December 4, 2023

ERRATA NOTICE

In the "Whole-rock geochemical trends of the Wekusko Lake pegmatite dikes" section found on page 58 of GS2023-7 from the *Report of Activities 2023*, the following sentence was added to the first paragraph:

> However, due to the extremely coarse grain size and variable local distribution of minerals in the studied pegmatites bodies, the selected samples used for whole-rock geochemistry analysis might not represent the total extent of the pegmatite bodies chemistry.

Figures GS2023-7-6 and GS2023-7-7 have also been updated.

GS2023-7

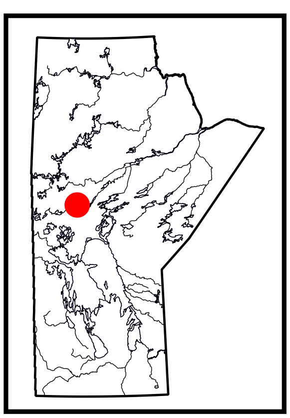
Regional pegmatite mapping and geochemical fractionation trends from the Wekusko Lake pegmatite field, west-central Manitoba (parts of NTS 63J13, 14, 63O4)

by D. Silva[1], T. Martins, L. Groat[2] and R. Linnen[3]

In Brief:

- The Wekusko Lake pegmatite field contains multiple types of Li-pegmatites including spodumene- and lepidolite-bearing dikes
- Pegmatite dike occurrences were explored and mapped, mainly adjacent to the Berry Creek fault in the Bur zone
- Pegmatite whole-rock geochemical fractionation trends are discussed for the region

Citation:
Silva, D., Martins, T., Groat, L. and Linnen, R. 2023: Regional pegmatite mapping and geochemical fractionation trends from the Wekusko Lake pegmatite field, west-central Manitoba (parts of NTS 63J13, 14, 63O4); *in* Report of Activities 2023, Manitoba Economic Development, Investment, Trade and Natural Resources, Manitoba Geological Survey, p. 52–63.



Summary

This report describes field observations gathered during the 2023 geological mapping campaign of lithium-bearing pegmatite dikes in the Wekusko Lake pegmatite field in west-central Manitoba, along with the regional geochemical fractionation trends of major and minor elements from pegmatite samples collected in the summer of 2022. Fourteen occurrences of pegmatite dikes were explored, primarily in the areas of north to northeast Wekusko Lake (Crowduck Bay, Sherritt-Gordon and Violet-Thompson pegmatite groups) and adjacent to the regional southwest-oriented Berry Creek fault in the Bur zone (Berry Creek pegmatite group). No new lithium-mineralized pegmatite dikes were discovered during the 2023 geological mapping; however, a new occurrence of spodumene- and lepidolite-bearing pegmatite in the Bur zone was recently discovered at depth, opening the potential for further discoveries of different types of lithium mineralization within the Wekusko Lake pegmatite field.

Whole-rock K/Rb, K/Cs and Nb/Ta ratios show a strong spatial geochemical trend, indicated by the evolution toward low elemental ratios in non-lithium–mineralized pegmatite groups located in the northern- and easternmost parts of the Wekusko Lake pegmatite field compared to those in lithium-enriched pegmatites near the Crowduck Bay shear zone. A decrease in the K/Rb ratio and an increase in P_2O_5 with increase in pegmatite peraluminosity is also observed in non-lithium–mineralized pegmatites compared to lithium-enriched pegmatites.

Introduction

As a result of electric-powered mobility and the transition to more sustainable electrical storage and energy production, the demand for lithium, nickel, cobalt, tantalum and rare-earth elements has increased. Because of the risk of supply to the manufacturing industry, as well as their economic and/or military significance, Canada classifies certain elements as 'critical minerals' (Natural Resources Canada, 2021). Rare-element pegmatites play an important role in the green revolution, because they contain large amounts of essential minerals, particularly lithium-bearing, making them targets for mineral exploration.

Manitoba is a well-established jurisdiction for lithium-bearing pegmatite exploration and mining due to the large scale of some deposits (e.g., the world-class Tanco deposit in southeast Manitoba; Černý, 2005). This report focuses on the Wekusko Lake pegmatite field in west-central Manitoba, which is known to contain spodumene- and lepidolite-bearing pegmatites. The Wekusko Lake pegmatite field is located about 25 km east of the town of Snow Lake. Numerous exploration programs targeting spodumene pegmatites are currently underway in the area due to the region's significant lithium potential (Lithium Foremost Resource & Technology Ltd., 2022; Snow Lake Lithium Ltd., 2022; Lodestar Battery Metals Corp., 2023). This study summarizes mineralogical and structural observations of the Wekusko Lake pegmatite field made during the summer of 2023, as well as results of lithogeochemical analyses on both barren and lithium-bearing pegmatite dikes.

Regional geology

The Wekusko Lake pegmatite field is part of the Snow Lake subdomain of the Flin Flon domain (Černý et al., 1981; Gordon et al., 1990; Lucas et al., 1996; Ansdell, 2005). The Snow Lake subdomain is located in the Reindeer zone of the Trans-Hudson orogen (Lewry and Collerson, 1990; David et al.,

[1] Department of Earth, Ocean and Atmospheric Sciences, The University of British Columbia, Vancouver, British Columbia, davidbsilva237@gmail.com
[2] Department of Earth, Ocean and Atmospheric Sciences, The University of British Columbia, Vancouver, British Columbia
[3] Department of Earth Sciences, Western University, London, Ontario

1996). The Kisseynew domain is part of the northeasternmost section of the Trans-Hudson orogen (Figure GS2023-7-1; David et al., 1996; Connors et al., 1999). The Snow Lake subdomain is underlain by three major 1.88–1.83 Ga Paleoproterozoic tectonostratigraphic packages: 1) the accreted Flin Flon arc and ocean-floor assemblages that formed the Flin Flon–Glennie complex (Gordon et al., 1990; Stern et al., 1993; Stern and Lucas, 1994; David et al., 1996; Ansdell et al., 1999; Machado et al., 2000; Reid, 2021a, b); 2) turbidite deposits of the Burntwood group (Bailes, 1980; Zwanzig, 1990); and 3) alluvial-fluvial sandstones of the Missi group (Figure GS2023-7-1; Ansdell, 1993; Ansdell and Connors, 1995; Ansdell and Norman, 1995; Reid, 2021a, b). In the Snow Lake region, 1.84–1.83 Ga late successor-arc plutons intruded all of these units (Gordon et al., 1990; David et al., 1996; Whalen et al., 1999). The Flin Flon domain is unconformably overlain in the south by a Paleozoic dolomitic limestone (NATMAP Shield Margin Project Working Group, 1998). The Flin Flon domain features a metamorphic field gradient that ranges from lower greenschist facies in the south to upper amphibolite facies in the north, near the boundary with the Kisseynew domain (Černý et al., 1981; Lewry et al., 1994; Kraus and Menard, 1997). The metamorphic field gradient in the Snow Lake area ranges from upper green-

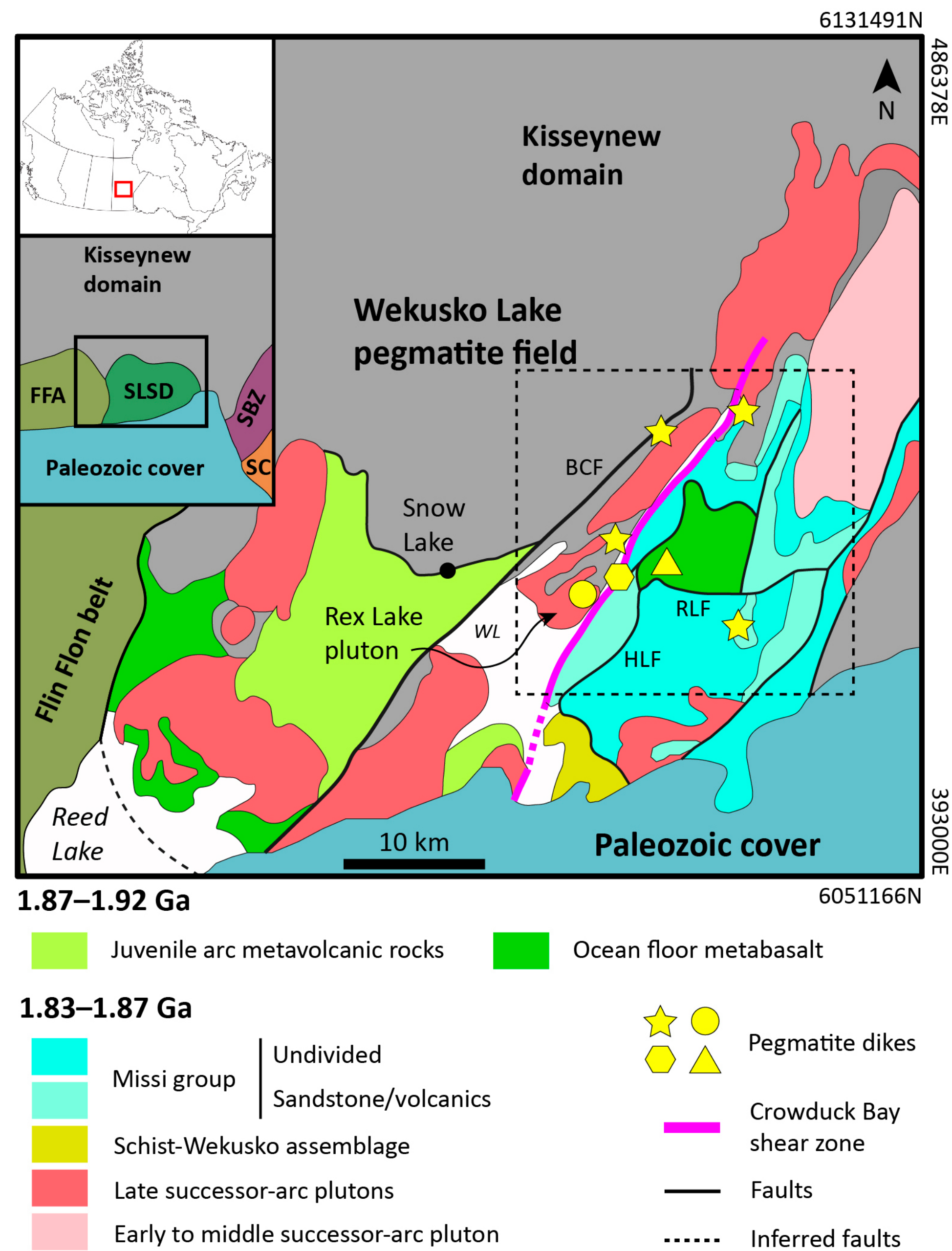


Figure GS2023-7-1: *Simplified regional geology of the Snow Lake subdomain (following Galley et al., 2007) and the location of pegmatite groups in the Wekusko Lake pegmatite field. Inset tectonic elements map of the Trans-Hudson orogen of central Manitoba is modified after Manitoba Geological Survey (2022). Symbols for pegmatite dikes: triangle, Green Bay group; circle, Sherritt-Gordon group; hexagon, Violet-Thompson group; star, unsubdivided. Abbreviations: BCF, Berry Creek fault; FFA, Flin Flon arc assemblage; HLF, Herb Lake fault; RLF, Robert Lake fault; SBZ, Superior boundary zone; SC, Superior craton; SLSD, Snow Lake subdomain; WL, Wekusko Lake. All co-ordinates are in UTM Zone 14, NAD83.*

schist–lower amphibolite facies to upper amphibolite facies, with migmatitic zones to the north, northeast and east of Wekusko Lake (Bailes, 1985; Lazzarotto, 2020).

Before craton stabilization at 1.70–1.65 Ga, the Snow Lake region underwent four deformational events (D_1–D_4). At 1.88–1.87 Ga, the Flin Flon–Glennie arc accreted, which is related to deformation event D_1 (Lucas et al., 1996; Connors et al., 1999; Schneider et al., 2007; Stewart et al., 2018). The Kisseynew domain and the Flin Flon–Glennie arc collided with the Sask craton, resulting in south to southwest compression at 1.84–1.81 Ga (Zwanzig, 1990; Connors, 1996; Connors et al., 1999). Peak metamorphism occurred around 1.81 Ga, coinciding with the transition from D_2 to D_3 in the east Snow Lake area (Connors et al., 2002). During the D_3 event, the main tectonic stress direction shifted from northeast-southwest compression to northwest-southeast compression, which is associated with the formation of the Crowduck Bay shear zone, and the Herb Lake and Roberts Lake regional transpressional faults (Connors and Ansdell, 1994; Kraus and Williams, 1994; Connors et al., 2002). The D_4 phase, which manifested as primarily brittle deformation, could be a continuation of the D_3 phase (Lucas et al., 1994; Fedorowich et al., 1995).

Dikes of the Wekusko Lake pegmatite field intruded a variety of lithologies, including conglomerate to quartzofeldspathic gneiss from the Missi group, and basalt to basaltic andesite of N-MORB (normal mid-ocean–ridge basalt) affinity from the Snow Lake arc assemblage (Syme et al., 2000; Benn et al., 2018). The pegmatite dikes vary in composition from barren to lithium bearing, with spodumene as the major lithium ore mineral (Černý et al., 1981; Martins et al., 2017). Lepidolite-bearing pegmatite dikes were recently discovered at depth in the northwest region of the Wekusko Lake pegmatite field, more specifically, in the Bur zone (Rockcliff Metals Corp., 2022). The Wekusko Lake pegmatite field was divided into three spodumene-mineralized groups by Černý et al. (1981): Sherritt-Gordon, Green Bay, and Violet-Thompson. Columbite from one Green Bay group pegmatite returned a U-Pb age of 1780 ±8.1 Ma, interpreted as the crystallization age (Martins et al., 2019). This pegmatite emplacement was considered by Benn et al. (2019) to be late D_3 to D_4, which predates the ca. 1.81 Ga peak metamorphism. The spodumene-bearing pegmatite dikes were considered by Černý et al. (1981) to be the result of fractional crystallization of nearby successor-arc granite suites; however, this leaves a roughly 50 m.y. time gap between the crystallization of the granite suites and the emplacement of the pegmatite dikes. Benn et al. (2019) associated the petrogenesis of the pegmatite dikes with the partial melting of metasedimentary rocks. Three emplacement mechanisms for spodumene-bearing pegmatites are proposed for the central Wekusko Lake pegmatite field: 1) oriented subparallel to the strike of shear zones in pull-apart openings (Violet-Thompson group of pegmatite dikes); 2) oriented subparallel to the main tectonic stress direction in tension-gash openings (Sherritt-Gordon group of pegmatite dikes); and 3) aligned in en échelon formation [Green Bay group of pegmatite dikes] (Černý et al., 1981; Silva et al., 2022, in press).

Regional pegmatite coverage and field description of pegmatite dikes

For this study, 14 occurrences of pegmatite dikes were explored, primarily in the areas of north to northeast Wekusko Lake (Crowduck Bay, Sherritt-Gordon and Violet-Thompson pegmatite groups), and adjacent to the Berry Creek fault (Highway 393) in the Bur zone. The subdivisions of Černý et al. (1981) are used herein to simplify the general description of the pegmatite occurrences. All the locations shown in Figure GS2023-7-2 were sampled for future geochemical and microstructural research.

Crowduck Bay pegmatite dikes

The pegmatite dikes of Crowduck Bay appear as a series of dikes 1 to 2 m thick, up to ~50 m in length and trending 030–050° along both sides of the northeast arm of Wekusko Lake, but occur mostly on the eastern shoreline of the lake and on islands in Crowduck Bay (Figure GS2023-7-3a). The pegmatites emplaced along the shoreline of Crowduck Bay occur as dikes physically spaced and segmented into elongated bodies 1 to 10 m in length (Figure GS2023-7-3a). Pegmatite dikes similar in width, length and strike are observed up to 120 m east of the Crowduck Bay shoreline. The majority of the islands in Crowduck Bay have pegmatite dikes, and their overall elongated shapes, parallel to the regional shear zone, are most likely a result of the competency contrast between the pegmatite dikes and the surrounding metasedimentary rock during deformation.

These pegmatite dikes consist of albite, quartz, K-feldspar and muscovite, with minor to trace tourmaline and garnet present in patches within the dikes (Figure GS2023-7-3b). The muscovite content of the pegmatite dikes varies, with higher concentrations found near contacts with the country rock. Tourmaline is usually observed in association with increased quartz content, and garnet is commonly found near mafic xenoliths or contacts with hostrocks. Lithium mineralization was not observed in this group of pegmatites. According to their mineralogy, these pegmatite dikes belong to the muscovite class of Černý and Ercit (2005). The dikes are most commonly found in the metasedimentary rocks of the Missi group and, less commonly, in the Burntwood group. The few pegmatite dikes observed to have intruded the Burntwood group were found along the western shoreline of Crowduck Bay. Postemplacement hematization was observed along fractures. This feature is common in pegmatite dikes of the Wekusko Lake pegmatite field (Benn et al., 2018), and the pink to red colouration associated with the metasomatic process can make feldspar identification difficult (e.g., Gysi et al., 2016; Benn et al., 2018). Tourmalinization of the hostrock is a typical occurrence around pegmatite contacts.

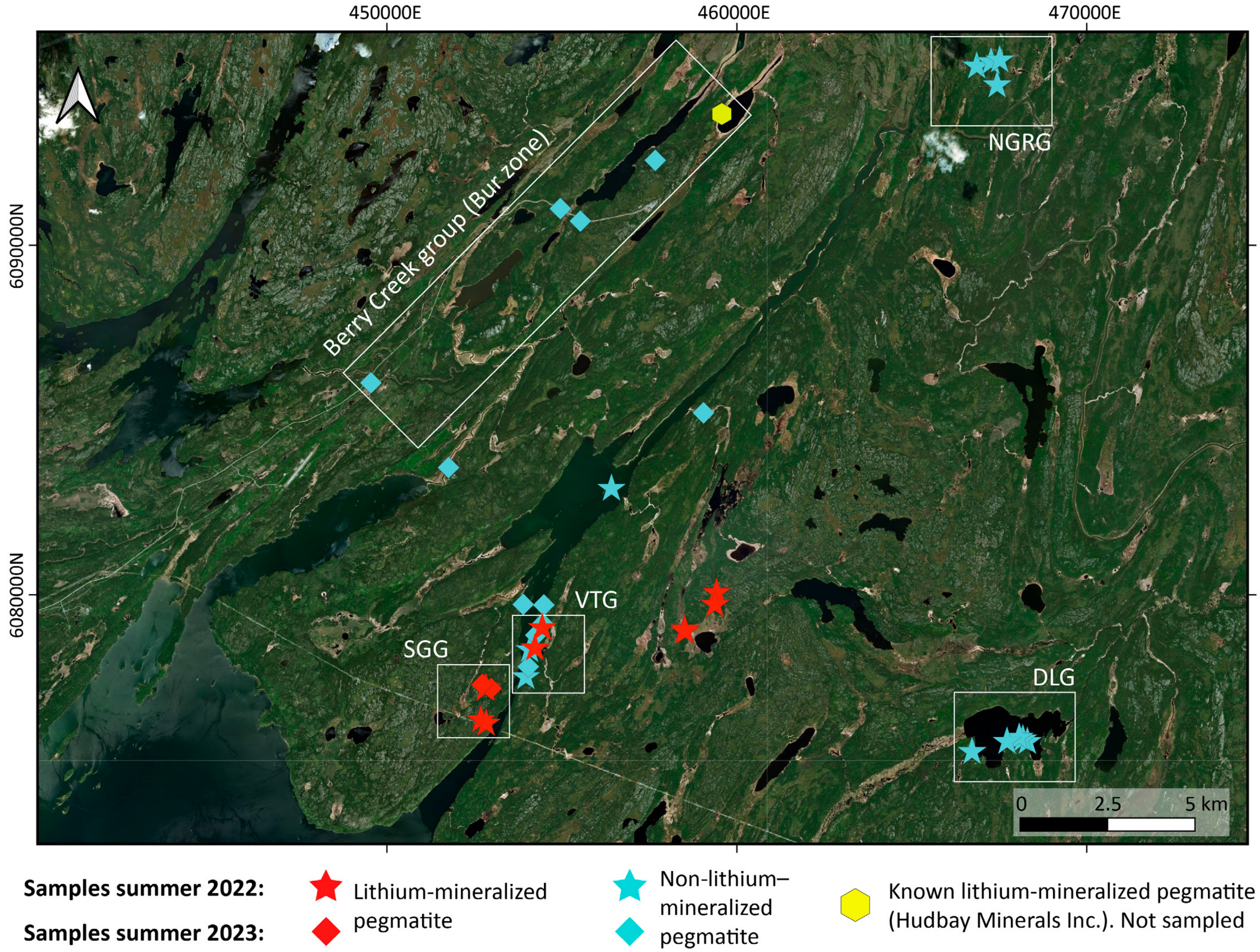


Figure GS2023-7-2: *Satellite imagery showing the locations of the pegmatite dikes visited and sampled during the summers of 2022 and 2023. Symbols for pegmatite dikes: red diamond and star, lithium-mineralized pegmatite dikes; blue diamond and star, non-lithium–mineralized or simple pegmatite dikes; hexagon, documented lithium-mineralized pegmatite dike. Abbreviations: DLG, Dion Lake pegmatite group; NGRG, North Grass River pegmatite group; SGG, Sherritt-Gordon pegmatite group; VTG, Violet-Thompson pegmatite group. All co-ordinates are in UTM Zone 14, NAD83.*

Sherritt-Gordon group (Grass River dikes)

This collection of metre-scale pegmatite dikes lies east-northeast of the Rex Lake pluton and intrudes masses of porphyritic gabbro west of the Crowduck Bay shear zone (Figures GS2023-7-1 and -2). The majority of pegmatite dikes from the Sherritt-Gordon group contain lithium mineralization in the form of green spodumene, classifying them as lithium-cesium-tantalum (LCT) rare-element pegmatites according to the pegmatite categorization of Černý and Ercit (2005). The main orientation of the pegmatite dikes is between 290 and 320°, with dips to the southwest of 60 to 70°. Lithium Foremost Resource & Technology Ltd. and Snow Lake Lithium Ltd. are presently exploring pegmatite dikes from this group. The pegmatites in this group are all exceedingly coarse grained (crystal size is >10 cm), with variable amounts of albite, K-feldspar, quartz, muscovite, garnet, tourmaline and spodumene inside a single pegmatite body. Spodumene can be found in the form of elongate prisms up to 50 cm long and 8 cm wide, or as equant basal sections 0.5–2.0 cm across. Spodumene prisms in the Grass River dikes are mainly oriented 045° and suborthogonal to the orientation of the pegmatite dikes. There is no clear mineral zonation within the dikes, based on observation of outcrops and drillcore; however, zones within pegmatite dikes with higher concentrations of spodumene (up to 40%) are usually associated with higher concentrations of quartz, muscovite and, in some cases, garnet. Tourmaline, apatite and garnet are present as accessory phases. Tourmaline concentrations are higher near dike margins, locally as parallel bands or as tourmaline crystals perpendicular to the contact of the dikes, and within zones of higher quartz concentration. The contacts of the pegmatite dikes appear to be gently folded perpendicular to the strike of the dikes (Figure GS2023-7-3c), indicating that southwest-directed compressional stress that resulted in the formation of

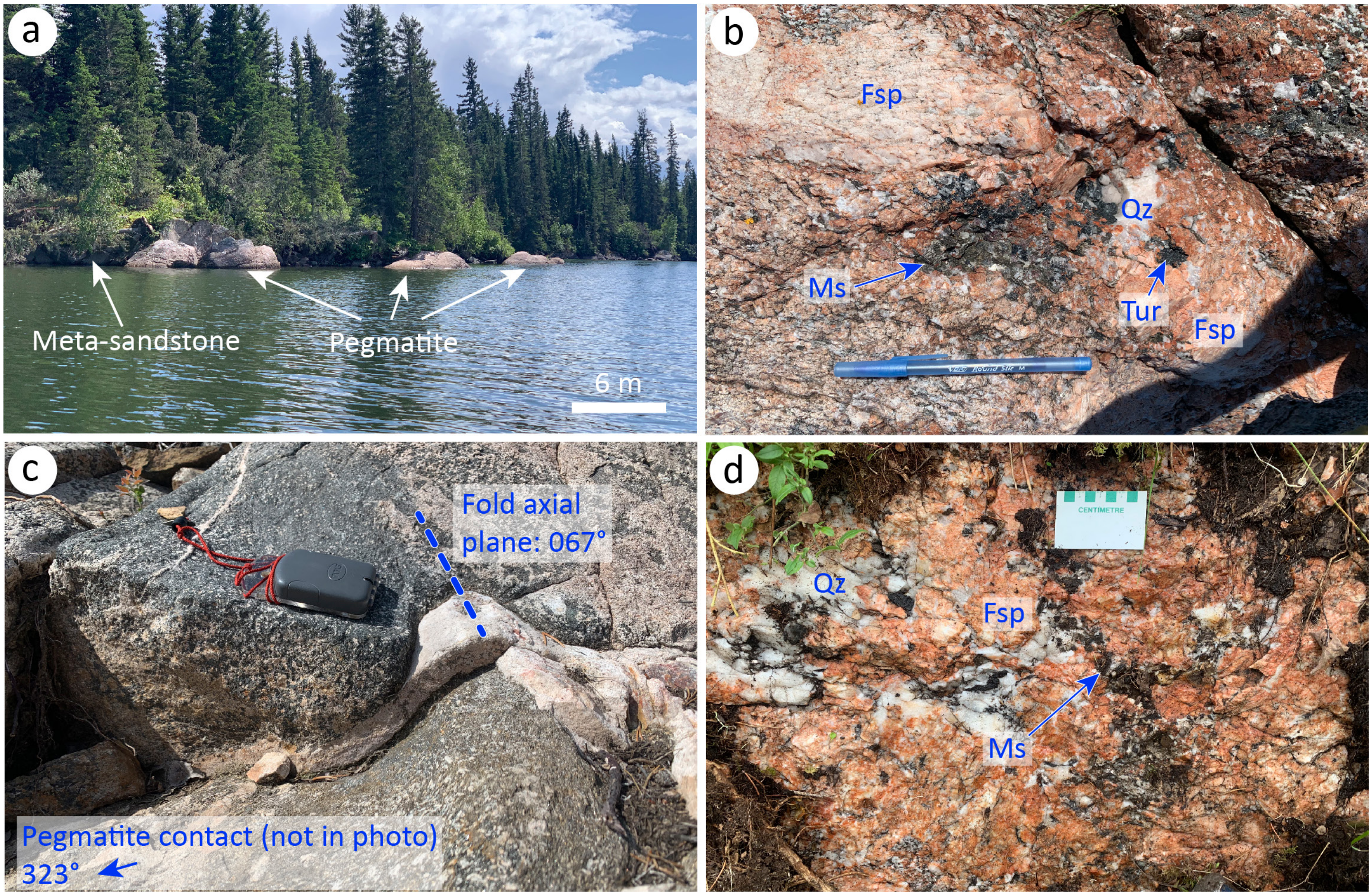


Figure GS2023-7-3: *Outcrop photographs showing pegmatite dikes from the Wekusko Lake pegmatite field:* ***a)*** *subvertical, hematized pegmatite dike segmented and interspersed with Missi group meta-sandstone, from the eastern shoreline of Crowduck Bay;* ***b)*** *example of simple mineralogical composition (albite-quartz-muscovite-tourmaline) of the Crowduck Bay pegmatite dike group;* ***c)*** *folded, centimetre-size offshoot of main pegmatite body of spodumene pegmatite from the Sherritt-Gordon pegmatite group. Fold axial plane is subperpendicular to the trend of the main pegmatite;* ***d)*** *example of simple mineralogical composition (albite-quartz-muscovite) and postemplacement hematization of a pegmatite dike located in the Bur zone. Pen for scale in panel (b) is 15 cm long, and the Silva compass in panel (c) is 10 cm long. Abbreviations: Fsp, feldspar; Ms, muscovite; Qz, quartz; Tur, tourmaline.*

extensional jogs used for emplacement of this pegmatite group melt (Silva et al., 2022, in press) persisted, or was reactivated, after crystallization of the pegmatites.

Berry Creek group (Bur zone)

The Berry Creek group within the Bur zone is located northeast of the town of Snow Lake, close to Highway 393 and the regional Berry Creek fault, which trends approximately northeast. The Bur zone is known for its high-grade copper-zinc potential within the Flin Flon–Snow Lake greenstone belt (Loveday, 2021) and, recently, lithium mineralization in the form of lepidolite-bearing pegmatites was found at depth (Rockcliff Metals Corp., 2022). The pegmatite dikes observed in outcrop in this area appear mostly as 1 to 3 m thick dikes that dip steeply, are up to ~30 m in length, and trend between 330° and 035–060° (Figure GS2023-7-4). From field observation, these pegmatite dikes do not appear to host lithium mineralization. Previous mapping of pegmatite dikes from these zones by the Manitoba Geological Survey (NATMAP Shield Margin Project Working Group, 1998) showed that multiple pegmatite dikes appear as large bodies of regional scale, with thicknesses of tens of metres and lengths of hundreds of metres. The trend of the pegmatite dikes varies, but it generally follows the northeast orientation of the deformation fabric observed in the bedrock. The pegmatite dikes are most commonly found intruding or adjacent to felsic gneiss within late successor-arc plutons (Figure GS2023-7-4). The pegmatites outlined in region A of Figure GS2023-7-4 form noticeable convex massive dikes tens of metres in both width and length, probably due to the difference in lithological competence compared to the surrounding felsic volcaniclastic rocks. Region B in Figure GS2023-7-4 has a 1.5–2 m wide elongated pegmatite dike that trends roughly northeast. The pegmatite dike in region C of Figure GS2023-7-4 differs from the others because of its approximate northwest trend and its intrusion into mafic igneous rocks.

The major mineral phases of these pegmatite dikes are albite, quartz, K-feldspar and muscovite, with minor to trace amounts

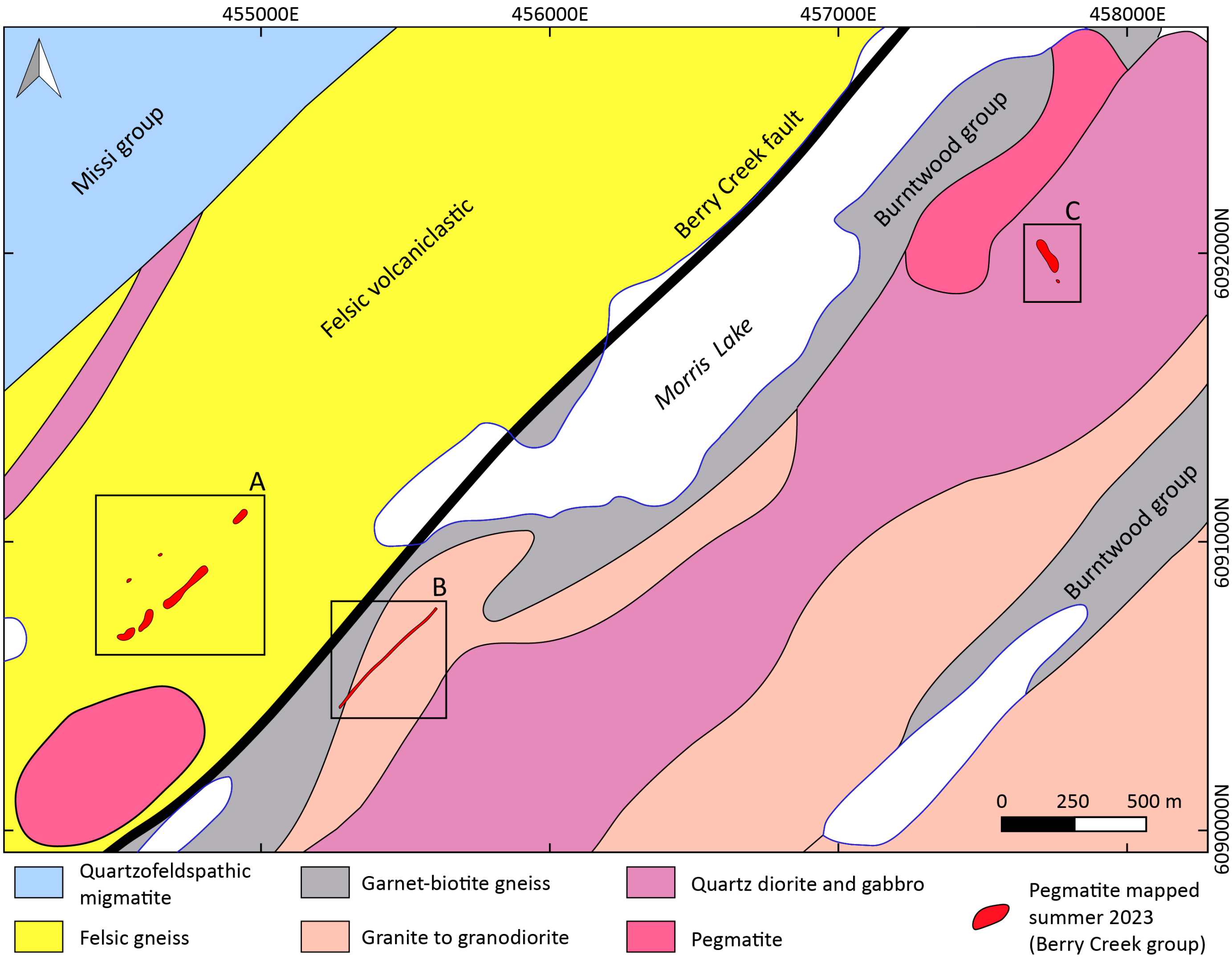


Figure GS2023-7-4: *Location of pegmatite dikes mapped during summer 2023 fieldwork in the Berry Creek group (Bur zone). The locations of the pegmatite dikes are superimposed on the Geological Survey of Canada's regional geology of the Flin Flon belt (NATMAP Shield Margin Project Working Group, 1998). Co-ordinates are in UTM Zone 14, NAD83.*

of tourmaline. The mineral grains range in size from medium to coarse. Similar to most non-lithium–mineralized pegmatite dikes in the Wekusko Lake pegmatite field, no internal zonation was observed in the pegmatite dikes mapped in the Berry Creek group dikes; however, some centimetre-size globular zones of higher concentrations of quartz, tourmaline and muscovite were observed (Figure GS2023-7-3d). Postemplacement hematization was observed in most of the pegmatite dikes in this region. Lithium mineralization was not observed in outcrop in this group of pegmatites, but spodumene- and lepidolite-bearing pegmatite dikes have recently been observed in drillcore from the Bur zone (Rockcliff Metals Corp., 2022).

Violet-Thompson group (Thompson Brothers dike)

The Violet-Thompson pegmatite group intruded a sequence of Missi group sandstone and pebble to cobble conglomerate. The Thompson Brothers pegmatite is located northeast of the Rex Lake pluton, proximal to the east side of the Crowduck Bay shear zone (Figures GS2023-7-1 and -2). Based on its mineral composition, this dike is classified as an LCT rare-element pegmatite, and contains spodumene, albite, quartz, K-feldspar, muscovite and black tourmaline. The pegmatite outcrop is up to 10 m wide, dips steeply, and is exposed for approximately 140 m along a strike of 035°. Drilling has revealed that the dike continues along strike for approximately 900 m (Snow Lake Lithium Ltd., 2022). This pegmatite dike shows a preferred alignment of spodumene crystals of 160°, which is oblique to the orientation of the dike and perpendicular to the orientation of the Crowduck Bay shear zone (Figure GS2023-7-5a). This preferred alignment is disrupted by local shear zones oriented subparallel to the pegmatite contact. These shear zones reoriented the spodumene crystals within the shear bands to an orientation closer to parallel with the trend of the dike (Figure GS2023-7-5a). Oriented samples collected from the Thompson Brothers pegmatite dike (Figure GS2023-7-5b) will

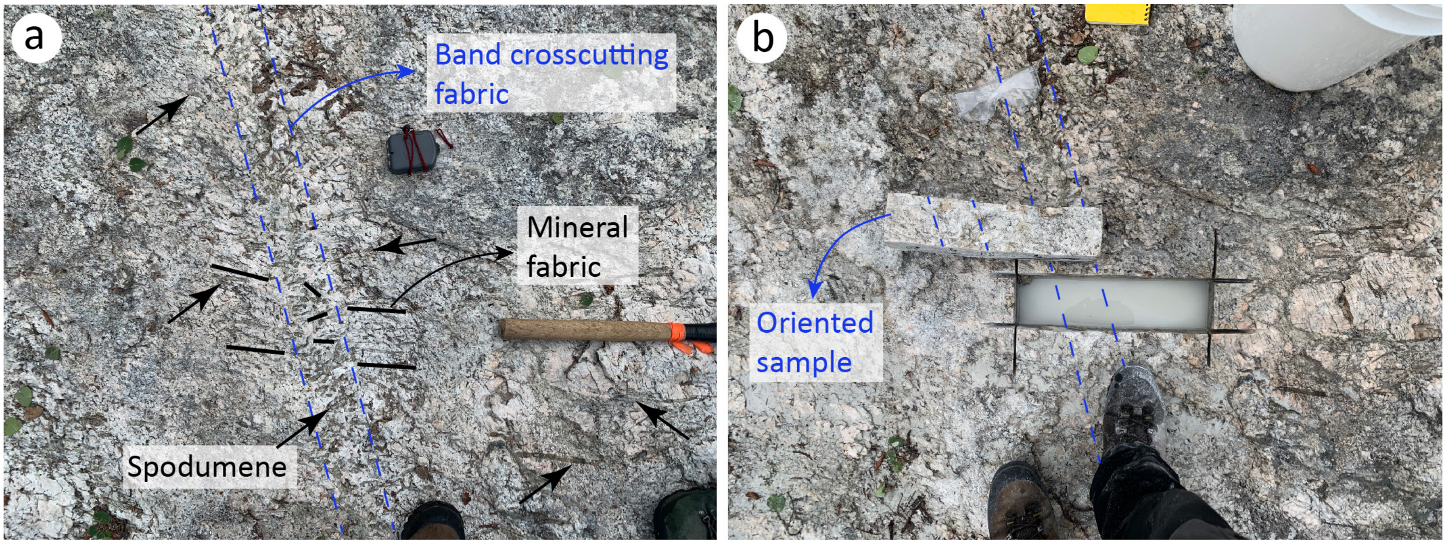


Figure GS2023-7-5: *Example of an oriented sample collected from the Thompson Brothers (Violet-Thompson pegmatite group) spodumene-bearing pegmatite dike from Snow Lake Lithium Ltd.:* ***a)*** *pegmatite outcrop before sample collection, showing a shear band crosscutting the mineral fabric;* ***b)*** *pegmatite outcrop after sample collection. Silva compass for scale in panel (a) is 10 cm long.*

be used for microchemical and microstructural analysis of the various minerals in the dike. These studies will help resolve the mode of crystallization, and the overall question of whether the fabric is the result of an igneous process or deformation.

Whole-rock geochemical trends of the Wekusko Lake pegmatite dikes

In the summer of 2022, twelve samples of pegmatite dikes from the Wekusko Lake pegmatite field (Dion Lake, North Grass River and Crowduck Bay islands groups) were gathered for whole-rock geochemical investigation (Figure GS2023-7-6a; Silva et al., 2022). All samples collected, usually pegmatite blocks between 20 to 50 cm in diameter, were selected to best represent the overall mineral composition of the pegmatite dike. However, due to the extremely coarse grain size and variable local distribution of minerals in the studied pegmatites bodies, the selected samples used for whole-rock geochemistry analysis might not represent the total extent of the pegmatite bodies chemistry. All samples were trimmed to eliminate weathered surfaces. Analyses were conducted by SRC Geoanalytical Laboratories (Saskatoon, Saskatchewan) using inductively coupled plasma–emission spectrometry (ICP-ES) to analyze major and minor elements, and inductively coupled plasma–mass spectrometry (ICP-MS) to analyze trace elements.

Ratios of K/Rb, K/Cs and Nb/Ta are well-documented bulk-rock or mineral indices for pegmatite fractionation systems (e.g., Černý and Burt, 1984; Černý, 2005; Selway et al., 2005). Using ratios of these elements derived from results of whole-rock geochemical analysis of samples from the Wekusko Lake pegmatite field, it is possible to see fractionation trends across the pegmatite field (Figure GS2023-7-6). Specifically, Rb and Cs are primarily partitioned into feldspar and muscovite, and Ta is enriched where there is a minor component of tantalite in the pegmatite dikes. Feldspar and muscovite minerals form a significant component of almost all of the dikes sampled, with muscovite content increasing in spodumene-bearing pegmatite dikes. The Wekusko Lake pegmatite dikes exhibit a strong fractionation trend, from simple pegmatites to lithium-enriched pegmatites, as shown in Figure GS2023-7-6. The non-lithium–mineralized pegmatite dikes of the Dion Lake group, and the barren North Grass River and Crowduck Bay islands groups all have high K/Rb, K/Cs and Nb/Ta ratios. The Dion Lake pegmatites are also enriched in uranium compared to the other pegmatites in the Wekusko Lake pegmatite field. The lowest values for K/Rb, K/Cs and Nb/Ta, which occur in the Sherritt-Gordon, Violet-Thompson and Green Bay pegmatite dikes, define a zone of highly differentiated pegmatites that are enriched in Be, Cs, Rb and Ta. In sum, the K/Rb, K/Cs and Nb/Ta values show fractionation trends toward highly differentiated lithium-enriched pegmatites, with an evolution from non-lithium–mineralized pegmatite dikes in the northern- and easternmost regions of the pegmatite field, to pegmatite dike groups with spodumene mineralization more centrally located in the Wekusko Lake pegmatite field (Figure GS2023-7-6), adjacent to the Crowduck Bay shear zone. Similar to the fractionation trend observed for spodumene-bearing pegmatite dikes, some barren pegmatites within the Sherritt-Gordon and Violet-Thompson groups show low K/Rb, K/Cs and Nb/Ta values. These low ratios, especially in the spodumene-bearing pegmatite dikes, are probably due to several factors, including the higher muscovite content and known enrichment of cesium-muscovite in the spodumene-bearing Zoro pegmatite dikes from the Green Bay group (Benn et al., 2022), Rb substitution in feldspars, and Ta enrichment from tantalite crystallization in comparison to the other pegmatite groups in the Wekusko Lake pegmatite field.

The increase in the alumina saturation index of the pegmatite dikes in the Sherritt-Gordon and Violet-Thompson groups fol-

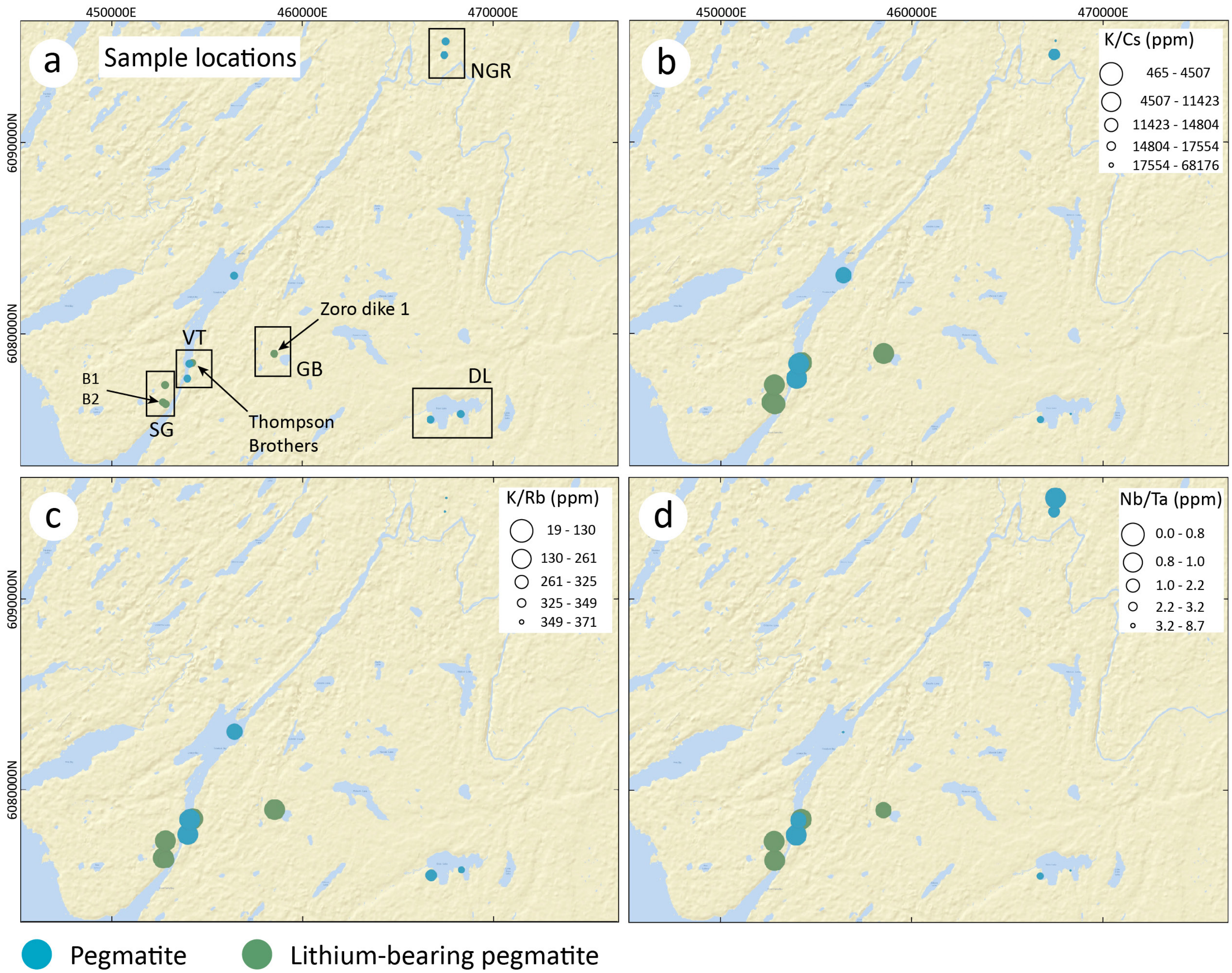


Figure GS2023-7-6: a) *Locations of pegmatite dikes sampled during the summer of 2022, and* ***(b–d)*** *spatial trends in elemental enrichment across the Wekusko Lake pegmatite field, superimposed on the same satellite imagery as in Figure GS2023-7-2:* ***b)*** *K/Cs;* ***c)*** *K/Rb; and* ***d)*** *Nb/Ta. Larger symbols represent lower values, to facilitate map interpretation. The main lithium-bearing pegmatite dikes are highlighted in panel (a). Co-ordinates are in UTM Zone 14, NAD83. Abbreviations: DL, Dion Lake pegmatite group; GB, Green Bay pegmatite group; NGR, North Grass River pegmatite group; SG, Sherritt-Gordon pegmatite group; VT, Violet-Thompson pegmatite group.*

lows the spatial trend of decreasing K/Rb, K/Cs and Nb/Ta ratios observed for the Wekusko Lake pegmatite field (Figure GS2023-7-7), reflecting the higher muscovite content of these dikes.

Figure GS2023-7-7 depicts the inverse relationship between increased peraluminosity (A/NK) and decreased K/Rb ratio from barren pegmatites to spodumene-bearing pegmatites, while also showing a positive relationship between peraluminosity and phosphorus content (P_2O_5). One clear outlier in P_2O_5 composition from a barren pegmatite is observed in Figure GS2023-7-7b. The anomalously high P_2O_5 composition could be explained as possible local enrichment of phosphate minerals in the analyzed sample (e.g., apatite, amblygonite or lithiophilite) that were not previously described for this sample. These element relationships have been observed in many other pegmatite fields (e.g., Selway et al., 2005; Roda-Robles et al., 2023), describing increased fractionation of incompatible elements and spatial pegmatite dike evolution. These element ratios can also vary, and imply a variability in the melt source for either fractionation from melt or direct anatexis models of pegmatite formation. According to the data shown in Figures GS2023-7-6 and -7, there may be a regional geochemical fractionation trend that extends from the eastern and northern boundaries of the Wekusko Lake pegmatite field to the spodumene pegmatite groups near the Crowduck Bay shear zone. This pattern also shows an evolution within the Wekusko Lake pegmatite field, from areas closer to high-grade metamorphism—up to migmatite—toward areas of lower metamorphic grade, of staurolite-first appearance (Lazzarotto, 2020).

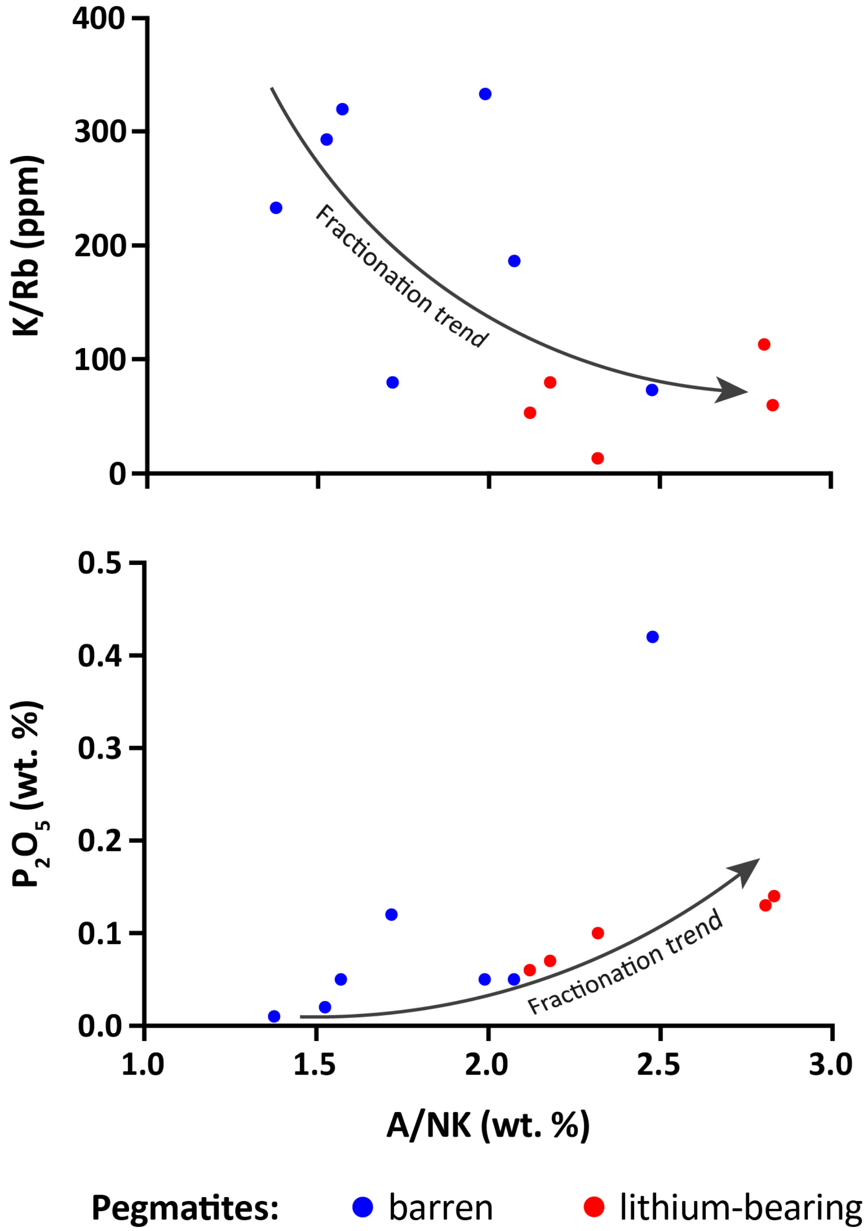


Figure GS2023-7-7: *Whole-rock geochemistry plots showing peraluminosity (A/NK) versus* ***(a)*** *K/Rb and* ***(b)*** *phosphorus content (P_2O_5), differentiating between barren pegmatites and spodumene-bearing pegmatites. The curved arrow demonstrates the fractionation trend.*

Economic considerations

Canada, and particularly Manitoba, is a key player in the green revolution due to the prevalence of lithium-bearing pegmatite occurrences like the Tanco pegmatite and pegmatites in the Wekusko Lake region. Because of its high concentration of lithium-mineralized dikes, ideal mineralogy for lithium extraction, and central location within Canada, the Wekusko Lake pegmatite field offers significant economic potential. The growing need for critical minerals, as well as the growing need to lessen our reliance on fossil fuels, emphasizes the economic relevance of identifying new rare-element pegmatite deposits and expanding our knowledge of existing ones. To accomplish these objectives, it is necessary to evaluate emplacement mechanisms and understand chemical fractionation models within the pegmatite fields. This is important, as it can contribute to a higher probability of discovering new lithium-bearing pegmatite bodies. The Wekusko Lake pegmatite field in west-central Manitoba is located in an active mining area, with established access and infrastructure, and well-studied regional geology. Several companies are actively exploring for lithium in the area. With the recent discovery of lepidolite-bearing pegmatites, the Wekusko Lake pegmatite field is now open for further discoveries of different types of lithium mineralization.

Acknowledgments

The authors thank Snow Lake Lithium Ltd. for access to their pegmatite properties and drillcore, and the Manitoba Geological Survey for providing fieldwork and logistical support in Snow Lake. The project benefited from discussions with B. Young, R. Scott and K. Reid. This study is supported by a Mitacs Accelerate Industrial Postdoc grant with Lithium Foremost Resource & Technology Ltd. as financial and logistical partner, and Natural Sciences and Engineering Research Council of Canada Discovery grants to L. Groat and R. Linnen. Edits from reviewers M. Rinne and K. Reid from the Manitoba Geological Survey are truly appreciated.

References

Ansdell, K.M. 1993: U-Pb constraints on the timing and provenance of fluvial sedimentary rocks in the Flin Flon and Athapapuskow basins, Flin Flon domain, Trans-Hudson orogen, Manitoba and Saskatchewan; *in* Radiogenic Age and Isotopic Studies, Report 7, Geological Survey of Canada, Current Research 93-2, p. 49–57.

Ansdell, K.M. 2005: Tectonic evolution of the Manitoba-Saskatchewan segment of the Paleoproterozoic Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 42, no. 4, p. 741–759.

Ansdell, K.M. and Connors, K.A. 1995: Geochemistry of mafic volcanic rocks, east Wekusko Lake, Manitoba; LITHOPROBE Trans-Hudson Orogen Transect, Report of Fifth Transect Meeting, April 3–4, 1995, Regina, Saskatchewan, LITHOPROBE Secretariat, University of British Columbia, Vancouver, British Columbia, Report 48, p. 198–205.

Ansdell, K.M. and Norman, A.R. 1995: U-Pb geochronology and tectonic development of the southern flank of the Kisseynew belt, Trans-Hudson orogen, Canada; Precambrian Research, v. 72, p. 147–167.

Ansdell, K.M., Connors, K.A., Stern, R.A. and Lucas, S.B. 1999: Coeval sedimentation, magmatism, and fold-thrust belt development in the Trans-Hudson orogen: geochronological evidence from the Wekusko Lake area, Manitoba, Canada; Canadian Journal of Earth Sciences, v. 36, no. 2, p. 293–312.

Bailes, A.H. 1980: Origin of early Proterozoic volcaniclastic turbidites, south margin of the Kisseynew sedimentary gneiss belt, File Lake, Manitoba; Precambrian Research, v. 12, no. 1–4, p. 197–225.

Bailes, A. 1985: Geology of the Saw Lake area; Manitoba Energy and Mines, Geological Services, Geological Report GR83-2, URL <https://manitoba.ca/iem/info/libmin/GR83-2.zip> [September 2022].

Benn, D., Linnen, R.L. and Martins, T. 2018: Geology and bedrock mapping of the Wekusko Lake pegmatite field (northeastern block), central Manitoba (part of NTS 63J13); *in* Report of Activities 2018, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 79–88, URL <https://manitoba.ca/iem/geo/field/roa18pdfs/GS2018-7.pdf> [September 2022].

Benn, D., Martins, T. and Linnen, R.L. 2019: Interpretation of U-Pb isotopic dates of columbite-group minerals in pegmatites, Wekusko Lake pegmatite field, central Manitoba (part of NTS 63J13); *in* Report of Activities 2019, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 52–59, URL <https://manitoba.ca/iem/geo/field/roa19pdfs/GS2019-5.pdf> [August 2023].

Benn, D., Martins, T. and Linnen, R. 2022: Fractionation and enrichment patterns in white mica from Li pegmatites of the Wekusko Lake pegmatite field, Manitoba, Canada; The Canadian Mineralogist, v. 60, p. 933–956.

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 17, p. 127–158.

Černý, P. and Burt, D.M. 1984: Paragenesis, crystallochemical characteristics and geochemical evolution of micas in granite pegmatites; *in* Micas, Reviews in Mineralogy, S.W. Bailey (ed.), Mineralogical Society of America, v. 13, p. 257–297.

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

Černý, P., Trueman, D.L., Zeihlke, D.V., Goad, B.E. and Paul, B.J. 1981: The Cat Lake–Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1, 216 p., URL <https://manitoba.ca/iem/info/libmin/ER80-1> [August 2023].

Connors, K.A. 1996: Unraveling the boundary between turbidites of the Kisseynew belt and volcano-plutonic rocks of the Flin Flon belt, eastern Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 33, p. 811–829.

Connors, K.A. and Ansdell, K.M. 1994: Timing and significance of thrust faulting along the boundary between the Flin Flon–Kisseynew domains, eastern Trans-Hudson orogen; LITHOPROBE Trans-Hudson Orogen Transect, Report of Fourth Transect Meeting, April 11–12, 1994, Saskatoon, Saskatchewan, LITHOPROBE Secretariat, University of British Columbia, Vancouver, British Columbia, Report 38, p. 112–122.

Connors, K.A., Ansdell, K.M. and Lucas, S.B. 1999: Coeval sedimentation, magmatism, and fold-thrust development in the Trans-Hudson orogen: propagation of deformation into an active continental arc setting, Wekusko Lake area, Manitoba; Canadian Journal of Earth Sciences, v. 36, no. 2, p. 275–291.

Connors, K., Ansdell, K. and Lucas, S. 2002: Development of a transverse to orogen parallel extension lineation in a complex collisional setting, Trans-Hudson orogen, Manitoba, Canada; Journal of Structural Geology, v. 24, no. 1, p. 89–106.

David, J., Bailes, A.H. and Machado, N. 1996: Evolution of the Snow Lake portion of the Paleoproterozoic Flin Flon and Caisson belts, Trans-Hudson orogen, Manitoba, Canada; Precambrian Research, v. 80, p. 107–124.

Fedorowich, J.S., Kerrich, R. and Stauffer, M.R. 1995: Geodynamic evolution and thermal history of the central Flin Flon belt, Trans-Hudson Orogen: constraints from structural development, $^{40}Ar/^{39}Ar$, and stable isotope geothermometry; Tectonics, v. 14, p. 472–503.

Galley, A.G., Syme, E.C. and Bailes, A.H. 2007: Metallogeny of the Paleoproterozoic Flin Flon belt, Manitoba and Saskatchewan; *in* Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods, W.D. Goodfellow (ed.), Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 533509–552531.

Gordon, T., Hunt, P., Bailes, A. and Syme, E. 1990: U-Pb ages from the Flin Flon and Kisseynew belts, Manitoba: chronology of crust formation at an early Proterozoic accretionary margin; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 177–199.

Gysi, A.P., Williams-Jones, A.E. and Collins, P. 2016: Lithogeochemical vectors for hydrothermal processes in the Strange Lake peralkaline granitic REE-Zr-Nb deposit; Economic Geology, v. 111, no. 5, p. 1241–1276.

Kraus, J. and Menard, T. 1997: A thermal gradient at constant P: implications for low- to medium-P metamorphism in a compressional tectonic setting, Flin Flon and Kisseynew domains, Trans-Hudson orogen, central Canada; Canadian Mineralogist, v. 35, p. 1117–1136.

Kraus, J. and Williams, P.F. 1994: Cleavage development and timing of metamorphism in the Burntwood group across the Threehouse synform, Snow Lake, Manitoba: a new paradigm; LITHOPROBE Trans-Hudson Orogen Transect, Report of Fourth Transect Meeting, April 11–12, 1994, Saskatoon, Saskatchewan, LITHOPROBE Secretariat, University of British Columbia, Vancouver, British Columbia, Report 38, p. 230–238.

Lazzarotto, M.C. 2020: Metamorphism of the Flin Flon greenstone belt, Manitoba; Ph.D. thesis, University of Calgary, Calgary, Alberta, 217 p.

Lewry, J.F. and Collerson, K.D. 1990: Trans-Hudson orogen: extent, subdivisions, and problems; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Publication 37, p. 1–14.

Lewry, J., Hajnal, Z., Green, A., Lucas, S.B., White, D., Stauffer, M.R., Ashton, K.E., Weber, W. and Clowes, R. 1994: Structure of Paleoproterozoic continent-continent collision zone: a LITHOPROBE seismic reflection profile across the Trans-Hudson orogen, Canada; Tectonophysics, v. 232, no. 1–4, p. 143–160.

Lithium Foremost Resource & Technology Ltd. 2022: Properties; URL <https://foremostlithium.com/> [September 2021].

Lodestar Battery Metals Corp. 2023: Lodestar advances exploration at flagship Peny project; URL <https://lodestarbatterymetals.ca/news/lodestar-advances-exploration-at-flagship-peny-project/> [September 2023].

Loveday, D. 2021: Bur zone project Manitoba, Canada; NI 43-101 technical report prepared for Rockcliff Metals Corp.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A. and Thomas, D.J. 1996: Intra-oceanic tectonics and the development of continental crust: 1.92–1.84 Ga evolution of the Flin Flon belt, Canada; Geological Society of America Bulletin, v. 108, p. 602–629.

Lucas, S.B., White, D., Hajnal, Z., Lewry, J., Green, A., Clowes, R., Zwanzig, H., Ashton, K., Schledewitz, D., Stauffer, M., Norman, A., Williams, P.F. and Spence, G. 1994: Three-dimensional collisional structure of the Trans-Hudson orogen, Canada; Tectonophysics, v. 232, p. 161–178.

Machado, N., Zwanzig, H. and Parent, M. 2000: U-Pb ages of plutonism, sedimentation, and metamorphism of the Paleoproterozoic Kisseynew metasedimentary belt, Trans-Hudson orogen (Manitoba, Canada); Canadian Journal of Earth Sciences, v. 36, no. 11, p. 1829–1842

Manitoba Geological Survey 2022: Bedrock geology of Manitoba; Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, Open File OF2022-2, scale 1:1 000 000.

Martins, T., Benn, D. and McFarlane, C. 2019: Laser-ablation inductively coupled plasma–mass spectrometry (LA-ICP-MS) analyses of columbite grains from Li-bearing pegmatites, Wekusko Lake pegmatite field (northeastern block), central Manitoba (part of NTS 63J13); Manitoba Agriculture and Resource Development, Manitoba Geological Survey, Data Repository Item DRI2019003, Microsoft® Excel® file, URL <https://manitoba.ca/iem/info/libmin/DRI2019003.xlsx> [August 2023].

Martins, T., Linnen, R., Fedikow, M. and Singh, J. 2017: Whole-rock and mineral geochemistry as exploration tools for rare-element pegmatite in Manitoba: examples from the Cat Lake–Winnipeg River and Wekusko Lake pegmatite fields (parts of NTS 52L6, 63J13); *in* Report of Activities 2017, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 42–51, URL <https://manitoba.ca/iem/geo/field/roa17pdfs/GS2017-5.pdf> [August 2023].

NATMAP Shield Margin Project Working Group 1998: Geology, NATMAP Shield Margin Project area, Flin Flon belt, Manitoba/Saskatchewan; Geological Survey of Canada, Map 1968A, scale 1:100 000.

Natural Resources Canada 2021: Critical minerals; URL <https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/critical-minerals/23414/> [September 2023].

Reid, K.D. 2021a: Bedrock geology of the Stuart Bay–Chickadee Lake area (east of Wekusko Lake), north-central Manitoba (parts of NTS 63J12, 13); Manitoba Agriculture and Resource Development, Manitoba Geological Survey, Preliminary Map PMAP2021-1, scale 1:15 000, URL <https://manitoba.ca/iem/info/libmin/PMAP2021-1.pdf> [October 2022].

Reid, K.D. 2021b: Results of bedrock geological mapping in the Stuart Bay–Chickadee Lake area (east of Wekusko Lake), north-central Manitoba (parts of NTS 63J12, 13); *in* Report of Activities 2021, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 29–39, URL <https://manitoba.ca/iem/geo/field/roa21pdfs/GS2021-4.pdf> [October 2022].

Rockcliff Metals Corp. 2022: Rockcliff completes drilling at the Bur property. Discovers lithium bearing pegmatite dykes near high grade Bur VMS deposit; URL <https://rockcliffmetals.com/investors/news-releases/rockliff-completes-drilling-at-the-bur-property-discovers-lithium-bearing-pegmatite-dykes-near-high-grade-bur-vms-deposit//> [August 2023].

Roda-Robles, E., Vieira, R., Lima, A., Errandonea-Martin, J., Pesquera, A., Cardoso-Fernandes, J. and Garate-Olave, I. 2023: Li-rich pegmatites and related peraluminous granites of the Fregeneda-Almendra field (Spain-Portugal): a case study of magmatic signature for Li enrichment; Lithos, v. 452–453 (2023), art. 107195.

Schneider, D., Heizler, M., Bickford, M., Wortman, G., Condie, K. and Perilli, S. 2007: Timing constraints of orogeny to cratonization: thermochronology of the Paleoproterozoic Trans-Hudson orogen, Manitoba and Saskatchewan, Canada; Precambrian Research, v. 153, p. 65–95.

Selway, J.B., Breaks, F.W. and Tindle, A.G. 2005: A review of rare-element (Li-Cs-Ta) pegmatite exploration techniques for the Superior Province, Canada, and large worldwide tantalum deposits; Exploration and Mining Geology, v. 14, no. 1–4, p. 1–30.

Silva, D., Groat, L., Martins, T. and Linnen, R. in press: Structural controls on the origin and emplacement of lithium-bearing pegmatites; The Canadian Journal of Mineralogy and Petrology, v. 61.

Silva, D., Martins, T., Groat, L. and Linnen, R. 2022: Preliminary observations on emplacement controls of pegmatite dikes from the Wekusko Lake pegmatite field, north-central Manitoba (parts of NTS 63J13, 14, 63O4); *in* Report of Activities 2022, Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, p. 49–60.

Snow Lake Lithium Ltd. 2022: Presentation; URL <https://snowlakelithium.com/presentation/> [September 2021].

Stern, R.A. and Lucas, S.B. 1994: U-Pb zircon age constraints on the early tectonic history of the Flin Flon accretionary collage, Saskatchewan; *in* Current Research 1994-F, Geological Survey of Canada, p. 75–86.

Stern, R.A., Lucas, S.B., Syme, E.C., Bailes, A.H., Thomas, D.J., Leclair, A.D. and Hulbert, L. 1993: Geochronological studies in the Flin Flon domain, Manitoba-Saskatchewan, NATMAP Shield Margin Project area: results for 1992–1993; *in* Radiogenic Age and Isotopic Studies, Report 7, Geological Survey of Canada, Current Research 93-2, p. 59–70.

Stewart, M.S., Lafrance, B. and Gibson, H.L. 2018: Early thrusting and folding in the Snow Lake camp, Manitoba: tectonic implications and effects on volcanogenic massive sulfide deposits; Canadian Journal of Earth Sciences, v. 55, no. 8, p. 935–957.

Syme, E.C., Lucas, S.B., Bailes, A.H. and Stern, R.A. 2000: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, no. 11, p. 1767–1788.

Whalen, J.B., Syme, E.C. and Stern, R.A. 1999: Geochemical and Nd isotopic evolution of Paleoproterozoic arc-type granitoid magmatism in the Flin Flon belt, Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 36, no. 2, p. 227–250.

Zwanzig, H.V. 1990: Kisseynew gneiss belt in Manitoba: stratigraphy, structure, and tectonic evolution; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 95–120.