GS2019-5

Interpretation of U-Pb isotopic dates of columbite-group minerals in pegmatites, Wekusko Lake pegmatite field, central Manitoba (part of NTS 63J13)

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In Brief:
- Pegmatite dikes have an emplacement age of 1.78 Ga determined by U-Pb isotopic dating of columbite
- Pegmatite dikes are structurally related to the brittle-ductile deformation event and place age constraints on the D_4 event
- Future Li exploration in the area should focus on north-northwestern trending anomalies and structural planes of weakness

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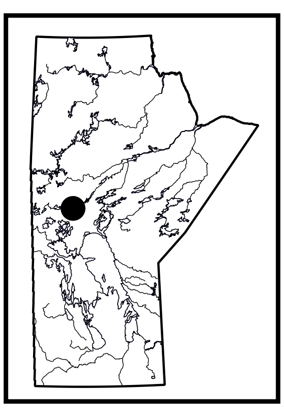

Summary

Recent geochronology results from lithium-bearing pegmatite dikes from the Green Bay group of the Wekusko Lake pegmatite field, along with related constraints on the regional structural history, are described in this report. In situ U-Pb dating of columbite grains yielded an isotopic U-Pb age of 1780 ±8.1 Ma, which is interpreted as the age of emplacement of the lithium-bearing dikes. The columbite-group minerals are commonly associated with coarse-grained tourmaline, vary in size between 100 and 150 µm and typically have an acicular or pear-shaped habit. The columbite grains show minor zonation, with a slightly Nb-enriched core. The age of the pegmatite dikes is also interpreted as the minimum age of the brittle–ductile deformation phase and the maximum age of the late-stage folding phase of the D_4 deformation event.

Introduction

In Manitoba, lithium exploration typically focuses on Li-Cs-Ta–bearing pegmatites. The world-class Tanco deposit in southeastern Manitoba is an example of a pegmatite deposit in this province, but other areas also have potential, including the Snow Lake area. The Li-bearing pegmatite dikes that are the focus of this report form part of the Green Bay pegmatite group within the Wekusko Lake pegmatite field (Černý et al.,1981) in the Snow Lake block of the Flin Flon–Glennie complex (Figure GS2019-5-1). These dikes are located approximately 25 km east of Snow Lake and are currently under exploration by Far Resources Ltd. for their lithium potential. This study builds on the previous work of Benn et al. (2018a, b), and provides an emplacement age for the Li-bearing pegmatite dikes and structural context. Tentative constraints on the timing of deformation events are also determined.

Geological setting

The Wekusko Lake pegmatite field is host to multiple pegmatite dikes characterized by variable amounts of Li mineralization. This area is also known for economic deposits of Au, Cu-Ni and Cu-Pb (e.g., Gagné et al., 2005; Stewart et al., 2018). The Snow Lake–Flin Flon area is part of the 1.91–1.83 Ga Flin Flon–Glennie complex (Figure GS2019-5-1; Connors et al., 2002) in the Trans-Hudson orogen (THO), a well-preserved Paleoproterozoic collisional belt between the Archean Superior and Rae–Hearne cratons (Hoffman, 1989) that spans from Scandinavia through Canada and into the central United States (Schneider et al., 2007). The central Canadian portion of the THO comprises four tectonic zones (Figure GS2019-5-1; Lewry et al., 1994) identified as

- the eastern boundary zone, which includes the Thompson nickel belt;
- the Reindeer zone, which consists of the Rottenstone–Southern Indian domain, the La Ronge–Lynn Lake–Leaf Rapids domain and the Flin Flon–Glennie complex (Glennie domain, Hanson Lake block, Flin Flon belt and Snow Lake block; Schneider et al., 2007);
- the Chipewyan/Wathaman batholith, an Andean-type continental magmatic arc (Meyer et al., 1992); and
- the reworked margin of the Hearne province.

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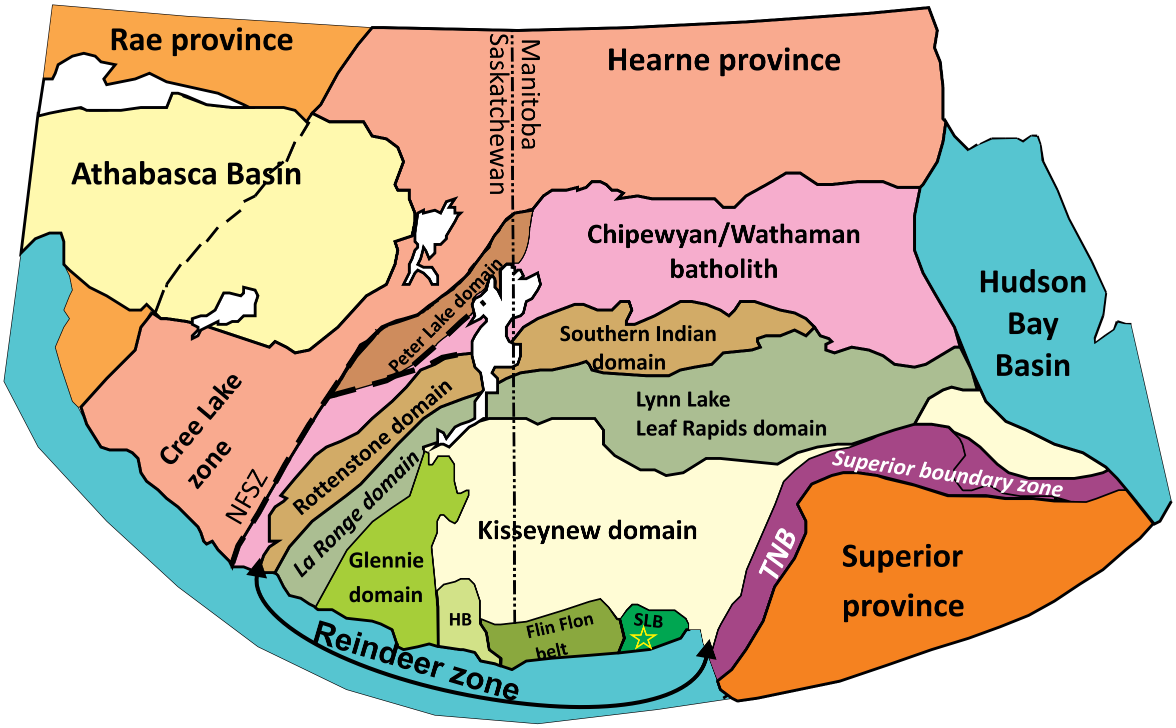

Figure GS2019-5-1: *Simplified geology of northern Saskatchewan and Manitoba, showing the main lithotectonic subdivisions and major structural boundaries. Abbreviations: HB, Hanson Lake block; NFSZ, Needle Falls shear zone; SLB, Snow Lake block; TNB, Thompson nickel belt (after Hoffman et al., 1988). The star overlies the field area of this study.*

Within the Reindeer zone, the Flin Flon–Glennie complex displays a metamorphic gradient from greenschist facies at the southern boundary to upper-amphibolite facies at its northern boundary with the Kisseynew domain (Černý et al.,1981).

Structural geology

The Wekusko Lake area has undergone four deformational events (D_1–D_4) as defined in Connors et al. (1999). The first deformation event (D_1) records the folding that occurred during the accretion (1.88–1.87 Ga) of the assemblages that formed the Flin Flon–Glennie complex. Plutonism and crustal shortening continued to steepen the synaccretionary schistose fabrics and isoclinal folding from 1.87 to 1.84 Ga (Černý et al., 1981; Lucas et al., 1996). The D_2 deformation event recorded south-southwest compression, which resulted in the inversion of the Kisseynew turbidite basin (Černý et al., 1981; Connors et al., 1999). Collison with the Sask craton led to the regional peak in metamorphism at 1.81 Ga (Gordon et al., 1990; David et al., 1996; Schneider et al., 2007). During peak metamorphism, the Snow Lake block (Schneider et al., 2007) reached temperatures between 500 and 700°C, and pressures ranged between 0.4 and 0.6 GPa (Kraus and Menard, 1997). The D_3 deformation event records northwest- trending transpressional shortening, which occurred during syn- to postpeak metamorphism at 1.81 Ga (Ryan and Williams, 1999). The final deformation event (D_4) records northwest-trending compression, which caused brittle to ductile deformation (Černý et al., 1981; Lucas et al., 1994; Conners et al., 1999). The age of the D_4 deformation event is unknown. Schneider et al. (2007) reported an additional thermal peak in the Flin Flon belt at 1.77 Ga that is associated with crustal melting. This was followed by rapid uplift and cooling.

Green Bay group pegmatites

The Green Bay group pegmatites in the study area are hosted primarily by a mafic volcanic unit metamorphosed to lower-amphibolite facies (Černý et al., 1981; Benn et al., 2018a, b); however, in the interest of brevity, the 'meta' prefix has been omitted. The mafic volcanic unit is unconformably overlain by the quartzofeldspathic gneiss of the Missi group sedimentary rocks (Connors et al., 1999), which is also host to pegmatite dikes. These units make up the Roberts Lake fault block (Connors et al., 1999, 2002), which is bound by a north-northeast-trending fault to the west and a broadly east-trending fault to the south. These faults intersect at the southwestern corner of the Roberts Lake fault block (Figure GS2019-5-2).

Bedrock mapping of the area outlined in Figure GS2019-5-2 was completed at a scale of 1:4000 during the

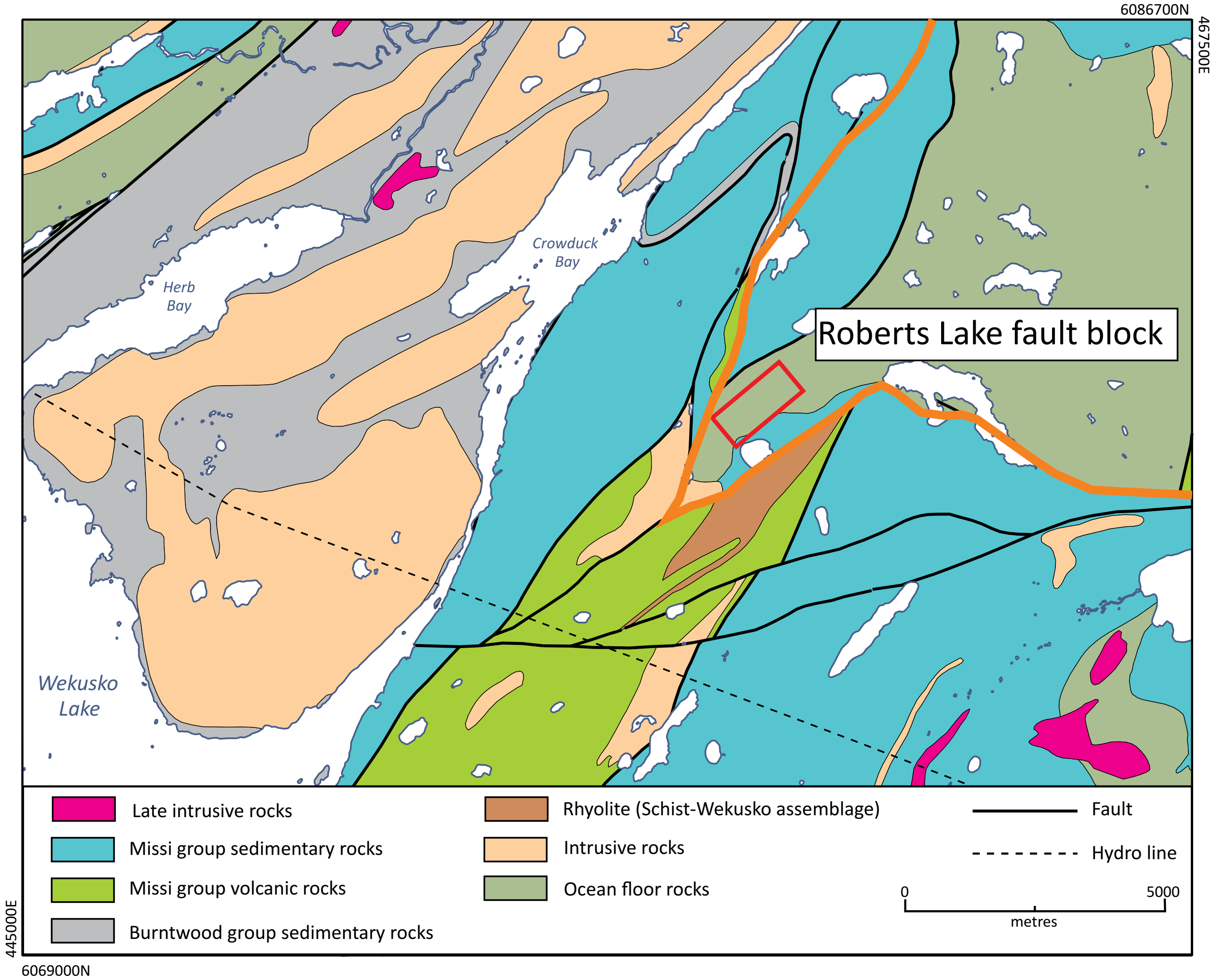

***Figure GS2019-5-2:** Regional geology of the eastern side of Wekusko Lake, central Manitoba. The red rectangle outlines the mapping area of Benn et al. (2018b) and the orange line outlines the Roberts Lake fault block (modified from NATMAP Shield Margin Project Working Group, 1998).*

2018 field season and eight dikes greater than 1 m thick were delineated (Benn et al., 2018b). Since that study, five new dikes have been discovered in the surrounding area (Far Resources Ltd., 2019). All the dikes in the mapping area trend northwest.

The pegmatite dikes in the Green Bay group were classified in Benn et al. (2018a) as belonging to the rare-element (REL) class, REL-Li subclass, complex type, spodumene subtype, based on the Černý and Ercit (2005) classification system. The pegmatites consist of quartz, albite, K-feldspar, muscovite, spodumene and tourmaline, with accessory beryl, apatite, Fe-Mn phosphate minerals, garnet, zircon and columbite-group minerals (CGMs; Benn et al., 2018a). The grain size of the minerals typically varies throughout the width of the dikes. Benn et al. (2018a) defined and described five zones within the pegmatite dikes: the border zone, the wall zone, the intermediate zone, the central zone and the core zone. The zones were determined based on mineralogy, grain size and degree of alteration. Quartz and feldspar crystals up to 30 cm in length are present in the core zone and display aplitic textures in patches throughout the dike. Hematization occurs throughout the dikes, giving the border, wall and intermediate zones a red to pink hue.

Dike thickness varies according to the hostrock. Dike 1, the largest dike, varies from 1 to 15 m in thickness and has a strike length of over the 300 m at surface. Dike 8 is the next largest and is over 13 m thick at depth (Far Resources Ltd., 2018). In the mafic volcanic rocks, the dikes range from 1 to 15 m thick, whereas the dikes hosted in sedimentary rocks thin to less than 1 m (Benn et al., 2018a). This difference is readily observed in dike 1: in those locations where it is hosted by mafic volcanic rock, dike 1 has an average width of approximately 10 m, whereas where the dike crosses into sedimentary rock, it tapers to a thickness of 10 cm before terminating (Benn et al., 2018a). Thin dikes (less than 30 cm) and dikelets (less than 1 cm) are also present, although these are usually nonmineralized (Benn et al., 2018a). The dikes crosscut S_3 (Connors et al., 2002) north-northeast-trending foliations in the hostrock.

The pegmatite dikes are folded over several metres (Figure GS2019-5-3; Benn et al., 2018a). Thinner dikes such as dike 7 are folded to a greater extent than the thicker dike 1 and the folding in these dikes can be more extreme (i.e., they display ptygmatic folds); their thickness also changes due to pinching and swelling (Benn et al., 2018a). Dike 1 is thicker and shows minimal folding at its northern tip.

Columbite-group minerals

Columbite-group minerals are present in all zones of the studied pegmatites. Drillcore samples collected from dikes 1, 5 and 8 were selected based on high Ta values from assays of drillcore from Far Resources (Far Resources Ltd., 2017, 2018). Polished thin sections were cut from the drillcore samples. Columbite-group mineral grains were identified by reflected-light microscopy and their compositions were qualitatively determined using a JEOL JCM-6000 benchtop scanning electron microscope; backscattered electron imagery and element maps were subsequently produced by a JEOL JXA-8530F microprobe at the University of Western Ontario.

The CGMs have either a tabular acicular or a pear-shaped habit, typically associated with larger tourmaline crystals. Grains are generally 100 to 150 µm long and rarely exceed 1000 µm in length. The CGMs display minimal to moderate zonation (Figure GS2019-5-4a–f); typically, the crystals consist of large cores enriched in Nb, with thin rims that are enriched in Ta (Figure GS2019-5-4a–f).

U-Pb geochronology of columbite-group minerals

Columbite-group minerals [$(Fe,Mg,Mn)(Nb,Ta)_2O_6$] have high U and low Pb contents, making them ideal for U-Pb isotopic dating (Romer and Smeds, 1994; Romer and Lehmann, 1995). The dating of CGMs can be useful for determining the emplacement age of rocks like pegmatites and rare-metal granites, which may lack zircon or where the zircon is not suitable for radiometric dating. Due to an abundance of U-rich inclusions in CGMs, in situ techniques, such as laser-ablation induction coupled plasma–mass spectroscopy (LA-ICP-MS; Smith et al., 2004) or secondary-ion mass spectroscopy (Legros et al., 2019) have become the favoured methods for dating CGMs.

Four U-Pb isotopic dates were obtained from CGMs of lithium-bearing pegmatites from the Green Bay group using LA-ICP-MS, as reported by Martins et al. (2019). Details regarding the analytical procedures and BSE imagery of the analysed CGMs are given in Martins et al. (2019). Combined results gave a concordia age of 1780 ±8.1 Ma with a mean square of weighted deviates of 1.6 (Martins et al., 2019; Figure GS2019-5-5).

Discussion

Tectonic implications

The orientation and shape of the pegmatite intrusions will be affected by the rheology of the hostrock (Brisbin,

Figure GS2019-5-3: *Outcrop photograph, showing folding in pegmatite hosted by mafic volcanic rocks.*

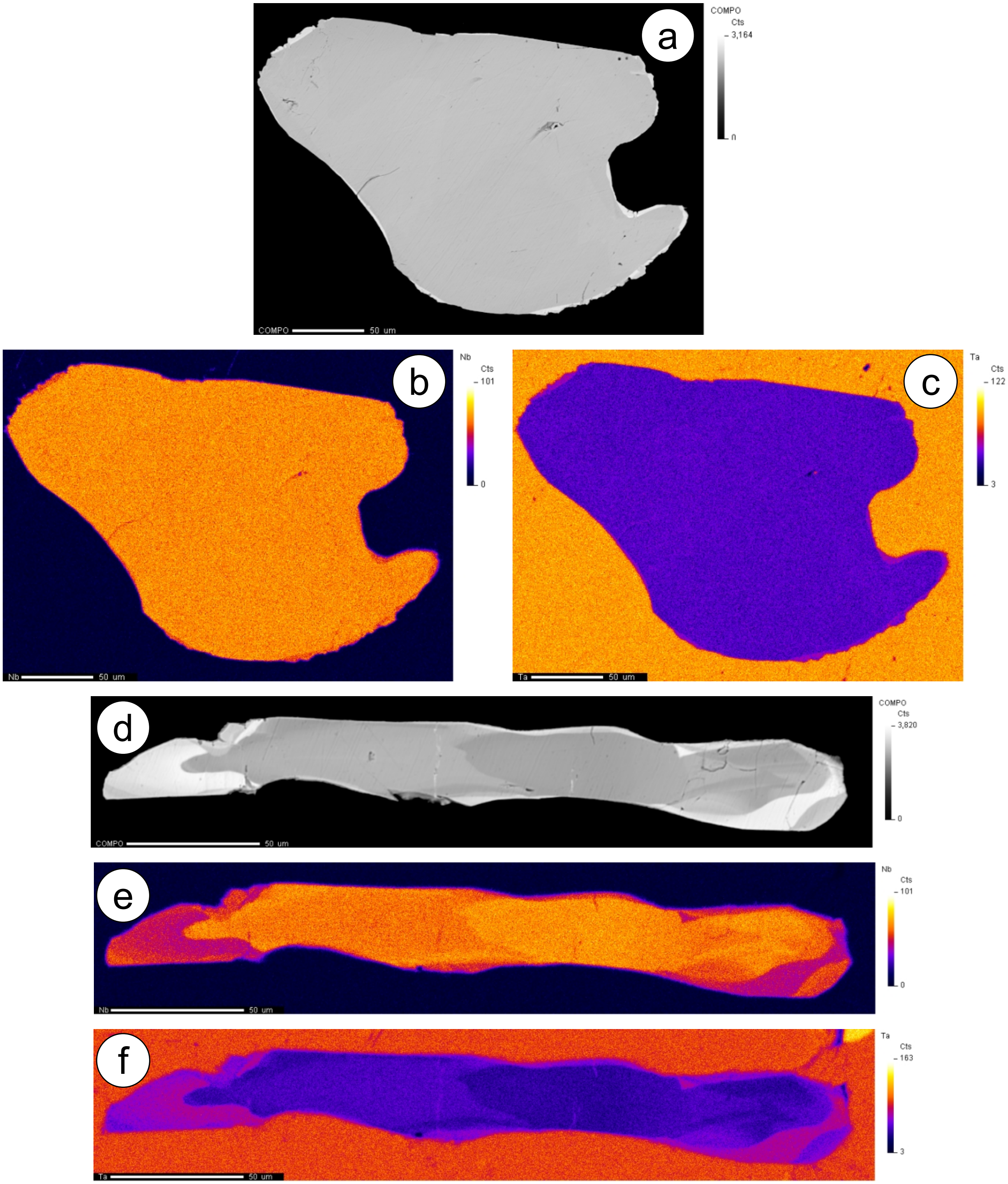

Figure GS2019-5-4: *Back-scattered electron (BSE) and false-colouring element maps of columbite-group minerals:* ***a)*** *BSE imagery of a minimally zoned columbite grain;* ***b)*** *Nb element map of the same grain as in a);* ***c)*** *Ta element map of the same grain as in a);* ***d)*** *BSE imagery of a moderately zoned columbite grain;* ***e)*** *Nb element map of the same grain as in d);* ***f)*** *Ta element map of the same grain as in d). Abbreviations: COMPO, composition; Cts, counts.*

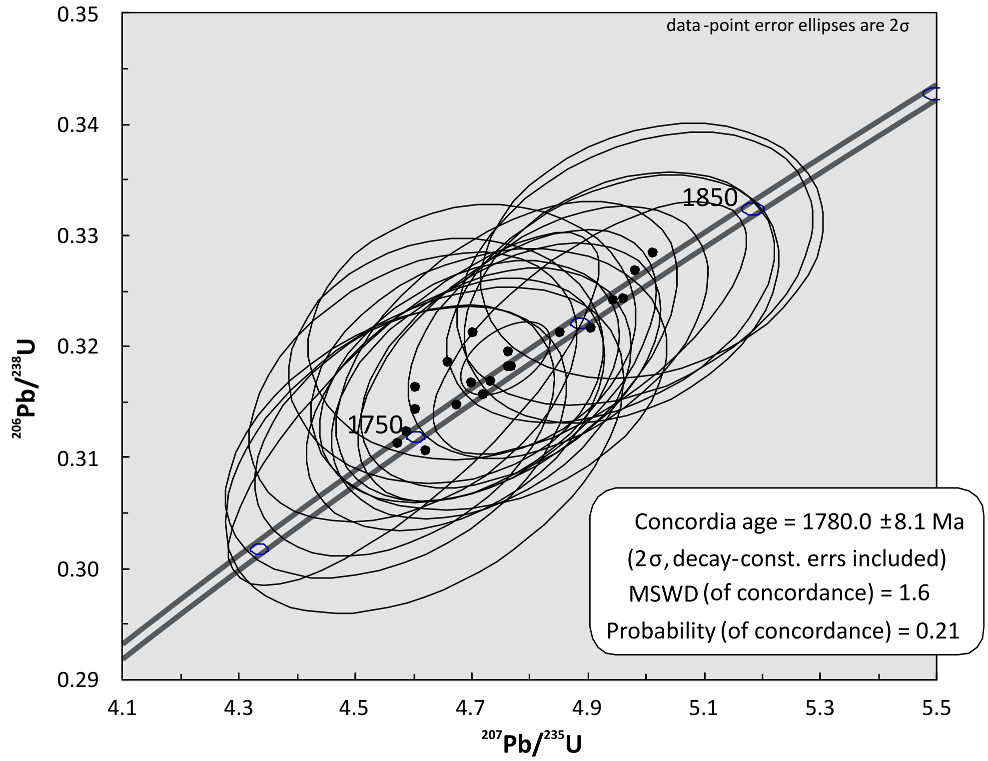

***Figure GS2019-5-5:** Concordia diagram for all data combined from columbite-group minerals of lithium-bearing pegmatites from the Green Bay group of the Wekusko Lake pegmatite field (modified from Martins et al., 2019). Abbreviations: const., constant; errs, errors; MSWD, mean square of weighted deviates.*

1986). Rocks are brittle at the upper level of the crust and become progressively more ductile with depth, which includes a transition zone where the rocks exhibit brittle–ductile behaviour. Pegmatites that intruded into the transition zone are podiform and lenticular in shape. Planes of weakness and anisotropic stresses also effect the orientation of the pegmatite (Brisbin, 1986). Pegmatite melts will intrude into sites where the pegmatite fluid pressure is greater than the combination of normal stress and tensile strength (Brisbin, 1986). Unidirectional tectonic stresses will commonly cause a singular direction of emplacement in brittle and brittle–ductile hostrocks.

The U-Pb age obtained by Martins et al. (2019) provides the first absolute-age constraint on the emplacement of dikes 1 and 8 of the lithium-bearing pegmatite dikes from the Green Bay group. The age also provides further constraints on the timing of deformation in the Wekusko Lake region. The emplacement age of the studied pegmatites is 1780 ±8.1 Ma, which corresponds to the period of postpeak metamorphism, as defined by several authors (e.g., Gordon et al., 1990; David et al., 1996; Schneider et al., 2007). This suggests that the intrusion of the pegmatites occurred during the D_3 or D_4 deformation events. The semiplanar shape and consistent north-northwest trend of the studied pegmatites suggest emplacement into a ductile–brittle hostrock (Brisbin, 1986) at a time when the tectonic stress from the north-northwest was greater than that from the east-northeast. These conditions best describe the D_4 deformation event (Černý et al., 1981; Lucas et al., 1994; Connors et al., 1999). The dikes are folded (Benn et al., 2018a); if this folding occurred during the final stages of D_4 deformation, then 1.78 Ga represents a maximum age for the late stages of D_4 deformation. Alternatively, the structural history of the region may be more complex than currently recognized.

Schneider et al. (2007) recorded a thermal peak of approximately 500–600°C at 1.77 Ga with associated mid-crustal melting. The same authors did not believe this event was related to slow cooling following peak metamorphism, but rather that it may have recorded rapid crustal extrusion and unroofing. This could have led to decompression melting and muscovite dehydration (Kraus and Menard, 1997). Although no formal conclusion can be reached as to these events being connected, the coinciding ages and nature of the events suggest a link. This thermal event may also be linked to the D_3 or D_4 deformation events.

Pegmatite genesis

There are currently two dominant models for pegmatite formation: fractional crystallization and anatexis

(London, 2018). Pegmatites are formed by fractional crystallization, where melt is extracted from the late stages of granite formation, or by anatexis, where metamorphic rock is subjected to a low degree of partial melting.

Given the above tectonic constraints, one possible model for the formation of the Wekusko Lake pegmatite field involves anatexis following peak metamorphism at 1.81 Ga. Several workers (e.g., Kraus and Menard, 1997; Schneider et al., 2007) reported high-temperature low-pressure metamorphic conditions around this time that were sufficient to generate lithium-enriched partial melts (Stewart, 1978). Such melts may have been later tapped by north-northwest-trending faults during D_4 deformation, leading to the emplacement of the pegmatite dikes.

As indicated above, the other model for the formation of the studied pegmatites is fractional crystallization; however, genetically related source granites have not been identified (Černý et al., 1981) and it is difficult to prove either the fractionation or the anatectic model.

Economic considerations

The pegmatite dikes of the Green Bay group are currently being explored for their economic viability. These pegmatites are enriched in Li, Cs, Nb and Ta. The Li-bearing pegmatites from the Green Bay group of the Wekusko Lake pegmatite field have an interpreted emplacement age of 1780 ±8.1 Ma. This group of pegmatites outcrops in a north-northwest trend, suggesting a structural relation to the regional D_4 deformation event. The folding in the pegmatite dikes must have taken place after emplacement; this suggests syndeformation emplacement of the pegmatites during the D_4 deformation event. The link between D_4 and the emplacement of the pegmatite dikes can be used to constrain a minimum age for early D_4 brittle–ductile events and a maximum age for late D_4 folding events. Understanding of the formation process, structural controls and age of these dikes is useful for exploration, and the discovery of new, possibly economic, dikes. Future exploration should focus on north-northwest-trending anomalies and planes of structural weakness in the hostrock, such as faults and shear zones.

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