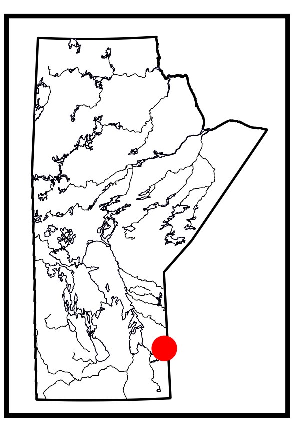

Summary

Underground samples were collected from the Tanco pegmatite in southeastern Manitoba in early May 2022 to investigate the textural varieties of spodumene and Li mineralization trends. Thin-section petrography, cathodoluminescence imaging, electron probe microanalysis, and laser-ablation inductively coupled plasma–mass spectrometry (LA-ICP-MS) were done at the University of Manitoba in late May 2022. Preliminary observations show four distinct groups of spodumene textures at Tanco: 1) classic spodumene and quartz intergrowths (SQUI) as shown by elongated unidirectional texture; 2) micro-SQUI with symplectic radial texture, replacing the classic SQUI; 3) equant SQUI, which forms larger, stubby, equant interlocking crystals; and 4) primary platy spodumene that is not necessarily associated with quartz. Cathodoluminescence imaging revealed a complex internal zonation sequence within the SQUI. Preliminary LA-ICP-MS results showed that the classic and micro-SQUI are geochemically similar, whereas equant SQUI has a highly variable trace-element composition. Future work will include subsequent LA-ICP-MS studies to determine the geochemical variability, which defines the zonation within the spodumene.

Introduction

The genesis and significant economic potential of pegmatites make them a fascinating field of study in economic geology. The Li-Cs-Ta (LCT) Tanco pegmatite in southeastern Manitoba represents one of the most economically important and fractionated pegmatitic bodies in the world. It has been the subject of numerous studies that have contributed significantly to understanding of pegmatite petrogenesis (Černý, 2005).

This project was initiated in August 2021 when two weeks of fieldwork were completed at the Tanco mine in order to collect a variety of drillcore and subsurface samples (Breasley et al., 2021). Preliminary visualization of spodumene and quartz intergrowths (SQUI) using X-ray computed tomography (micro-CT) was presented at AME Roundup 2022 (Breasley et al., 2022a). The bulk of Li mineralization at Tanco occurs as SQUI, which may have formed by the breakdown of petalite (Černý and Ferguson, 1972). Rietveld analysis of SQUI indicates that they can consist of up to 80% spodumene and 19.1% quartz (Breasley et al., 2022a). This contradicts the hypothesis of an idealized breakdown of petalite, which should result in a SQUI vol. % ratio of ~60% spodumene and ~40% quartz.

This project aims to better constrain the different types of SQUI, analyze proportional variability of spodumene and quartz within these types, and characterize compositions and timing of formation of additional Li-bearing minerals. Analysis of the compositional variability of SQUI (using X-ray computed tomography, electron backscatter diffraction, and powder X-ray diffraction Rietveld methods) will reveal information on their crystallization history. The results from this study are expected to help explain the notable lack of abundant petalite within the Li-rich zones of the pegmatite examined here. Furthermore, studying variability of the SQUI groups at Tanco is of economic importance to the mineral processing protocols for different styles of mineralization.

Due to unprecedented high-water levels in the region, access to the Tanco mine as initially planned did not take place. Fieldwork conducted at the Tanco mine in early May 2022 consisted of subsurface sampling instead. A range of subsurface samples were collected to investigate the textural variability of Li mineralization, enrichment in different zones, and spatial trends within the pegmatite. The work carried out at the University of Manitoba involved analysis of the samples collected in 2021, including thin-section petrography, cathodoluminescence (CL) imaging, electron probe microanalysis (EPMA),

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and laser-ablation inductively coupled plasma–mass spectrometry (LA-ICP-MS). These analytical results were presented at the Goldschmidt 2022 meeting (Breasley et al., 2022b), and are summarized in this report.

Geological setting

The Tanco pegmatite is part of the Bernic Lake group of pegmatites of the Cat Lake–Winnipeg River pegmatite district in southeastern Manitoba (Figure GS2022-4-1). This district is situated in the southern limb of the Bird River greenstone belt (2.75–2.72 Ga; Gilbert, 2006). Rock assemblages within the belt are separated into northern and southern assemblages constituting part of the Archean Superior province.

The Bernic Lake formation (2724.6 ±1 Ma; Gilbert, 2008) is a 2 by 45 km, dominantly mafic, volcanic-rich unit. It is located in the southern assemblage of the Bird River greenstone belt and hosts the Tanco gabbro, into which the Tanco pegmatite was emplaced. The Tanco gabbro crystallized at 2723.1 ±0.8 Ma and was subsequently metamorphosed along with surrounding lithologies of the region in an amphibolite-grade Abukuma-style system (Černý, 2005; Gilbert, 2008; Kremer, 2010). The Tanco gabbro and Bernic Lake formation are hypothesized to have formed during a single episode of magmatism because of their similar ages and spatial relationships (Kremer, 2010). Gilbert (2006, 2007, 2008) provided detailed descriptions of the various lithologies of the Bird River greenstone belt.

The extensive Cat Lake–Winnipeg River pegmatite district is divided into two subdistricts: the Winnipeg River and the Cat Lake–Maskwa Lake subdistricts (Černý et al., 1981). The Bernic Lake pegmatite group that hosts the Tanco pegmatite forms part of the Winnipeg River subdistrict. The multiple pegmatites of the Bernic Lake group are notably enriched in Li, however Li enrichment in the Tanco pegmatite far exceeds the volume and grade of mineralization of the other Li-rich pegmatites of the group.

Tanco pegmatite

The morphology of the Tanco pegmatite intrusion is bilobate, with maximum dimensions of 1520 m in length, 1060 m in width and 100 m in thickness (Černý, 2005). Uranium-lead tantalite dating (Camacho et al., 2012) showed an intrusive age of 2641 ±3 Ma, similar to a U-Pb zircon age of 2647.4 ±1 Ma reported by Kremer (2010). These data are concurrent with the hypothesized reactivation of the Bernic Lake shear zone during the period of ca. 2650–2640 Ma, which facilitated emplacement

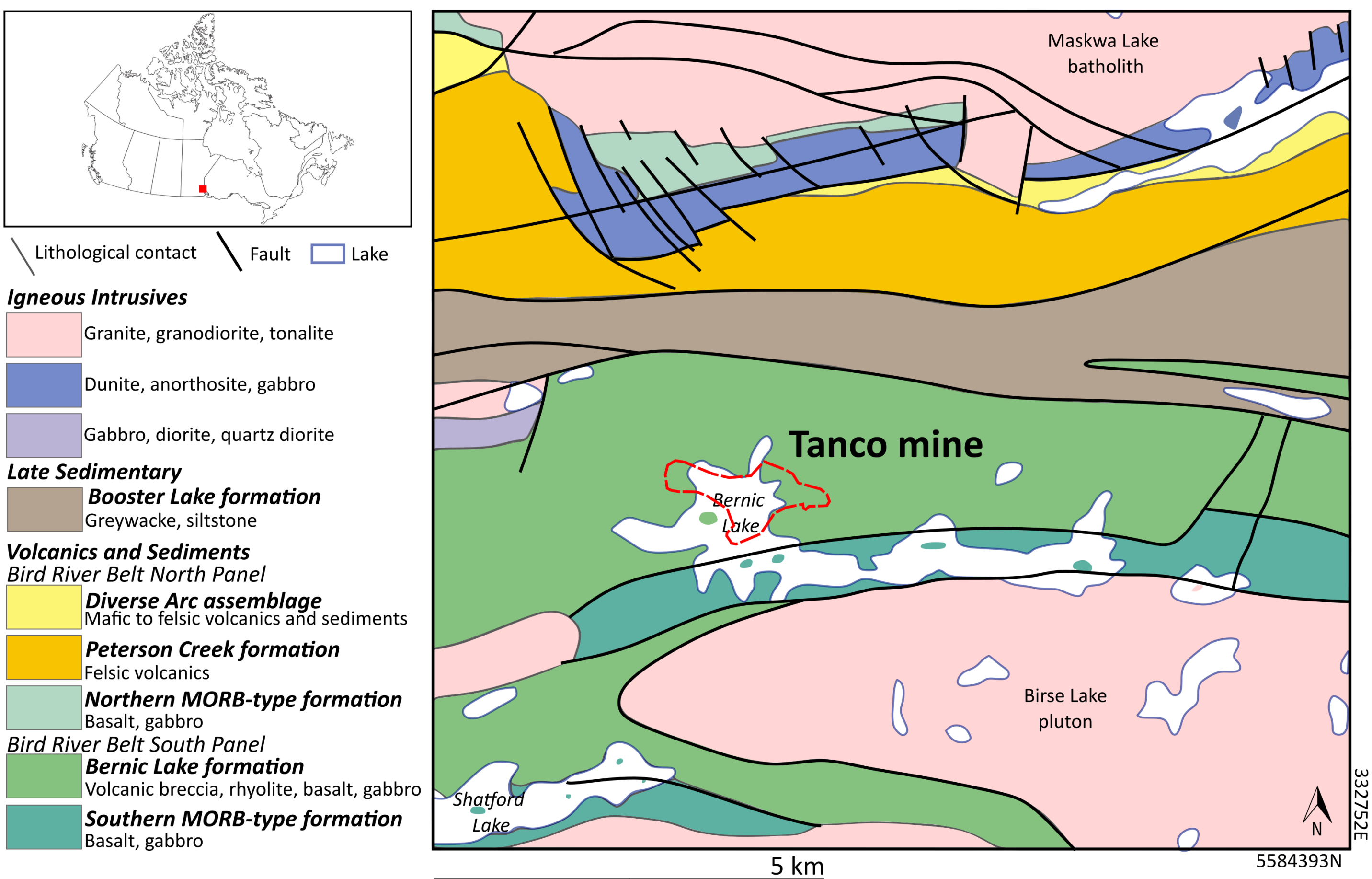


Figure GS2022-4-1: Location and local geology surrounding the Tanco pegmatite (dashed red outline; Stilling et al., 2006) in southeastern Manitoba. Adapted from Breasley et al. (2021) and Gilbert (2008). Abbreviation: MORB, mid-ocean–ridge basalt.

of the igneous body along the west-trending fault system in the surrounding area (Kremer, 2010; Martins et al., 2013).

The Tanco pegmatite is classified as a petalite subtype, attributed to complex LCT pegmatites (Černý and Ercit, 2005). The mineralogy of the Tanco pegmatite lacks considerable petalite; spodumene is the dominant Li aluminosilicate phase. Spodumene and quartz intergrowths that form the bulk of Li mineralization are hypothesized to have formed via the breakdown of petalite as a re-equilibration reaction. The pegmatite has a peraluminous composition that is generally depleted in Fe, Mg and Ca (Stilling et al., 2006). Other Li minerals used to classify pegmatites, such as lepidolite, amblygonite-montebrasite and primary spodumene, are also present (Černý, 2005).

Mineralized zones

Tanco has been divided into nine major mineralized zones (zones 10 to 90), which contain several subzones differentiated on the basis of their differences in mineralogy, geochemistry and textures (Figure GS2022-4-2). The nature of zonation and geo-

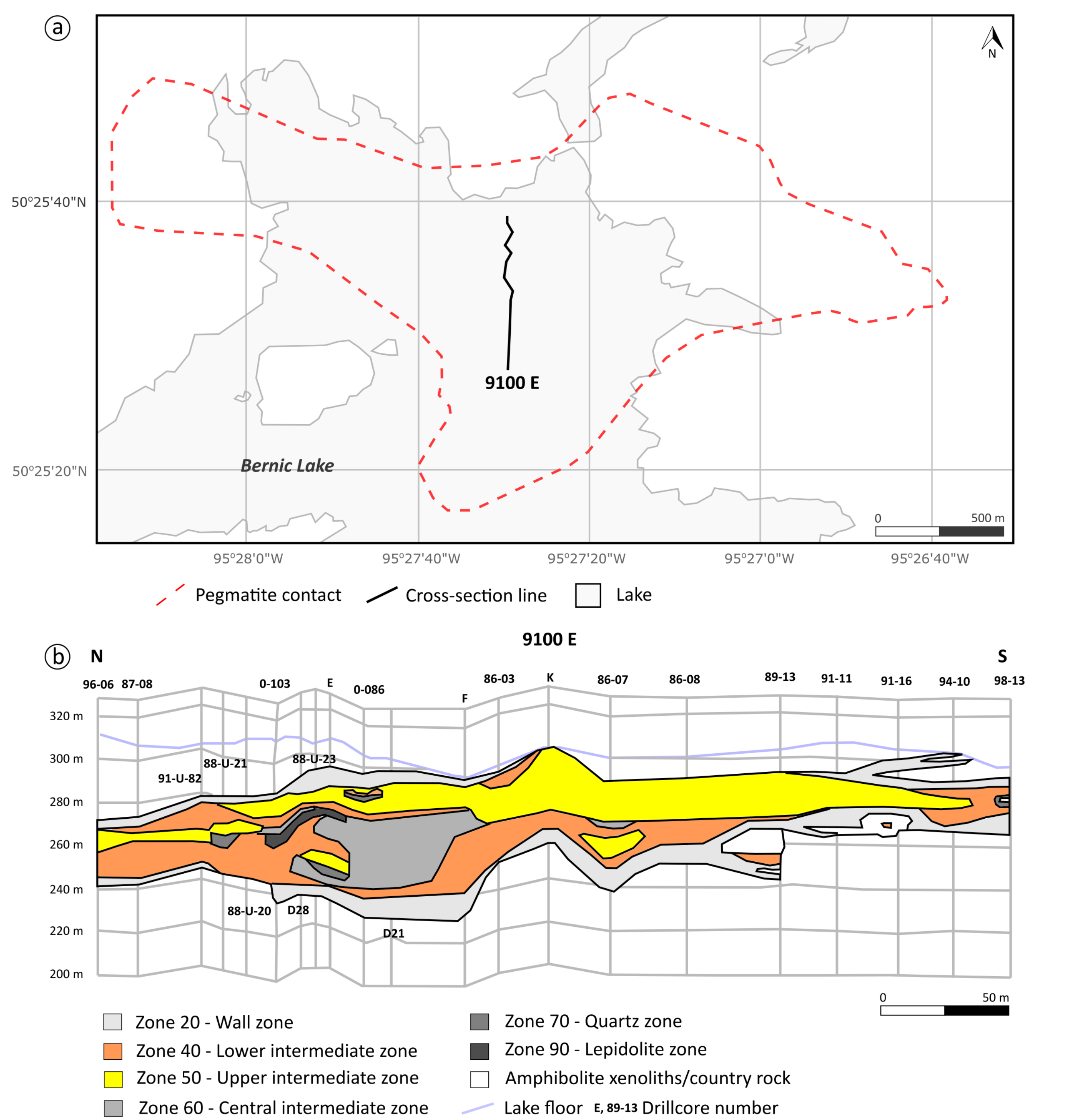


Figure GS2022-4-2: ***a)*** *Location of Tanco pegmatite and line of cross-section shown in (b);* ***b)*** *Cross-section of zones based on drillcore data (adapted from Stilling et al., 2006, Figure 6).*

graphical location of the zones at Tanco reveals information on the evolution of the pegmatite melts and Li mineralization over time. Previous works (Černý et al., 1998; Černý, 2005; Stilling et al., 2006) presented detailed descriptions of these zones. In this report we present an overview of the Tanco zones detailed in the literature and in historical core logs written by Tanco mine geologists, and include descriptions of several subzones.

Zone 01 (overburden): Lake and till sediments.

Zone 05 (host rock): The host rock is generally called amphibolite, but it is much more diverse and gabbroic in composition in some areas. The amphibolite host rock surrounding Tanco comprises 54% Fe-hornblende, 37% plagioclase (An_{38}), 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 portions of the Tanco pegmatite that crystallized first. It is composed of a very thin band of quartz and albite, which locally penetrates the host rock. This zone, less than 30 cm thick, 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. The mineralogy of this zone is composed predominantly of megacrystic microcline-perthite, quartz, albite and curvilamellar lithian muscovite. Minor components include beryl, tourmaline, muscovite, lithian muscovite and perthite. Some notable features of this zone include red perthite, exocontact tourmaline growths perpendicular to the contact with country rock, and white beryl. This zone hosts giant potassium feldspar phenocrysts in a 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 pegmatites are simple in mineralogy, and not enriched in metals. They are 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, with minor tantalum oxides, beryl, apatite, tourmaline, cassiterite, ilmenite, zircon and sulphides. This zone is generally pale blue-white and contains dark brown and black clots of remobilized Ta/Nb–bearing minerals. The blue colour is attributed to micro-scale blades of massive 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. Another interesting feature of this zone includes the presence of a 'beryl fringe' at contact zones with other units (Stilling et al., 2006) and the typical association with Ta and Nb mineralization. Some spatial trends of this zone include ragged lenses of mineralization in the eastern area of the pegmatite, where they are found beside the wall zone, 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 – muscovite and quartz after microcline (MQM) zone): In this zone, the abundance of zone 30 aplite is greater than zone 60 MQM secondary alteration. The rock in this zone is typically green or white, with coarser crystalline growth than the massive blue albite. This zone often contains beryl and is associated commonly with Ta mineralization.

Zone 39 (aplitic albite – lepidolite zone): Zone 30 albite is more abundant in this zone than zone 90 lepidolite.

Zone 40 (lower intermediate (mixed) zone): This zone is highly internally variable and is often used to describe chaotic zones in historical drillcore. Common components include microcline-perthite, albite, quartz, spodumene (with SQUI crystals up to 2 m in length) and amblygonite. Minor components include lithian 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-dominant minerals (Černý et al., 1996).

Zone 45 (low-grade spodumene zone): This zone represents the mixed zone but is more enriched in SQUI. It has a higher sodium content than zone 50, with common blue-white aplite bands and patches. Thin-section analysis revealed a highly complex internal mineralogy, indicative of high-temperature remobilization processes, including relatively high-temperature/pressure spodumene phases. However, multiple generations of aplite are found at Tanco, therefore it is unknown whether the aplites in zone 45 are genetically linked to those in zone 30.

Zone 50 (upper intermediate (spodumene) zone): Major components in this zone include giant crystals of spodumene and quartz (in multiple co-existent textural forms) and amblygonite. Minor components include microcline-perthite, pollucite, lithiophilite, petalite, eucryptite, tantalum oxides, albite and lithian muscovite. Historical drill 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 (MQM) zone): This zone is hypothesized to be entirely metasomatic in origin and displays a variety of colours, including green, yellow and brown. 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, tantalum 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 that locally are seen to grade into zones 30 and 90 (Černý et al., 1996).

Zone 63 (MQM (aplitic albite) zone): This zone is a mixture between zones 60 and 30. MQM is found as green, coarser micaceous domains with blue aplitic albite and common white beryl. MQM is found in greater abundance in this zone than in the aplitic albite zone.

Zone 69 (MQM (lepidolite) zone): This is a mix of zones 60 and 90, with MQM in greater quantities than lepidolite. Lepidolite can range from fine micro-crystals to fine interlocked equant growths.

Zone 67 (quartz-rich MQM zone): This is a mixture of zones 60 and 70 (the quartz zone), with quartz being the dominant mineral.

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 that contains crystals of SQUI oriented normal to the contact. Zone 70 represents a truly highly evolved pegmatitic 'core' and is found in the eastern side of the Tanco deposit. Pink quartz of this zone is noted to contain minor petalite (Stilling et al., 2006).

Zone 80 (pollucite zone): This zone is almost entirely composed of monomineralic pollucite. Minor components include quartz, spodumene, petalite, muscovite, lepidolite, albite, microcline and apatite. This zone is geochemically part of zone 50 and is gradational between them, although it is large enough in scale to be defined as a new unit. It hosts a remarkably pure (75%) pollucite unit and is commonly crosscut by late veins of lepidolite, quartz and feldspar. This zone comprises several lens-like bodies found above zone 50. The largest segment of this zone is found in the eastern portion of the Tanco pegmatite (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 from metasomatism, with purple lithian muscovite having replaced primary feldspar. Microlite is the dominant tantalum mineral found intermixed with MQM alteration in this zone. Thin-section microscopy and scanning electron microscopy (SEM) imaging revealed microlite crystals to be highly internally zoned. Dominant minerals include lithian muscovite, lepidolite and microcline-perthite. Minor components include albite, quartz, beryl, tantalum oxides, cassiterite and zircon. This zone is <18 m thick and is composed predominantly of fine-grained micas. It is economically important because of high concentrations of rubidium and cesium micas, and tantalum and niobium oxides. This zone forms two major bodies that trend east-west, along with multiple smaller bodies found within zone 60 (Černý et al., 1996).

Zone 93 (lepidolite–aplitic albite zone): This is a mixture of zones 90 and 30. Lepidolite is found in greater abundance here than in the aplitic albite zone.

Zone 96 (lepidolite-MQM zone): This zone contains a mix of zones 90 and 60, with the lepidolite being the main mineralization.

Zone 99 (potassium feldspar zone): This zone is typically composed of massive potassium feldspar crystals, and contains minor amblygonite-montebrasite.

Lithium at Tanco

Lithium is a critical element because it plays a major role in the global transition to green energy sources as a vital component in rechargeable batteries. Studying the nature of mineralization and Li distribution is therefore key to understanding the behaviour and mechanism of concentration of this important element.

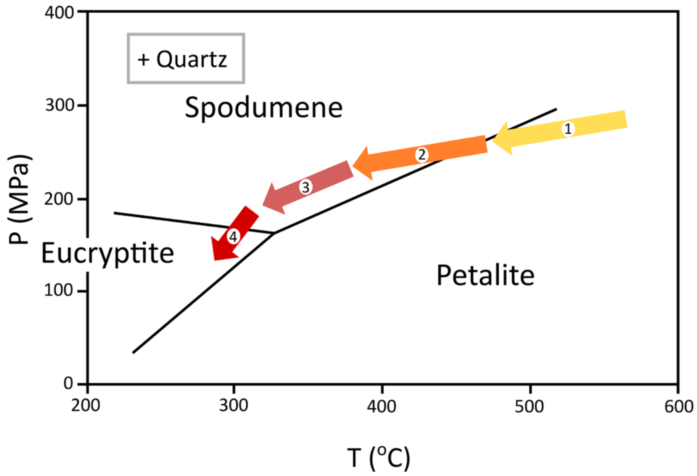
The Li aluminosilicate relationships at Tanco can be explained by a reaction path that shows the nature of primary Li mineral crystallization (London, 1986, 1990, 2008; Černý et al., 1998). The crystallization path shows an initial primary petalite phase that crystallized from a hydrous granitic melt. As the melt cooled, it crossed the petalite-spodumene reaction boundary, where the bulk of petalite is hypothesized to have broken down into 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 (180 megapascals (MPa); Figure GS2022-4-3).

Extensive re-equilibration of spodumene to eucryptite did not occur, due to the presence of exsolved CO_2 liquid and lack of hydrated fluids, which inhibit breakdown of spodumene (Černý and London, 1983). Černý and Ferguson (1972) found that the SQUI at Tanco had similar bulk composition to petalite, and therefore concluded that all spodumene and quartz intergrowths at Tanco were a result of the breakdown from petalite. The variable coarseness of SQUI, reduction in volume during recrystallization (18.6%), and subsequent silica migration are hypothesized to explain the deviations from the petalite composition (Černý and Ferguson, 1972).

There are multiple Li-bearing minerals at Tanco, such as lithian mica, which are abundant in the lepidolite zone (zone 90). Little research has taken place to assess the Li distribution between these mineral phases, which could have economic value.

Lithium-bearing minerals

The Tanco pegmatite is well known for its extensive mineralogy, with in excess of 100 minerals having been identified (Černý, 2005; Martins et al., 2013). This report addresses and describes the Li-bearing mineral phases. A full description of the other



① Primary phase of petalite crystallization

② Mass recrystallization tranforms petalite into spodumene and quartz intergrowths (SQUI)

③ Primary spodumene crystallization

④ Minor primary eucryptite crystallization

Figure GS2022-4-3: *Li silicate phase diagram showing the proposed crystallization path of the Tanco pegmatite (adapted from London, 2008, Figure 7-7). Abbreviations: MPa, megapascals; P, pressure; T, temperature.*

minerals at Tanco may be found in Černý et al. (1996) and Černý (2005). A summary of these mineral descriptions can be found in Breasley et al. (2021).

Silicates

Li aluminosilicates

Petalite occurs in zones 50 and 80 (Černý and Ferguson, 1972). Petalite is uncommon in the Tanco pegmatite and is thought to have been mostly replaced by SQUI (London, 1986, 1990; Černý et al., 1998).

Spodumene is typically milky white in colour, except near the contacts with gabbroic rafts where it can be pale green. It ranges in size from micro-SQUI texture to megacrysts up to 2 m long (Černý and Ferguson, 1972). Černý and Ferguson (1972) described three different types of spodumene at the Tanco pegmatite: 1) secondary breakdown product of petalite into SQUI; 2) primary spodumene; and 3) spodumene that has broken down and recrystallized into spodumene and quartz. The recrystallized type of spodumene is distinct from SQUI and occurs as coarser crystals that lack the intimate intergrowth textures shown by SQUI. Lithium is currently being mined at Tanco from zones 40 and 50, where 90% of the spodumene is SQUI.

Eucryptite at Tanco is grey to pink, with a distinct red-orange fluorescence in ultraviolet light (Černý, 1972). Crystals are up to 4 cm long and are intergrown with SQUI or in crosscutting vein structures.

Tourmaline

Tourmaline is easily distinguishable and abundant in many zones. In zones 10, 20, 30 and 60, the tourmaline crystals tend to be brown or black, and locally are green in colour. Pink and green tourmalines are found in zones 40 and 50 (Selway et al., 2000b). Tourmalines present a detailed geochemical evolution series and are also found in contact zones with the country rock (Selway et al., 2000a).

Elbaite is a common Na-Li–bearing tourmaline at Tanco. It can be found in a variety of colours, including pink (locally rubellite), green and blue (due to iron content; Selway et al., 2000b).

Rossmanite (the X-site-vacant variety of tourmaline) is present at Tanco, often found as either core or rim of evolved zoned elbaite in zone 40 or 50 (Selway et al., 2000b).

Micas

A wide variety of micas are present in nearly all zones of the Tanco pegmatite. There are noticeable changes in the growth habits of micas, from curvilinear 'ballpeen' crystals to normal micaceous books (Figure GS2022-4-4). The mica crystallography and chemistry at Tanco were described by Rinaldi et al. (1972) and were investigated in relation to Ta mineralization by Van Lichtervelde et al. (2008). Micas at Tanco exist as a substitution series of dioctahedral muscovite (which contains Al>Li) to trioctahedral lepidolite (which contains Li>Al; Van Lichtervelde et al., 2007).

Although zone 90 is termed the lepidolite zone, the dominant mineral in this zone is fine equant growths of lithian muscovite. These purple equant intergrowths show the highest Li contents on average out of all the micas at Tanco (7% Li_2O; Van Lichtervelde et al., 2008). True lepidolite (trilithionite-polylithionite) is found in association with lithian muscovite in zone 90.

Other silicates

Holmquistite occurs in association with epidote, chlorite, albite, calcite, titanite, iron/titanium oxides and quartz in country rock close to contacts with the pegmatite.

Holmquistite is interpreted to have been formed in a late-stage crystallization event, as veins crosscut the previously metasomatically altered country rock. Holmquistite in the Tanco country rock is interpreted to have replaced actinolite (London, 1986).

Phosphates

Amblygonite-montebrasite

Mineral phases from the amblygonite-montebrasite series occur as large primary crystals up to 1.5 m in size but can also be present as smaller tabular aggregates (1–3 cm in size). Montebrasite can be present as a secondary phase along grain boundaries and fractures (Černá et al., 1972). Amblygonite occurs in three main zones of Tanco as white, pink and yellow crystals with vari-

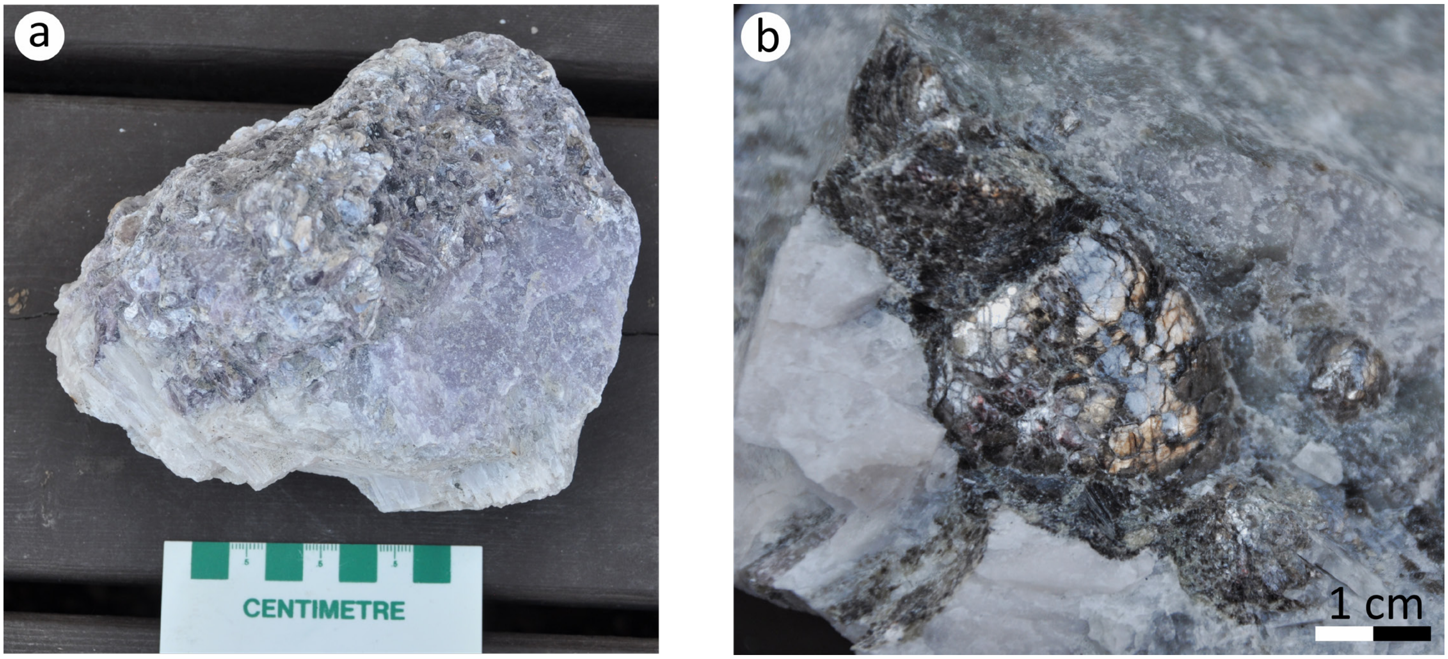


Figure GS2022-4-4: *Images of micas from Tanco showing different growth habits:* ***a)*** *pale purple lithian muscovite crystallized in mesh of mica books (1–3 cm);* ***b)*** *ballpeen mica growth habit of muscovite.*

able fluorine content (4–6.8%; Černá, 1970). Fluorine content is associated with the colour sequence of amblygonite at Tanco, with decreasing fluorine content leading to a transition from pink to white to yellow in the amblygonite (Černá, 1970). Where in its primary form, amblygonite is commonly replaced by fluorine-poor montebrasite via late-stage hydrothermal alteration (Černá, 1970; Černá et al., 1972).

Lithiophosphate and lithiophilite

Lithiophosphate is found as a secondary assemblage from hydrothermal alteration of zone 50 (Simpson, 1974). Lithiophosphate can be found in crystals up to 5 cm in size and is often found in association with quartz, cesian analcime and cookeite as cavity infills (Černý, 1972). Lithiophilite is found in a series with triphylite in zones 10 through to 60 (Černý et al., 1996). It occurs as coarse brown-orange crystals up to 40 cm in size.

Tancoite

Tancoite is an orthorhombic-dipyramidal anhydrous phosphate discovered at Tanco (Ramik et al., 1980). It is typically found in association with lithiophosphate and apatite in zone 50, within secondary hydrothermal vugs.

Clay minerals

Generally, clays at Tanco formed only as a result of secondary breakdown reactions and hydrothermal alteration.

Cookeite is often found as a breakdown product of spodumene and is associated with muscovite. Cavities in zones 40 and 50 host cookeite and it is also found as an epitaxial growth on earlier phases in zones 50 and 60 (Černý, 1972).

Preliminary results

Petrography

Thin-section petrography was used to devise a textural grouping scheme for the spodumene at the Tanco mine from zone 50 (Breasley et al., 2022b).

1) Classic SQUI (Figure GS2022-4-5a, b) shows elongated spodumene and quartz laths, which are intimately intergrown and have a dominant singular orientation. The modal composition is highly variable, with a range of spodumene to quartz ratios visible in thin section. The crystals show prominent cleavage and lack internal mottling. Classic SQUI contains a varied suite of crystal sizes, grouped here into fine (<0.5 cm), medium (0.5–1 cm), and coarse (>1 cm). Classic green SQUI occurs proximal to gabbroic rafts and wallrock, which formed green crystals from Fe contamination. Petalite parental skeletal crystals, which are hypothesized to have broken down into classic SQUI, locally create bounding structures for oriented growth observed in hand sample, and were previously noted in the literature (Černý and Ferguson, 1972).
2) Micro-SQUI crystals (Figure GS2022-4-5c, d) are milky white, massive, and microcrystalline in hand sample. This SQUI variety represents symplectic intergrowth 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 in length) and commonly textures of very fine intergrowths with no

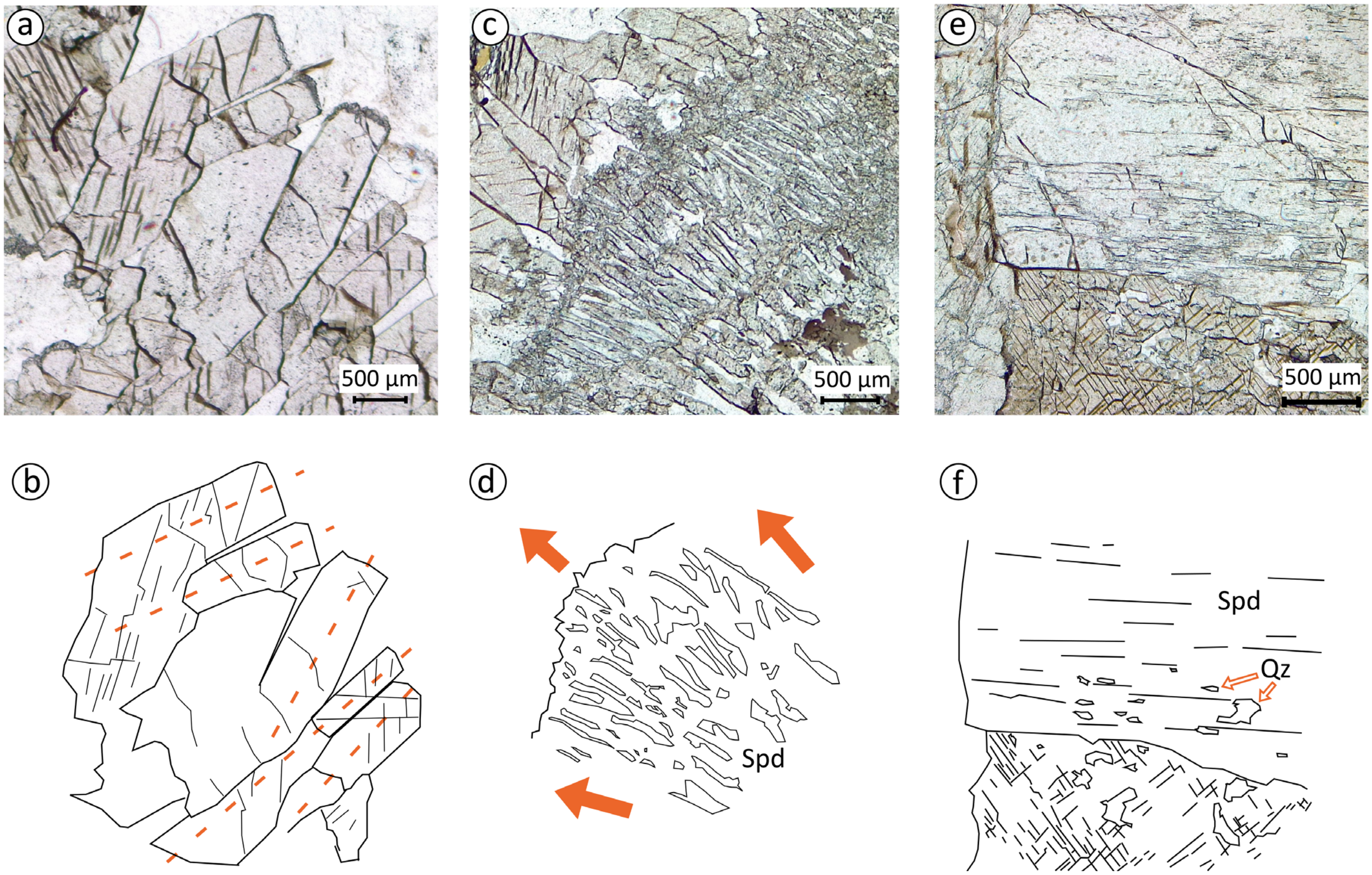


Figure GS2022-4-5: *Photomicrographs and schematic representations of different varieties of spodumene-quartz intergrowth (SQUI; adapted from Breasley et al., 2022b):* ***a)*** *PPL image of classic SQUI;* ***b)*** *digitization of representative classic SQUI showing strong crystallographic orientation of growth (orange dashed line);* ***c)*** *PPL image of micro-SQUI;* ***d)*** *digitization of representative micro-SQUI showing radial symplectic growth (highlighted by orange arrows);* ***e)*** *PPL image of equant SQUI;* ***f)*** *digitization of representative equant SQUI showing interlocking boundaries with surrounding crystals. Abbreviations: PPL, plane polarized light; Qz, quartz; Spd, spodumene.*

obviously elongated crystals of spodumene (<20–50 µm in length). Samples have a high internal textural variability and are in both sharp and gradational breakdown contacts with classic SQUI. In thin section, the micro-SQUI texture is interpreted to represent fluid-flow pathways, with microcrystalline reprecipitation of minerals (Figure GS2022-4-5c).

3) Equant SQUI (Figure GS2022-4-5e, f) shows angular crystal boundaries, and spodumene and quartz are not intimately intergrown. Spodumene crystals grew contemporaneously with quartz, and crystals are in planar contact. Spodumene contains micro inclusions of quartz, eucryptite and mica that lack preferred orientation.
4) Primary spodumene forms larger platy crystals of monomineralic spodumene. It is locally found in association with quartz, but commonly occurs as large monomineralic masses.

Cathodoluminescence imaging and electron probe microanalysis

The use of cathodoluminescence (CL) imaging revealed highly complex internal zoning within spodumene grains (Figure GS2022-4-6). The internal zoning can be caused by trace-element variations within the spodumene, as well as structural variations (Wise and Brown, 2019). Electron probe microanalysis (EPMA) of the spodumene showed minimal variation of bulk elements between spodumene from all sample groups. The silicate values of all EPMA points were averaged for internal LA-ICP-MS calibration.

Laser-ablation inductively coupled plasma–mass spectrometry

Trace-element compositions of spodumene were determined using a combination of LA-ICP-MS points and linear ablations. Due to mass interferences, two ablations were used per point and line to minimize data error (low resolution: 55 µm, and medium resolution: 80 µm). Similar CL-zoned regions were selected for each resolution, to maximize comparability of points between low and medium resolutions. The external standard used was NIST 610 synthetic glass; the internal standard used was silicate values from EPMA. A known ‘unknown’ of BCR basalt (400 ppm Li) was also used as an internal standard. The low-resolution data acquisition included analyses for Li, Be, Mg, Al, Mn,

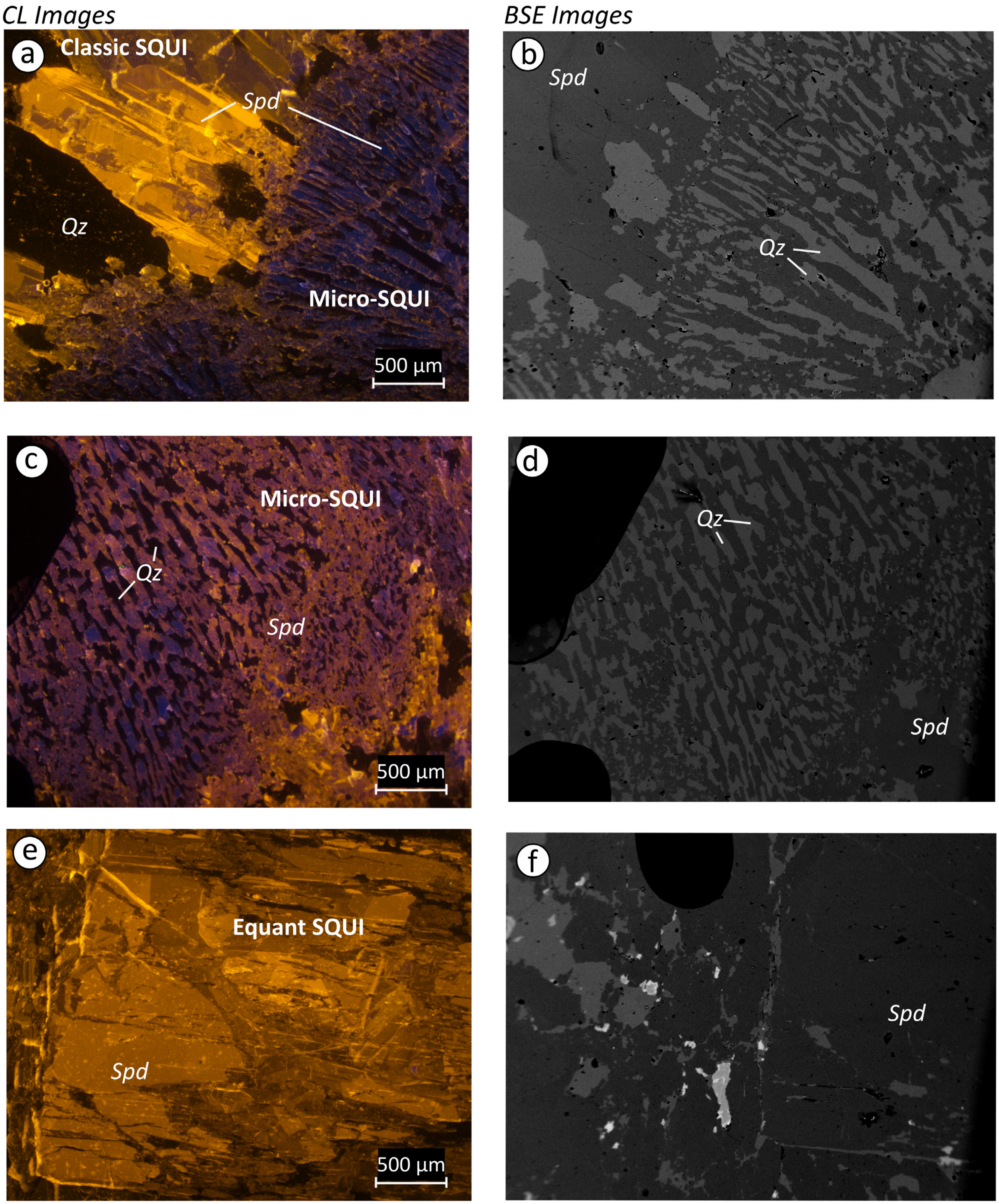


Figure GS2022-4-6: *Cathodoluminescence (CL) and backscattered electron (BSE) imagery of different spodumene samples (all photos are at the same scale):* ***a)*** *sample 22 SII SQUI A showing classic SQUI and second generation of micro-SQUI growth (blue symplectite fan);* ***b)*** *BSE image of classic and micro-SQUI showing notable lack of zonation;* ***c)*** *sample 91-14 B4C1 C showing micro-SQUI texture;* ***d)*** *BSE image of micro-SQUI;* ***e)*** *sample 91-9 B4C1 K showing equant SQUI with chaotic zonation;* ***f)*** *BSE image of equant SQUI. Abbreviations: Qz, quartz; Spd, spodumene.*

Co, Ni, Zn, Rb, Zr, Sn, Cs, Ba, Hf, Ta and Tl. Medium-resolution measurements included Na, K, V, Cr, Fe, Ge and Nb.

Preliminary results

Classic and micro-SQUI are generally geochemically similar when found adjacent to one another in thin section but show different concentrations of Mn, Sn and Ge. Green classic SQUI show highest Fe contents in all of the classic SQUI category. Equant SQUI show little geochemical trace-element similarities to classic and micro-SQUI.

Future work

Subsequent studies will further utilize micro-CT to visualize and quantify the variable proportions of spodumene to quartz in SQUI. Breasley et al. (2021, 2022a) showed that the density differences between spodumene and quartz crystals are sufficient to provide contrast on micro-CT scans in 2-D and 3-D to an impressive level of detail. This method will be developed and used to create 3-D renderings of the different groups of SQUI presented in this report. Origins and formation conditions of the spodumene, and textural and geochemical variability of the different groups will be examined and delineated. The abundance of SQUI at Tanco provides a unique opportunity to constrain this information.

Studying the variety of Li-bearing minerals will give insight into the Li partitioning between crystalline phases during melt crystallization and subsequent metasomatism. Microprobe analysis, LA-ICP-MS, and powder X-ray diffraction will aid in this part of the study, as well as the attempt to identify petalite.

Economic considerations

Pegmatites are lucrative exploration targets because of their potential to host significant enrichments of critical elements (Linnen et al., 2012). Lithium, cesium and tantalum are all recognized as critical minerals by the Government of Canada (2021). This project focuses on lithium, which is currently used mainly in rechargeable batteries (U.S. Geological Survey, 2022). This battery technology will undoubtedly play a significant role as the world transitions to a decarbonized economy (Zubi et al., 2018). Therefore, studying pegmatites that contain economic quantities of these elements will be key to maintaining the economic competitiveness and resource security of Canada into the future. Minor associations of other economically important elements at Tanco are notable, such as Be and Rb.

The province of Manitoba has multiple sources of Li associated with Li-bearing pegmatites and brines (Manitoba Geological Survey, 2022). The Tanco pegmatite, which is the focus of this study, is the most economically viable. The research avenues detailed in this report explore the nature of Li mineralization and distribution trends within Tanco, which will have implications for targeting and understanding Li sources elsewhere. Future work will help confirm the trends seen in the mine and allow the quantification of Li in different minerals to show the behaviour of the highly volatile nature of this element during primary crystallization and post-crystallization remobilization.

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References

Breasley, C.M., Martins, T., Groat, L.A. and Linnen, R.L. 2021: Results of a preliminary investigation into the lithium mineralization, distribution trends and remobilization in the Tanco pegmatite, southeastern Manitoba (part of NTS 52L6); *in* Report of Activities 2021, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 8–17, URL <https://manitoba.ca/iem/geo/field/roa21pdfs/GS2021-2.pdf> [May 2022].

Breasley, C.M., Linnen, R.L., Barker, I.R., Groat, L.A. and Martins, T. 2022a: Utilizing X-ray computed tomography to visualise lithium silicate minerals: insights into mineralization at the Tanco pegmatite, Manitoba; AME Roundup 2022, January 31–February 3, 2022, Vancouver, British Columbia, poster presentation.

Breasley, C.M., Martins, T., Linnen, R.L. and Groat, L.A. 2022b: Textures and trace element geochemistry of spodumene at the Tanco pegmatite, Manitoba, Canada; Goldschmidt 2022, July 10–15, 2022, Honolulu, Hawaii, poster presentation.

Camacho, A., Baadsgaard, H., Davis, D.W. and Černý, P. 2012: Radiogenic isotope systematics of the Tanco and Silverleaf granitic pegmatites, Winnipeg River pegmatite district, Manitoba; The Canadian Mineralogist, v. 50, no. 6, p. 1775–1792.

Černá, I. 1970: Mineralogy and paragenesis of amblygonite-montebrasite with special reference to the Tanco (chemalloy) pegmatite, Bernic Lake, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 90 p.

Černá, I., Černý, P. and Ferguson, R.B. 1972: The Tanco pegmatite at Bernic Lake, Manitoba, III – Amblygonite-montebrasite; The Canadian Mineralogist, v. 11, no. 3, p. 643–659.

Černý, P. 1972: The Tanco pegmatite at Bernic Lake, Manitoba, VII – Eucryptite; The Canadian Mineralogist, v. 11, no. 3, p. 708–713.

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

Černý, P. and Ercit, T.S. 2005: The classification of granitic pegmatites revisited; The Canadian Mineralogist, v. 43, no. 6, p. 2005–2026.

Černý, P. and Ferguson, R.B. 1972: The Tanco pegmatite at Bernic Lake, Manitoba, IV – Petalite and spodumene relations; The Canadian Mineralogist, v. 11, no. 3, p. 660–678.

Černý, P. and London, D. 1983: Crystal chemistry and stability of petalite; Tschermaks mineralogische und petrographische Mitteilungen, v. 31, no. 1, p. 81–96.

Černý, P., Ercit, T.S. and Vanstone, P.T. 1996: Petrology and mineralization of the Tanco rare element pegmatite, southeastern Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, May 27–29, 1996, Winnipeg, Manitoba, Field Trip Guidebook A4.

Černý, P., Ercit, T. and Vanstone, P. 1998: Mineralogy and petrology of the Tanco rare-element pegmatite deposit, southeastern Manitoba; International Mineralogical Association, 17th General Meeting, August 10, 1998, Toronto, Ontario, Field Trip Guidebook B6, 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., URL <https://manitoba.ca/iem/info/libmin/ER80-1.zip> [May 2022].

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, URL <https://manitoba.ca/iem/geo/field/roa06pdfs/GS-17.pdf> [May 2022].

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, URL <https://manitoba.ca/iem/geo/field/roa07pdfs/GS-12.pdf> [May 2022].

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, URL <https://manitoba.ca/iem/geo/field/roa08pdfs/GS-11.pdf> [May 2022].

Government of Canada 2021: Critical minerals, URL <https://www.nrcan.gc.ca/criticalminerals> [March 2021].

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, Waterloo, Ontario, 91 p.

Linnen, R.L., Van Lichtervelde, M. and Černý, P. 2012: Granitic pegmatites as sources of strategic metals; Elements, v. 8, no. 4, p. 275–280.

London, D. 1986: Magmatic-hydrothermal transition in the Tanco rare-element pegmatite: evidence from fluid inclusions and phase-equilibrium experiments; American Mineralogist, v. 71, no. 3–4, p. 376–395.

London, D. 1990: Internal differentiation of rare-element pegmatites: a synthesis of recent research; *in* Ore-bearing Granite Systems: Petrogenesis and Mineralizing Processes, H.J. Stein and J.L. Hannah (ed.), Geological Society of America, Special Paper, v. 246, p. 35–50.

London, D. 2008: Rare-element pegmatites; Chapter 7 *in* Pegmatites, The Canadian Mineralogist, Special Publication 10, p. 108–114.

Manitoba Geological Survey 2022: Lithium in Manitoba; Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, URL <https://manitoba.ca/iem/geo/lithium/index.html> [June 2022].

Martins, T., Kremer, P. and Vanstone, P. 2013: The Tanco mine: geological setting, internal zonation and mineralogy of a world-class rare element pegmatite deposit; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, May 22–24, 2013, Field Trip Guidebook FT-C1; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Open File OF2013-8, 17 p., URL <https://manitoba.ca/iem/info/libmin/gacmac/OF2013-8_FT-C1.pdf> [May 2022].

Morgan, G.B. and London, D. 1987: Alteration of amphibolitic wallrocks around the Tanco rare-element pegmatite, Bernic Lake, Manitoba; American Mineralogist, v. 72, no. 11–12, p. 1097–1121.

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; The Canadian Mineralogist, v. 18, no. 2, p. 185–190.

Rinaldi, R., Černý, P. and Ferguson, R.B. 1972: The Tanco pegmatite at Bernic Lake, Manitoba, VI – Lithium-rubidium-cesium micas; The Canadian Mineralogist, v. 11, no. 3, p. 690–707.

Selway, J.B., Novák, M., Černý, P. and Hawthorne, F.C. 2000a: The Tanco pegmatite at Bernic Lake, Manitoba, XIII – Exocontact tourmaline; The Canadian Mineralogist, v. 38, no. 4, p. 869–876.

Selway, J.B., Černý, P., Hawthorne, F.C. and Novák, M. 2000b: The Tanco pegmatite at Bernic Lake, Manitoba, XIV – Internal tourmaline; The Canadian Mineralogist, v. 38, no. 4, p. 877–891.

Simpson, F.M. 1974: The mineralogy of pollucite and beryl from the Tanco pegmatite at Bernic Lake, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 71 p.

Stilling, A., Ćerný, P. and Vanstone, P.J. 2006: The Tanco pegmatite at Bernic Lake, Manitoba, XVI – Zonal and bulk compositions and their petrogenetic significance; The Canadian Mineralogist, v. 44, no. 3, p. 599–623, URL <https://doi.org/10.2113/gscanmin.44.3.599>.

U.S. Geological Survey 2022: Final list of critical minerals 2022; International Energy Agency, URL <https://www.iea.org/policies/15271-final-list-of-critical-minerals-2022> [June 2022].

Van Lichtervelde, M., Salvi, S., Beziat, 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, no. 2, 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, no. 6, p. 791–806.

Wise, M.A. and Brown, C.D. 2019: Cathodoluminescence (CL) microscopy–a technique for understanding the dynamics of pegmatite crystallization; The Canadian Mineralogist, v. 57, no. 5, p. 821–823.

Zubi, G., Dufo-López, R., Carvalho, M. and Pasaoglu, G. 2018: The lithium-ion battery: state of the art and future perspectives; Renewable and Sustainable Energy Reviews, v. 89, p. 292–308.