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Exploring use of nitrogen-isotope applications in the study of the magmatic evolution and rare-element ore genesis of pegmatites from southeastern Manitoba (parts of NTS 52L5, 6, 11)

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In Brief:

- Outcrop and subsurface pegmatite and granitoid samples were collected from four different localities in southeastern Manitoba
- Future work will take place utilizing nitrogen isotope analyses as a novel tool

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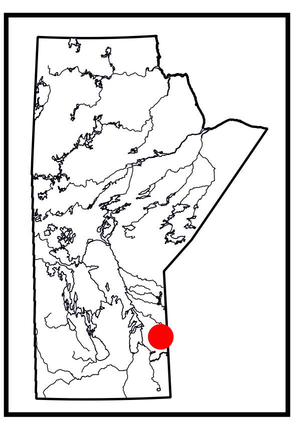

Summary

Southeastern Manitoba is renowned for its well-preserved Archean cratonic rocks of the Superior province as well as for its substantial economic potential (e.g., critical metal-enriched granitic pegmatites). In the summer of 2023, the Manitoba Geological Survey and the Stable Isotope Geochemistry Laboratory at the University of Alberta initiated a collaborative project to explore the magmatic evolution of the Neoarchean granitoids and pegmatite-related ore genesis in southeastern Manitoba, relying on the use of novel nitrogen-isotope techniques. The results of field sampling conducted in July 2023 are summarized in this report. Outcrop and underground samples were collected from the Tanco lithium-cesium-tantalum–bearing pegmatite, a pegmatite found in the Cat Creek area, the Bird Lake supracrustal-type granitoid and the Lac du Bonnet granitoid. Future work will focus on detailed petrographic, geochemical (especially nitrogen-isotope) and petrogenetic analyses to shed light on the genesis of the Neoarchean granitoids and the spatially related pegmatites, as well as their critical metal-enrichment mechanism.

Introduction

The Bird River domain (BRD) in southeastern Manitoba has long been the subject of geological and economic investigations due to the presence of well-preserved Archean rocks (e.g., the western Superior Neoarchean tonalite-trondhjemite-granodiorite [TTG] suite; Percival et al., 2012; Yang, 2014, 2023; Yang et al., 2019) and the world-class rare-element pegmatite deposit hosting lithium (Li), cesium (Cs) and tantalum (Ta) in the Bernic Lake area (Li-Cs-Ta [LCT] Tanco pegmatite; Černý, 2005). While numerous studies have been carried out on the tectonic evolution of the Superior province (see summary in Yang et al., 2019) and the petrogenesis of the pegmatites from the Bernic Lake pegmatite group (e.g., Stilling et al., 2006), the genesis of the Neoarchean granitoids and the spatially related pegmatites from the Cat Lake–Winnipeg River pegmatite field (Černý et al., 1981) remains unresolved.

Nitrogen (N) is one of the few elements that exists in all reservoirs of the Earth (i.e., the atmosphere, hydrosphere, biosphere, lithosphere and mantle). In the lithosphere, N exists mainly as ammonium (NH_4^+) that can replace potassium (K^+) in the crystal lattice of silicate minerals (Honma and Itihara, 1981) and as NH_4^+/NH_3 or N_2 in hydrothermal fluids (Li et al., 2021). Therefore, N isotopes can potentially serve as a robust tool to trace geological processes (e.g., Li et al., 2014, 2019) and the formation of ore deposits (e.g., orogenic gold deposits; Jia et al., 2003) for the following reasons:

- the significant N isotopic difference between the crust and the mantle
- the large magnitude of isotope fractionation among NH_4^+, NH_3 and N_2 (e.g., Li et al., 2021)
- the close affinity of NH_4^+ to alkali metals (e.g., Honma and Itihara, 1981)
- the fact that NH_3 acts as a complexing agent to enhance heavy metal migration in fluids (e.g., Li et al., 2021)

In particular, the pegmatites in southeastern Manitoba are enriched in alkali metals, which provide an excellent opportunity to apply the N-isotope technique to the understanding of the petrogenesis of the Neoarchean granitoids and spatially related LCT pegmatites, and further explore the mechanisms behind the rare-metal enrichment. The use of N isotopes can help tackle three significant scientific issues: 1) the genesis of the Neoarchean TTG suite in southeastern Manitoba; 2) the genesis of the LCT pegmatites in southeastern Manitoba; and 3) the source and rare-metal enrichment processes of the LCT pegmatites.

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As a first step, fieldwork was carried out in July 2023. The general sample characteristics and field relationships recorded at four localities (Tanco LCT pegmatite, Cat Creek pegmatite, Bird Lake supracrustal [S]-type granitoid and Lac du Bonnet granitoid) in southeastern Manitoba are summarized in this report (Figure GS2023-3-1).

Geological background

General geology

Southeastern Manitoba, which is geologically located in the western Superior province, is subdivided into several tectonic elements, including the Uchi domain, English River domain, Bird River domain, Winnipeg River domain and Western Wabigoon domain (Percival et al., 2012; Gilbert et al., 2013; Yang et al., 2019). The Neoarchean BRD, situated between the English River domain and the Western Wabigoon domain, is an east-trending granite-greenstone belt approximately 150 km long extending from Lac du Bonnet, in the west, to Separation Lake (Ontario), in the east (Figure GS2023-3-1; Percival et al., 2006; Gilbert et al., 2008). The supracrustal rocks in the BRD are composed mainly of metavolcanic and metasedimentary rocks and associated synvolcanic intrusive rocks that are separated into two arms by the Mesoarchean Maskwa Lake batholith (Figure GS2023-3-1; Gilbert et al., 2008; Yang and Houlé, 2020). Both the Bird River sill (southern arm) and the Mayville intrusion (northern arm) consist of a series of layered mafic to ultramafic intrusive rocks with a similar age of ca. 2743 Ma, which suggests that they are comagmatic and both part of the Bird River magmatic event (Yang and Houlé, 2020). The later and final stage of mafic magmatism in the BRD is documented by the Maskwa Lake batholith II suite (2726 ±6 Ma; see Wang, 1993), along with granitoids and associated minor gabbroic dikes (Yang and Houlé, 2020). The granitic rocks of the Inconnu plutons and the intrusion at Cat Creek were subsequently emplaced into the belt (Yang and Houlé, 2020). The final stage of BRD magmatism is recorded by the emplacement of the pegmatites along belt-scale faults (Yang and Houlé, 2020).

Numerous granitoid rocks in the BRD have been described in detail (Yang, 2014, 2023; Yang and Houlé, 2020; Yang et al., 2019), including the Maskwa Lake batholith (Bailes et al., 2003), the Marijane Lake pluton, the Birse Lake pluton, the intrusion in the Tin–Osis lakes area and sanukitoid intrusions (Yang, 2014, 2023). The granitoids are defined in part as TTG in the field and represent either the core (i.e., Maskwa Lake batholith I) of the Neoarchean BRD or younger plutons (i.e., Marijane Lake pluton, Birse Lake pluton, intrusion in the Tin–Osis lakes area and sanukitoid intrusions) that have intruded and disrupted the supracrustal rocks of the domain (Yang, 2014, 2023; Yang et al., 2019). Parts of the Marijane Lake pluton, the Birse Lake pluton and the intrusion in the Tin–Osis lakes area are classified as S-type and ilmenite-series granites (Yang, 2014, 2023; Yang et al., 2019). The BRD is also recognized for its LCT pegmatite resources (Černý et al., 1981; Bannatyne, 1985), which are not only spatially related to the S-type granitoids but also considered genetically related to them (Yang, 2014, 2023; Yang et al., 2019).

Tanco LCT pegmatite suite

The Bernic Lake formation in the BRD hosts one of the most economically important and highly fractionated LCT pegmatites in the world (Černý, 2005). The Neoarchean Bernic Lake formation (2724.6 ±1.1 Ma) is dominated by mafic intrusive and volcanic rocks (Gilbert, 2008). The gabbros that host the Tanco LCT pegmatite crystallized at 2723.1 ±0.8 Ma and were subsequently regionally metamorphosed under low-pressure amphibolite-facies conditions (Černý, 2005; Gilbert, 2008; Kremer, 2010). The similar age and close spatial relationship between the Bernic Lake formation and the gabbroic hostrocks indicate that these two units were likely formed during a single magmatic event (Kremer, 2010). The Tanco LCT pegmatite is a bilobate, unexposed intrusion approximately 1520 m long, 1060 m wide and 100 m thick (Černý, 2005). Uranium-lead tantalite (2641 ±3 Ma; Camacho et al., 2012) and zircon (2647.4 ±1.0 Ma; Kremer, 2010) radiometric dating of the pegmatite yielded similar intrusive ages. These ages are consistent with the reactivation of the Bernic Lake shear zone from ca. 2650 to 2640 Ma, facilitating emplacement of the igneous body along the west-trending fault system (Kremer, 2010; Martins et al., 2013). The Tanco LCT pegmatite is granitic and peraluminous in nature, and extremely enriched in economically valuable Li, Cs and Ta (Stilling et al., 2006).

Cat Creek pegmatite suite

The Cat Creek pegmatite suite consists of two main pegmatite bodies and several smaller pegmatite dikes (<20 cm in width), which intruded into a suite of mafic to felsic rocks belonging to the northern arm of the BRD (Yang and Houlé, 2020). Gabbro is the most common hostrock at this location, containing roughly equal proportions of hornblende and plagioclase. The bulk mineral assemblage for this pegmatite is composed of roughly equal proportions of albite and quartz (~40% each, modal abundance), along with minor spodumene and muscovite (~10% each), as well as accessory garnet, apatite and Nb-Ta oxides (~1%).

Samples and field relationships

Outcrop and subsurface samples were collected from four localities in the BRD region of southeastern Manitoba. Brief sample descriptions recorded in the field are presented below.

Tanco LCT pegmatite

The Tanco LCT pegmatite is a highly fractionated pegmatite that is classified as belonging to the LCT family, rare-element class, petalite subtype (Černý and Ercit, 2005). The Tanco pegmatite is composed of nine mineralization zones (Černý, 2005; Stilling et al., 2006). Fist-sized pegmatite samples were collected from the five zones that are currently accessible via the underground mine working faces. The general description of each zone

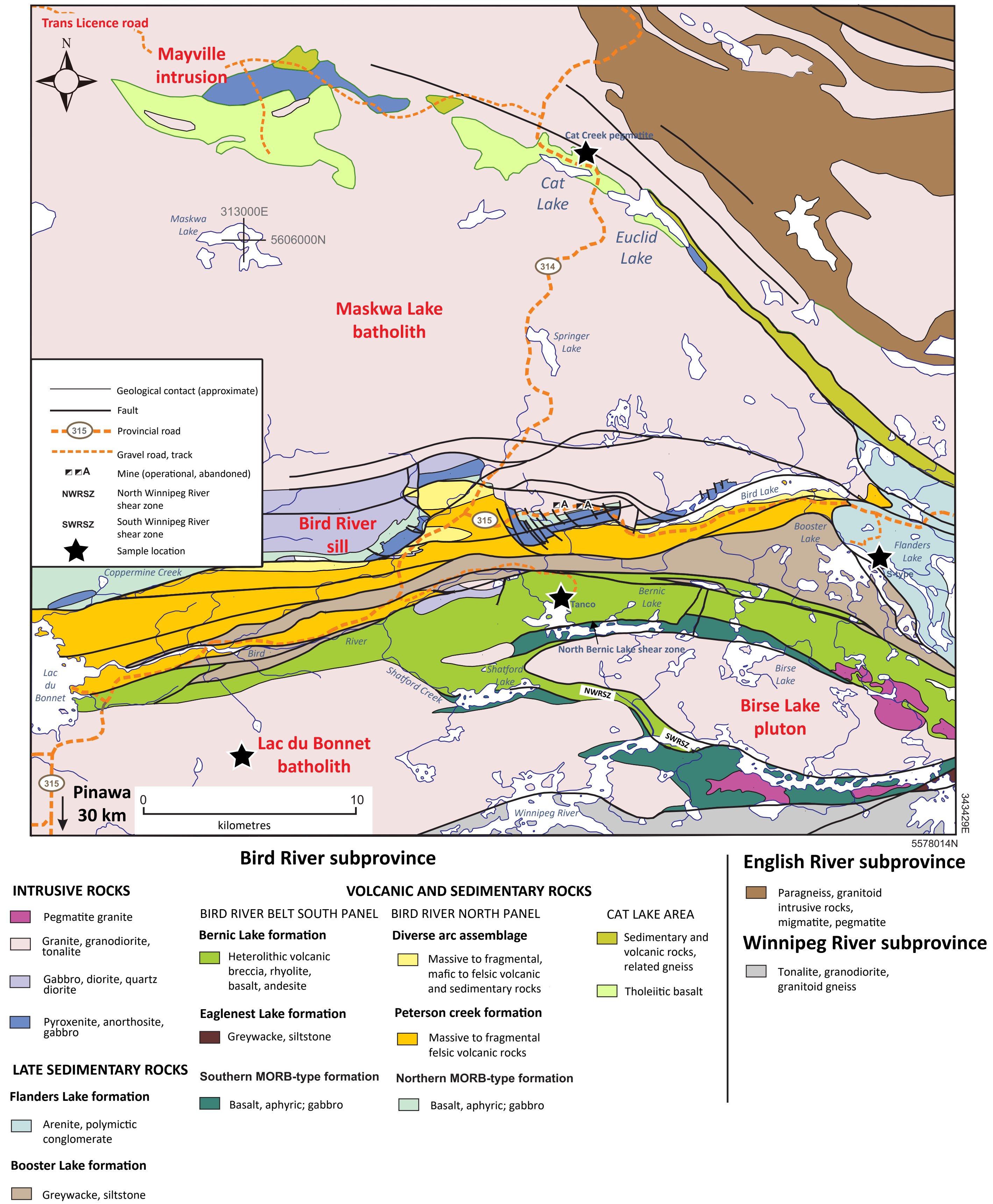

Figure GS2023-3-1: *Regional geology of the Cat Lake–Euclid Lake and Winnipeg River area, southeastern Manitoba, showing the main part of the Bird River greenstone belt between Lac du Bonnet and Flanders Lake, and the northern arm extending as far as the Mayville intrusion (modified from Yang et al., 2013). Abbreviation: MORB, mid-ocean–ridge basalt. All co-ordinates are in UTM Zone 15, NAD83.*

is given below based on field observations as well as literature summaries from Černý (2005) and Stilling et al. (2006).

Zone 20 (wall zone)

The mineralogy of the pegmatite wall zone is mostly megacrystic microcline-perthite, quartz and albite. Minor components of tourmaline, muscovite, lithian muscovite and beryl are evident. The geochemical composition of the wall-zone pegmatite is considered to represent the bulk composition of the Tanco pegmatite (Černý, 2005; Stilling et al., 2006).

Zone 50 (spodumene zone)

The spodumene zone is composed mainly of microcrystalline to megacrystic spodumene and quartz intergrowths with various textures (Breasley et al., 2022). Minor amounts of microcline-perthite, petalite, eucryptite, tantalum oxides, albite and lithian muscovite are present. Xenoliths of amphibolite hostrocks were observed in this zone of the pegmatite, which is of significant economic importance due to the presence of high-grade Li within the Tanco LCT pegmatite.

Zone 70 (quartz zone)

The quartz zone consists of nearly monomineralic quartz. Spodumene xenoliths as well as muscovite veins are commonly observed within the megacrystic quartz. The quartz zone locally has a K-feldspar–rich cap that contains spodumene and quartz intergrowths. The genesis of the quartz zone and its potential role in metal enrichment of the Tanco pegmatite is uncertain.

Zone 80 (pollucite zone)

The pollucite zone consists of nearly monomineralic pollucite. Minor amounts of quartz, spodumene, petalite, muscovite, lepidolite, albite, microcline and apatite can be observed. This zone contains a significant amount of Cs (~75% pure pollucite; Stilling et al., 2006).

Zone 90 (lepidolite zone)

The lepidolite zone is hypothesized to have formed from metasomatism, with purple lithian muscovite replacing primary feldspar (Černý, 2005). Microlite, which is the main Ta-bearing mineral at the Tanco mine, is found intermixed with muscovite and quartz that has replaced microcline (Černý, 2005). The dominant minerals in this zone include lithian muscovite, lepidolite and microcline-perthite, with minor amounts of albite, quartz, beryl, Ta oxides, cassiterite and zircon. This zone is of economic interest due to the high concentrations of Rb and Cs in micas, and the presence of Ta and Nb oxides.

Other pegmatite samples

Samples from a pegmatite in the Cat Creek area were collected for this study. Both the amphibolite hostrock and the pegmatite itself were sampled. In the contact zone, both the amphibolite and pegmatite show varying intensity of shear fabrics, indicating deformation during pegmatite emplacement. The amphibolite hostrock is composed mostly of hornblende and plagioclase, with minor biotite, apatite, epidote and chlorite. The pegmatite is mainly composed of albite, K-feldspar and quartz, with spodumene, tourmaline, muscovite, apatite, garnet and epidote as accessory minerals.

Granitoid samples

Bird Lake S-type granitoid samples were collected along with spatially associated metasedimentary hostrocks (metagreywacke from the Flanders Lake formation; Yang, 2014). The lithology of the S-type granitoid is predominantly medium- to coarse-grained two-mica granite. The sharp contact between the granitoid and hostrock, and the presence of metasedimentary enclaves within the granitoid body, imply that the granitic magma intruded into the metasedimentary hostrock (Figure GS2023-3-2) and potentially assimilated the sedimentary rocks, but this has yet to be determined.

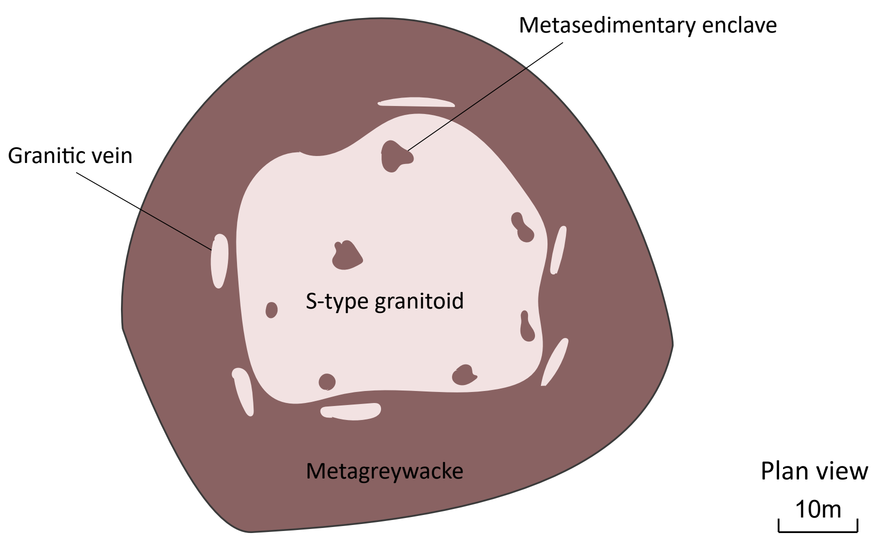

Figure GS2023-3-2: *Schematic illustration of the field relationship between the Bird Lake S-type granitoid and metasedimentary hostrock. Abbreviation: S, supracrustal.*

Samples of the Lac du Bonnet batholith were collected in the Pinawa dam area. The batholith was identified as TTG in the field (Yang, 2014, 2023). The major minerals in these rocks are quartz, K-feldspar and plagioclase, with minor biotite.

Economic considerations

The pegmatites from the Cat Lake–Winnipeg River pegmatite field in southeastern Manitoba are economically significant due to their high contents of rare metals, such as Li, Cs and Ta (Černý, 2005). The increasingly high demands for Li for rechargeable batteries as well as for Cs for drilling fluids make the exploration of pegmatitic resources in Manitoba crucial to the Canadian economy. This project is designed to use the novel N-isotope technique, which is currently one of the best tools to assess the geochemical affinity of alkali metals, to trace the source and enrichment mechanism of Li and Cs. The results are expected to provide insights for greater exploration potential in Manitoba and elsewhere in the Archean Superior province in Canada.

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