GS2022-6

Preliminary results from targeted sampling of the Brezden Lake intrusive complex, west-central Manitoba (parts of NTS 64C4)

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In Brief:

- The Brezden Lake intrusive complex consists predominantly of silica saturated syenites
- The syenites were intruded by dikes of lamprophyre-like rock, as well as calcite carbonatite
- The discovery of carbonatite and associated fenitic alteration indicates potential for rare-earth element mineralization

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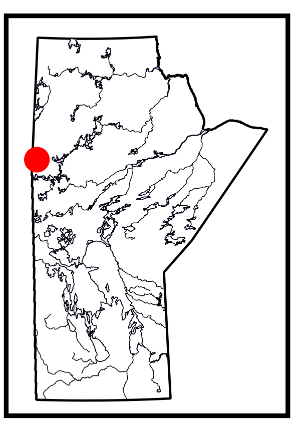

Summary

The Brezden Lake intrusive complex is an alkali-rich pluton of largely syenitic composition. The complex is hosted in a granodiorite intrusion within the Burntwood group metasedimentary rocks of the Kisseynew domain. The Brezden Lake intrusive complex consists predominantly of silica-saturated syenites, which are classified into several subunits based on field, macroscopic and petrographic observations. Foliated and massive syenite, quartz syenite, calcite-bearing melasyenite and pegmatoid syenite are interpreted to represent multiple intrusive phases and products of their evolution. The syenites were intruded by dikes of lamprophyre-like rocks, akin to vogesite, and calcite-carbonatite. The discovery of carbonatite and associated fenitic alteration expands exploration potential for rare-earth elements in this part of Manitoba significantly further west of the Eden Lake carbonatitic-alkaline complex and beyond the Lynn Lake belt.

Introduction

Field observations and preliminary petrographic results from five days of reconnaissance sampling of the Brezden Lake intrusive complex (BLIC) in west-central Manitoba during June 2022 are summarized in this report. Previous studies of the BLIC by the Manitoba Geological Survey are described in Lenton (1981), McRitchie (1988) and Martins et al. (2012). The 2012 project resulted in the discovery of metasomatized syenites that locally contain interstitial calcite. This finding was significant in that it demonstrated the potential for carbonatite magmatism in the area.

Historically, the BLIC has been considered similar to the Eden Lake complex (ELC), which is located approximately 110 km northeast of the study area and known to host calcite-carbonatite (Chakhmouradian et al., 2008) and associated rare-earth element (REE) mineralization (Mumin, 2010; Medallion Resources, 2011). The primary objective of the 2022 sampling program was to follow up on the work completed in 2012 by Martins et al. (2012) and to investigate the BLIC for large-scale lithological or structural variations, as well as the possible presence of carbonatites and REE mineralization.

Regional geology

The westernmost edge of the BLIC is located approximately 600 m east of Brezden Lake, which can be reached by floatplane from Lynn Lake situated some 95 km to the south-southwest. The BLIC is exposed over a length of approximately 4 km with a maximum width of 800 m (Figure GS2022-6-1). The BLIC is hosted in a granodiorite intrusion within the metasedimentary Burntwood group, which itself lies within the northern flank of the Kisseynew domain (KD). The KD is part of the internal zone of the Trans-Hudson orogen and is bound to the north by the Leaf Rapids domain, to the east and southeast by the Superior boundary zone, and to the south by the Flin Flon domain (Lenton, 1981; Ansdell et al., 1995; Corrigan et al., 2007).

The KD tectonic environment has been interpreted as either a back-arc (Ansdell et al., 1995) or fore-arc basin (Zwanzig, 1999). In recent years, the back-arc regime has become accepted as the most likely tectonic model for the KD (Ansdell, 2005; Corrigan et al., 2009). The KD is a belt of upper-amphibolite– to lower-granulite–facies metasedimentary gneisses, which consist predominantly of the Burntwood group metaturbidite (Corrigan et al., 2007). However, arkose-derived gneisses of the Sickle group (terrestrial equivalent to the Burntwood group) are exposed on the northern flank of the KD. The Sickle group was deposited unconformably on the Granville complex, which is interpreted as back-arc metabasalts with slightly altered mid-ocean–ridge basalt (MORB) affinity (Murphy and Zwanzig, 2021).

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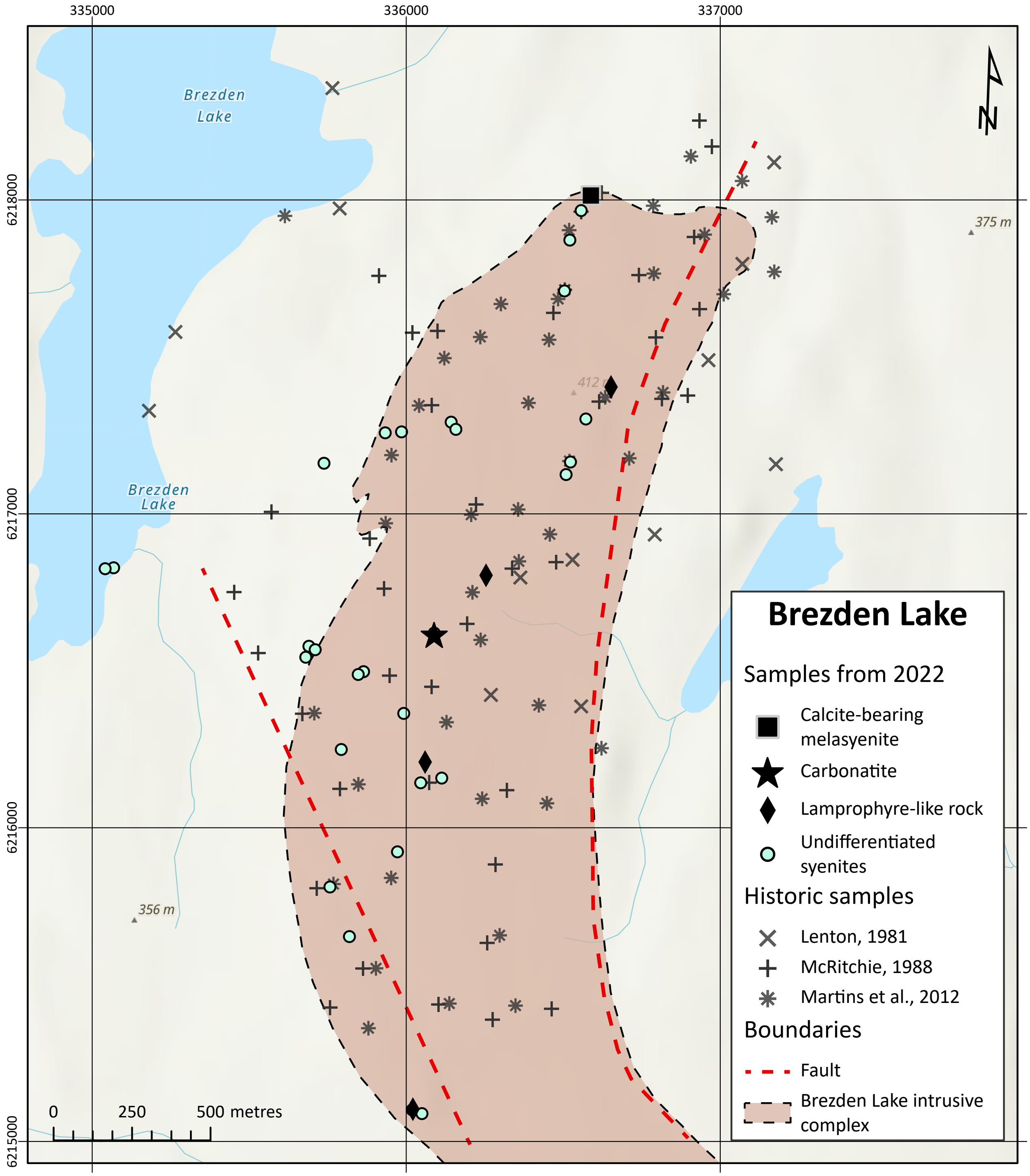

Figure GS2022-6-1: *Simplified geological map showing the extent of the Brezden Lake intrusive complex, west-central Manitoba (after Martins et al., 2012; all co-ordinates are projected in UTM Zone 14N, NAD 83).*

The BLIC is emplaced in a granodiorite intrusion hosted exclusively in the Burntwood group but lies approximately 6 km south of the Sickle group rocks at Russell Lake (Martins and Couëslan, 2019). The Burntwood group, which was deposited between ca. 1.86 and 1.84 Ga, grades laterally and vertically into the fluvial to alluvial deposits along the flanks of the KD (1.85–1.84 Ga; Machado et al., 1999; Zwanzig, 2008 Corrigan et al., 2009). Sedimentation was followed by a period of calcalkaline arc magmatism and D_1 deformation dated at 1.84–1.83 Ga (Machado et al., 1999; Zwanzig, 1999; Hollings and Ansdell, 2002). The KD collided with the Superior boundary zone between 1.84 and 1.82 Ga, which resulted in two deformation phases (D_2–D_3) at 1.82–1.81 Ga (White, 2005). The D_2–D_3 phases produced nappe-like folds accompanied by peak metamorphic conditions in the central KD (750 ±50°C, 5.5 ±1 kbar; Gordon, 1989). Peak metamorphic conditions were not homogeneous across the KD, whose peripheral areas are characterized by lower grades of metamorphism. Lenton (1981) reported peak conditions for the

Brezden Lake area to be 600–630°C and 2.5 kbar. This period of deformation and metamorphism was coeval with the emplacement of a voluminous granitoid suite. Advection from the granitic intrusions is thought to be the cause of high-temperature conditions after the cessation of D_3 (Kraus and Menard, 1997). The F_4 folds and D_5 faults are the last major deformation phases and occurred after 1.79 Ga. This period was accompanied by retrograde metamorphism and dike emplacement until 1.78 Ga. (Machado et al., 1999).

Description of the Brezden Lake intrusive complex units

The following rock-unit descriptions are based on multiple outcrop, hand-specimen and petrographic observations, and build upon the previous work and interpretations presented in Martins et al. (2012). The carbonatite, fenite, and lamprophyre-like rocks were identified in the course of this current study and, therefore, more detailed descriptions of these units are provided in this report.

Syenites

The bulk of the BLIC is composed of modally and texturally diverse syenites (syenite, quartz syenite, melasyenite, calcite-bearing melasyenite), whose mineralogy is dominated by K-feldspar and plagioclase. Plagioclase is predominantly sodic in composition (<15 mol. % anorthite), as indicated by its optical characteristics. Quartz and a variety of ferromagnesian silicates are common minor constituents in these rocks but locally gain the status of major rock-forming minerals (in quartz syenite and melasyenite, respectively). Wide variations in the morphology and distribution of these minerals are responsible for textural variants such as spotted, pegmatoid, foliated, massive and inequigranular syenites. Volumetrically, the most common rock type by far is pink, massive, fine- to medium-grained syenite. In addition to feldspars, this rock contains on average 6 vol.% quartz (locally up to 20%, grading into quartz syenite) and up to 15 vol. % greenish-black clinopyroxene and/or calcium amphibole. Wedge-shaped, brown titanite crystals and black platy biotite are the only accessory minerals identifiable in hand specimens.

Significant grain-size variations are common at the outcrop scale, leading to tabular and lenticular bodies of pegmatoid syenite showing complex crosscutting relationships (Figure GS2022-6-2a). Near the BLIC margins, clinopyroxene, amphibole and feldspar crystals (or their aggregates) exhibit preferred orientations subparallel to the contact and the proportion of dark-coloured minerals generally decreases toward the interior of the complex. Away from the marginal zone, clinopyroxene and amphibole crystals are randomly oriented, subhedral in morphology and generally do not exceed several millimetres in size. However, in pegmatoid varieties, ferromagnesian silicates are euhedral and reach several centimetres in diameter.

Based on limited outcrop observations, early massive to foliated syenite is crosscut by pegmatite dikes and lenses, which in turn are crosscut by younger, fine-grained melasyenite (Figure GS2022-6-2a).

Quartz syenite

This rock type contains the same minerals as the syenite units described above. However, quartz syenite is commonly much coarser-grained and differs by its higher modal content of quartz (up to 20 vol. %) and plagioclase (25 vol. %) relative to the predominant syenite varieties. Quartz syenite is more abundant close to the contacts of the BLIC, particularly in the midsection. One notable exception is a spotted variety, which contains ovoid aggregates of ferromagnesian silicates in a leucocratic fine-grained mesostasis. The majority of foliated syenites observed are quartz syenite.

Melasyenite

Melasyenite is the least abundant variety of syenite exposed at the BLIC and typically shows extensive iron staining on weathered surfaces due to decomposition of ferromagnesian silicates. All observed melasyenite is foliated, regardless of its location in the BLIC. The melasyenite differs from the predominant syenite units by its higher modal proportion of clinopyroxene and calcium amphibole (35 vol. %). Other dark-coloured constituents (biotite and titanite) do not exceed a few per cent in abundance. Melasyenite is typically medium grained; however, a single dike of fine-grained melasyenite was observed crosscutting a pegmatite dike but could not be sampled (Figure GS2022-6-2a). The medium-grained syenite variety is crosscut by pegmatite dikes (Figure GS2022-6-2a), lamprophyre-like rocks and calcite-carbonatite.

Calcite-bearing melasyenite

This unit was observed along the northwestern edge of a ridge forming the northernmost exposure of the BLIC (Figure GS2022-6-1). In outcrop, the melasyenite is structurally uniform, but crosscut by multiple pegmatite dikes (Figure GS2022-6-2b). The rock is patchy green, fine grained and appears pitted on weathered surfaces. The green colour of the rock is due to the high modal percentage of clinopyroxene (50–55 vol. %). Albite and orthoclase (identified by their optical properties) each constitute approximately 20 vol. % of the rock, whereas quartz does not exceed 5 vol. % in abundance. The presence of interstitial calcite grains, which are present throughout the rock and explain the surface pitting, should be noted.

Pegmatoid syenite

Pegmatite was observed throughout the BLIC and crosscuts most other units, except for late fine-grained melasyenite dikes (Figure GS2022-6-2a–c). In addition to well-defined tabular intrusions with sharp contacts (dikes), a smaller number of pegmatoid

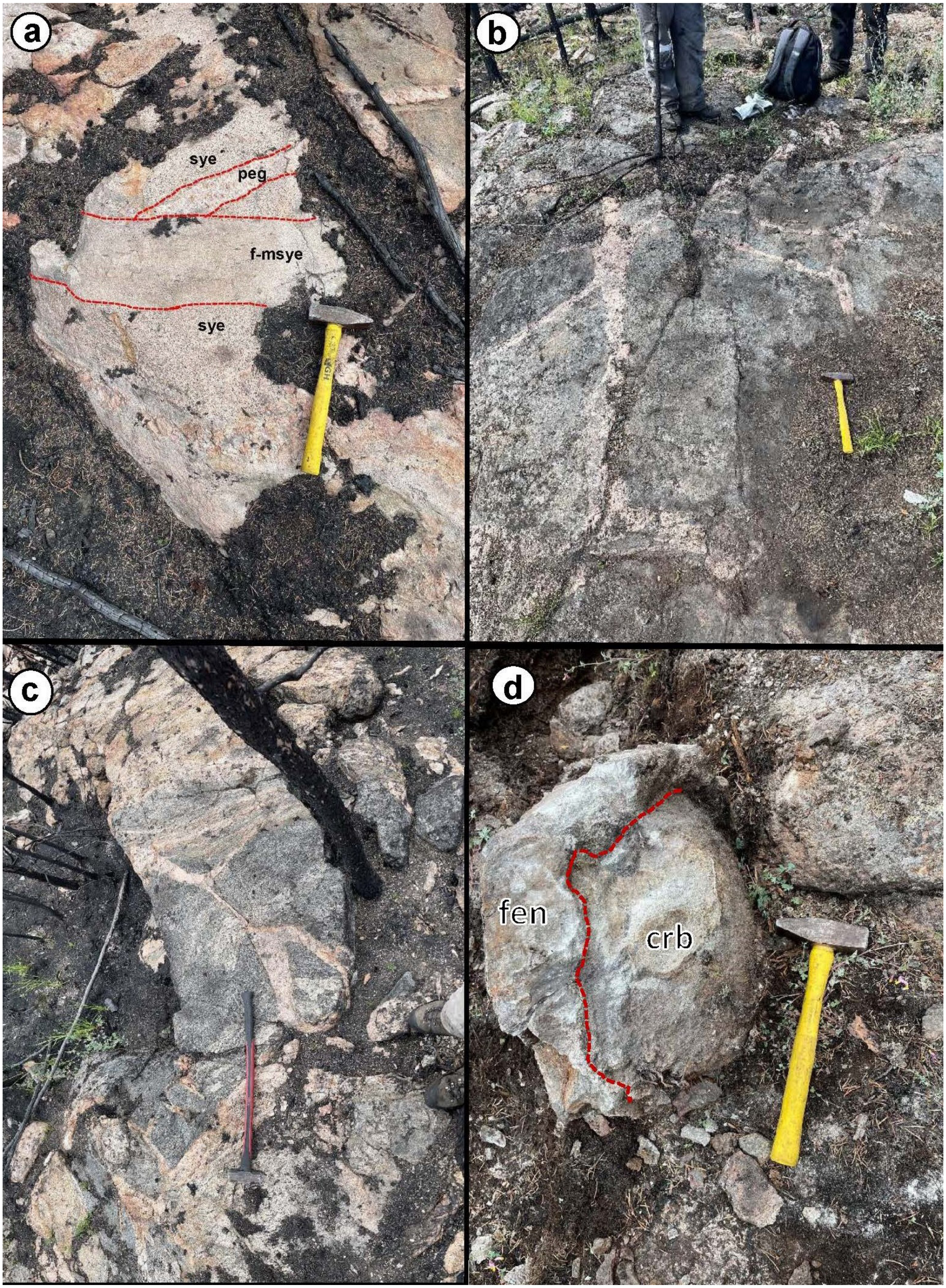

Figure GS2022-6-2: *Outcrop photographs from the Brezden Lake intrusive complex, with examples of contacts and crosscutting relationships:* ***a)*** *fine-grained melasyenite (f-msye) crosscutting pegmatite dike (peg), both emplaced in syenite (sye);* ***b)*** *multiple pegmatite veins crosscutting melasyenite host;* ***c)*** *pegmatite veins (pink) crosscut lamprophyre-like rock;* ***d)*** *recessively weathered carbonatite (crb) and adjacent fenite (fen).*

syenite pods were observed; their contacts with the host syenites are diffuse, resulting from gradual grain coarsening. This textural change is accompanied by a decrease in the modal content of plagioclase in the pegmatoid variety and its enrichment in quartz and black calcium amphibole. No preferential orientation was evident in the distribution of pegmatite bodies, but some areas within the BLIC show a greater density of dikes (Figure GS2022-6-2b). Locally, areas of concentrated crosscutting pegmatite represent megabreccias comprising rafts of metasomatized country rocks cemented by medium-grained and pegmatoid syenites. Mineralogically, the pegmatoid rocks are similar to one another, with the predominance of sub- to anhedral microcline-perthite and quartz (~1–5 cm across), and euhedral clinopyroxene, amphibole and titanite crystals (each up to 3 cm in length).

Lamprophyre-like rocks

In comparison with the calcite-bearing melasyenite (see above), dark-coloured inequigranular rocks containing large (up to 2 cm across) euhedral phenocrysts of calcium amphibole set in a fine-grained clinopyroxene-feldspar mesostasis are much more common. Visually, these rocks resemble amphibole-phyric feldspathic lamprophyres (vogesite and spessartites) and, hence, are referred to as lamprophyre-like rocks in the present report. The exposures of these rocks are restricted to recessed areas within syenites more resistant to weathering, which precluded accurate determination of their structural and dimensional characteristics. A series of isolated outcrops of this unit, each measuring up to several tens of square metres, were observed in the central and west-central parts of the BLIC. Based on limited field evidence, the lamprophyre-like rocks occur as thick dikes, which are possibly arranged in clusters. The lamprophyre-like rocks appear to crosscut the massive syenite and, in turn, are intruded by pegmatite dikes (Figure GS2022-6-2c).

Mineralogically, the lamprophyre-like rocks comprise amphibole rhombs (20–25 vol. %) immersed in a fine-grained mesostasis of sub- to euhedral clinopyroxene and anhedral microcline-perthite (30–35 vol. % each). Minor to accessory constituents include sodic plagioclase, apatite, titanite and allanite. The amphibole crystals are poikilitic with numerous small (<1 mm) inclusions of apatite, allanite, titanite and clinopyroxene. Locally, the density of inclusions is such that their host amphibole should be more appropriately termed ‘oikocryst’ rather than ‘phenocryst’. In addition to discrete inclusions, oikocrysts in some lamprophyre-like rocks enclose lithic clusters of clinopyroxene and apatite (~75 and 15 vol. %, respectively), associated with accessory plagioclase, titanite and allanite.

Carbonatite and associated fenite

A calcite-carbonatite dike crosscutting foliated melasyenite was identified at a single outcrop in the central part of the BLIC (Figures GS2022-6-1, 2d). The carbonatite exposure is recessed and appears tan on the weathered surface. Locally, the exocontact zone is darker coloured, owing to its enrichment in clinopyroxene, and coarser grained relative to wallrock further away from the carbonatite. The exocontact rock comprises anhedral microcline-perthite, quartz and plagioclase (~40–45, 20–25 and 10–15 vol. %, respectively) associated with prismatic clinopyroxene (10–15 vol. %), which is variably replaced by calcium amphibole. Euhedral crystals of titanite and apatite (<1 mm in length) are accessory constituents (Figure GS2022-6-3a). The observed textural and mineralogical variations are interpreted as the product of alkali metasomatism (fenitization) of the wallrock syenite at its contact with the carbonatite (Le Bas, 2008; Elliott et al., 2018). Consequently, the exocontact parageneses are interpreted as fenite rather than quartz syenite.

The calcite-carbonatite is distinctly banded parallel to the dike margins. The banding is expressed on a millimetre to centimetre scale and involves both textural and modal variations. Macroscopically, the rock comprises inequigranular, mosaic-textured calcite, euhedral black clinopyroxene, yellowish-green apatite prisms, brownish-black titanite, andradite and allanite grains. The latter three minerals are visible in hand specimen but are reliably distinguished from one another only in thin section.

Calcite makes up approximately 70 vol. % of the rock. Calcite grains are anhedral and range from 0.2 to 7 mm in size. In predominantly carbonate areas, calcite grains form a recognizable mosaic pattern with triple junctions. Most of the grains exhibit polysynthetic twinning and, in some cases, bent or tapering-out twin lamellae (Figure GS2022-6-3b). Also ubiquitous are undulatory extinction, grain-boundary bulging, lineage and core-mantle structures (Figure GS2022-6-3b, c). All these microtextural characteristics are indicative of low-strain deformation and syndeformational recrystallization (Chakhmouradian et al., 2015). The carbonatite contains elongate syenite xenoliths, as well as isolated xenocrysts of microcline, plagioclase and quartz locally mantled by calcsilicate phases.

Clinopyroxene and apatite are ubiquitous minor constituents (~10 vol. % each) and occur as prismatic crystals ranging from 0.3 to 2.0 and from 0.2 to 1.5 mm in length, respectively. The clinopyroxene is pleochroic, varying from pale yellow to pale green in plane-polarized light. A large proportion of the grains are fractured and replaced by minute elongate crystals of bluish-green amphibole and pale-brown biotite along the fractures. Apatite crystals of crudely prismatic habit show concentric zonation in cross-polarized light (Figure GS2022-6-3b) and cathodoluminescence images. Their blue luminescence is indicative of elevated REE contents (Barbarand and Pagel, 2001; Chakhmouradian et al., 2017).

Economic considerations

Carbonatites are economically important sources for REE and host the largest REE deposits known (i.e., the Bayan Obo and Mianning–Dechang deposits in China and the Mountain Pass deposit in the United States). China is currently the largest producer of REE ore concentrate worldwide (168 000 t in 2021; Cor-

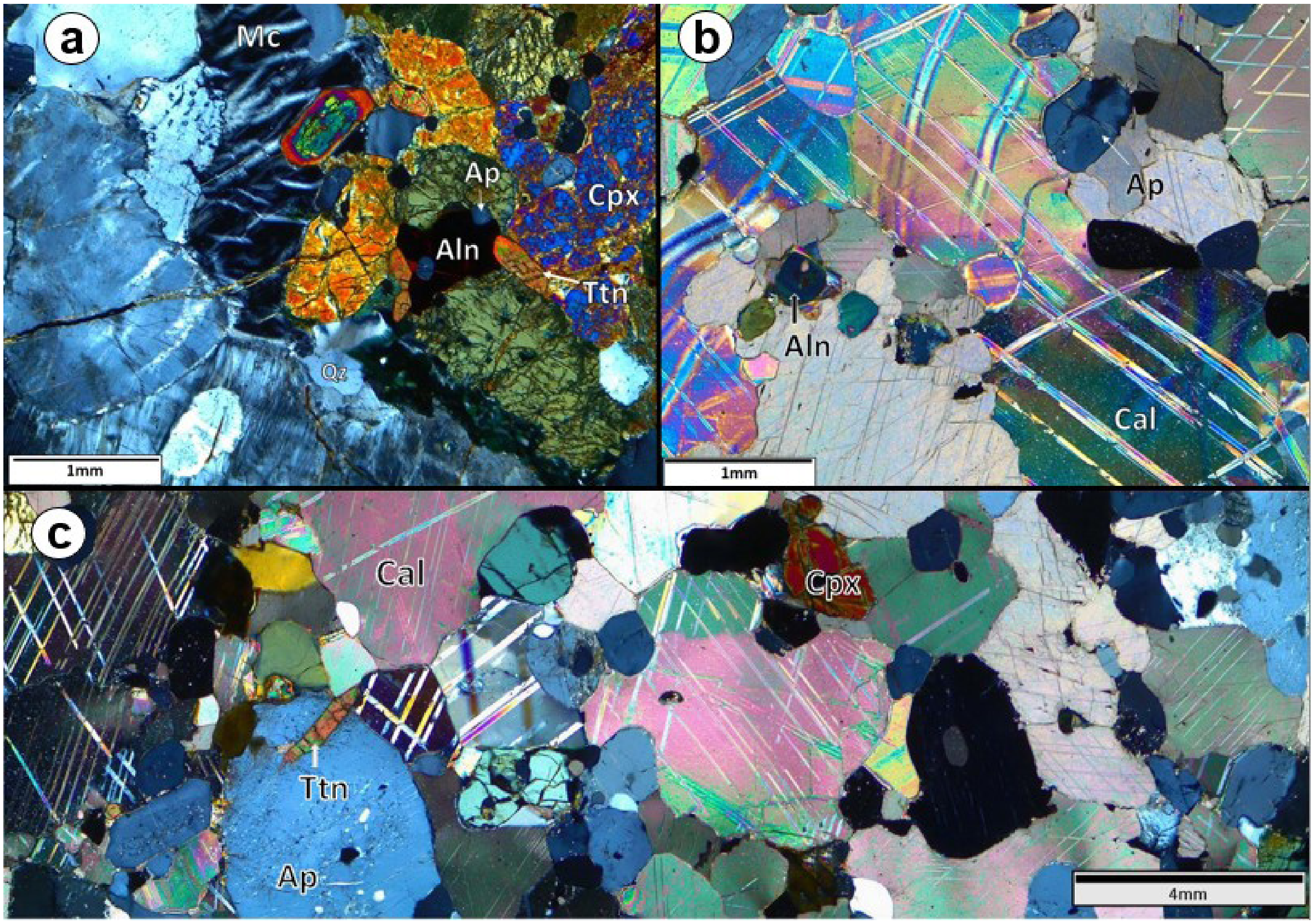

Figure GS2022-6-3: *Photomicrographs, taken in cross-polarized light, of representative textures and mineral associations in fenite and calcite-carbonatite from the study area:* ***a)*** *fenite composed of microcline (Mc), apatite (Ap), allanite (Aln), clinopyroxene (Cpx), quartz (Qz) and zoned titanite (Ttn);* ***b)*** *deformation textures in carbonatite, mechanical twinning in calcite (Cal), and grain-size variations due to dynamic recrystallization;* ***c)*** *further example of the microtextural characteristics shown in photo b.*

dier, 2022). The Mountain Pass mine in California is the second largest producer, with an annual output of 43 000 t; however, all its production is currently exported (Cordier, 2022). Increased demand for REE, spurred on by the electronics and green-technology industries, has created a need for economically viable REE deposits, as well as stable and reliable sources of REE, outside of the current producers. This has prompted the Government of Canada to include REE to the list of critical minerals (Natural Resources Canada, 2021) and support mineral exploration and research efforts focused on REE under the Targeted Geoscience Initiative (TGI) and other programs.

The BLIC is geologically similar to the ELC, situated some 110 km north-northwest in the Lynn Lake Paleoproterozoic greenstone belt. The ELC, predominantly composed of syenites, hosts calcite-carbonatite and associated REE mineralization and has been the subject of REE exploration in recent years (Medallion Resources, 2011). The newly discovered carbonatite occurrence at the BLIC further underscores this similarity, particularly given the nearly identical textural characteristics and mineralogy of this rock at both localities (Chakhmouradian et al., 2008). At the same time, there are significant petrographic differences between the syenites at Brezden and Eden lakes. Firstly, the BLIC appears to lack cumulate rocks akin to foliated coarse-grained melasyenites in the western part of the ELC. Secondly, amphibole and biotite are far more common in the Brezden Lake suite, attesting to a much higher level of activity of water and alkalis in its parental magma(s). Thirdly, lamprophyres are a prominent lithology in the BLIC, but were not observed at Eden Lake. These petrographic differences suggest not only that the BLIC magmas are of a more evolved nature but also that the prevailing geotectonic regime prevented volatile loss during their emplacement. Overall, the preliminary results of the current work indicate significant REE exploration potential outside the Lynn Lake belt, including the BLIC, but probably tied to similar processes in the lithospheric mantle.

Acknowledgments

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