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Indicator minerals for lithium exploration in glaciated terrain

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INTRODUCTION

In 2021 and 2022, the Geological Survey of Canada (GSC) and the province of Nova Scotia Department of Natural Resources and Renewables (NSDNRR) collected glacial sediment (till) samples around a pair of known lithium-cesium-tantalum (LCT) pegmatites as part of critical mineral exploration research funded by the GSC's Targeted Geoscience Initiative (TGI) program. Only a few studies have ever investigated till indicator mineral methods for exploring for lithium-bearing pegmatites. To address this knowledge gap, a detailed glacial sediment and bedrock study was conducted around the known pegmatites to investigate how spodumene, the key Li ore mineral, is glacially dispersed in till. This indicator mineral study focuses on the North and South Brazil Lake LCT pegmatites in southwestern Nova Scotia, Canada (Fig. 1) (McClenaghan et al. 2023a,b, 2024; Brushett and Tupper 2021; Brushett et al. 2022, 2024). In these pegmatites, lithium is hosted in spodumene ($LiAlSi_2O_6$), a clinopyroxene and a highly sought after Li-bearing mineral for hard rock Li mining globally as it is less energy intensive to process than lepidolite (Gao et al. 2023).

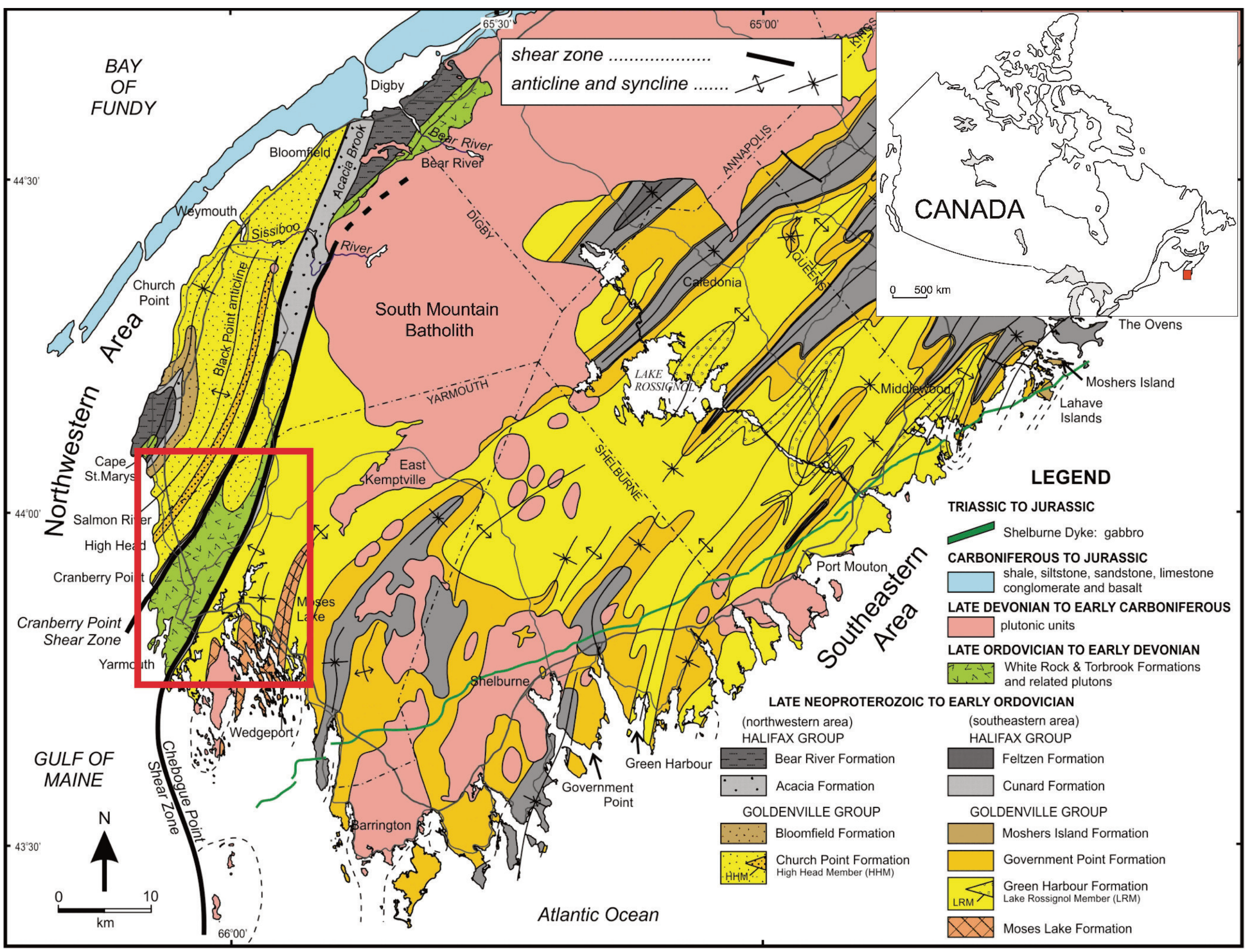

Fig 1. Bedrock geology of southwestern Nova Scotia (modified from White 2010; White et al. 2018). Location of the Brazil Lake study area is indicated by the red box.

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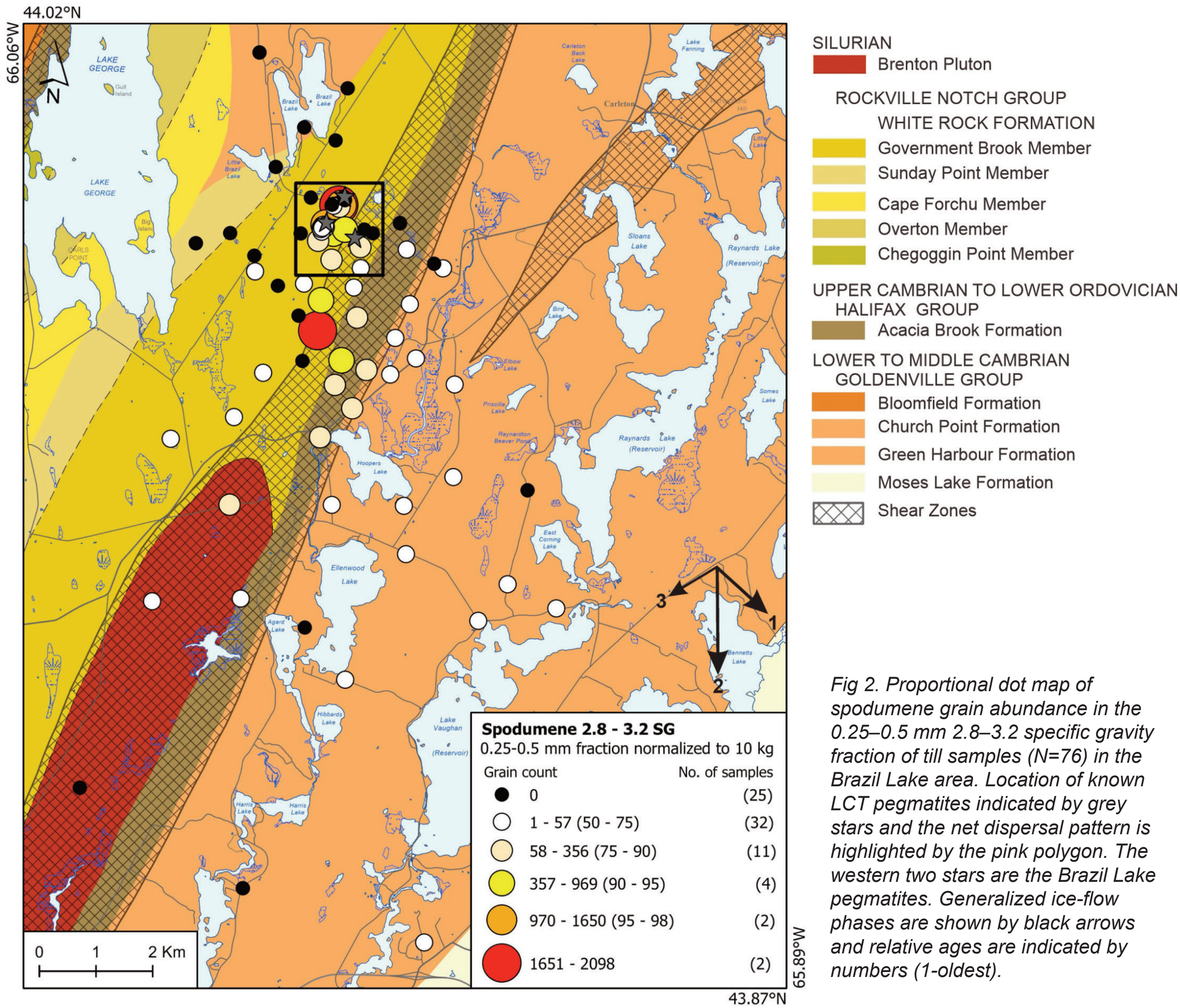

Fig 2. Proportional dot map of spodumene grain abundance in the 0.25–0.5 mm 2.8–3.2 specific gravity fraction of till samples (N=76) in the Brazil Lake area. Location of known LCT pegmatites indicated by grey stars and the net dispersal pattern is highlighted by the pink polygon. The western two stars are the Brazil Lake pegmatites. Generalized ice-flow phases are shown by black arrows and relative ages are indicated by numbers (1-oldest).

GEOLOGY

Bedrock geological setting

The study area is underlain by rocks of the Meguma terrane, the most easterly component of the northern Appalachian orogen (Hibbard et al. 2006; White et al. 2018), and that is characterized by a thick sequence of Cambrian to Early Ordovician metasedimentary rocks, comprising the meta-sandstone-dominated Goldenville Group and the overlying siltstone- and slate-dominated Halifax Group (White 2010). The majority of these rocks were intruded by the ca. 373 Ma peraluminous South Mountain Batholith and related granitoid rocks (Fig. 1, White and Barr 2017). Numerous tin, base, and precious metal occurrences are found throughout south-west Nova Scotia. The most significant deposit is the East Kemptville Sn deposit along the western edge of the South Mountain Batholith (e.g. O'Reilly and Kontak 1992; Fig. 1). There are numerous smaller granite-hosted greisen deposits and metasediment-hosted shear and replacement style Sn-Zn-Cu-Pb-In deposits, many of which are associated with the Kemptville Shear Zone, a zone of tectonic shearing comprising multiple shear and fault zones (Fig. 2). The Brazil Lake pegmatites are hosted by shallow marine metased-

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imentary rocks interbedded with minor mafic metavolcanic units, which locally include quartzite, amphibolite, and pelitic schist (Figs. 1, 2, White 2010; White and Barr 2017). Kontak (2006) suggested that the Brazil Lake pegmatites were emplaced in an active shear zone where high-temperature ductile deformation occurred during consolidation of the pegmatite. Age dates of tantalite (U-Pb) from the South pegmatite indicate that pegmatite crystallization occurred at ca. 395 Ma (Kontak et al. 2005; Kontak and Keyser 2009).

The pegmatite dykes are named and described with respect to their relative locations to each other, North or South. The brief description of the pegmatites below is summarized from Corey (1995), Kontak, (2004, 2006), Kontak et al. (2005), Barr and Cullen (2010), Black (2012) and Cullen et al. (2022). The dykes are 300 m apart and occur as lenticular forms with wider cores transitioning to thinly tapered ends. The North dyke is at least 700 m in length and reaches a maximum thickness of 21 m at its centre. The South dyke has a defined strike length of ~300 m and a thickness of ~ 8–12 m. Both dykes have southwest-plunging trends of ~ 30–40°. The pegmatites are albite-spodumene types and are characterized by coarse crystals of spodumene (Fig. 3) and K-feldspar, with intergranular spodumene, muscovite, albite, and quartz. Key minerals present in the pegmatites that could be useful indicator minerals for drift prospecting include white spodumene, black to blue tourmaline, black columbite/tantalite, blue apatite, green beryl, cassiterite, wolframite, sphalerite, zircon, epidote, topaz, titanite, and phosphate minerals. The recently discovered Army Road LCT pegmatite is just east of the Brazil Lake pegmatites (Fig. 2), although not much has been reported about the geology of this pegmatite.

Fig. 3. Large spodumene crystals exposed on the weathered subcropping surface of the South pegmatite (photograph by M.B. McClenaghan, NRCan photo 2023-464).

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Surficial geology

The Brazil Lake area underwent extensive glacial modifications during the late Wisconsin glaciation, leaving thick unconsolidated glacial sediments in south-trending drumlins over much of the region. Till thickness is variable, ranging from thin veneers (<2 m) over parts of the pegmatites to drumlin ridges consisting of over 40 m of till (Brushett et al. 2024). The surficial geology of the region is the product of multiple glacial advances and retreats throughout several glacial events (Grant 1980; Stea and Grant 1982; Stea et al. 2011): 1) older east to southeastward ice-flow; 2) southward regional ice-flow; and 3) younger flow to southwest (Fig. 2).

METHODS

Five pegmatite samples (~1 kg) were collected to provide insights into the types and abundances of LCT pegmatite indicator minerals that could be in glacial sediments down ice. A total of 84 bulk (7–20 kg) heavy mineral till samples were collected from 77 sites according to the till sampling protocols established by the GSC (McClenaghan et al. 2020, 2023c). Sites consisted of hand-dug pits and till exposures in borrow pits, sections along local roads, or backhoe trenches dug 50 to 100 m south (down ice) of both the North and South pegmatites. Field data, site descriptions, and site photos are reported in GSC Open File 9148 (Brushett et al. 2024). Cobble to pebble-sized spodumene clasts (Fig. 4) were readily visible in till within 100 m down-ice (south) of the pegmatites.

Sample processing

The bulk till samples and bedrock samples were processed at Overburden Drilling Management Limited (ODM), Ottawa, Canada to produce mid-density and heavy mineral concentrates from which indicator minerals were counted and selected minerals removed for further study. Specific details about the methods used, fractions generated, quality control, and flow sheets are reported in McClenaghan et al. (2024). Briefly, the <2.0 mm fraction of each sample was processed to produce a preconcentrate using shaking table methods. The table preconcentrate was subsequently subjected to two heavy liquid separations and ferromagnetic separations to produce 2.8–3.2 specific gravity (SG) and >3.2 SG non-ferromagnetic heavy mineral concentrates for visual identification and counting of indicator minerals.

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Fig. 4. Photograph of spodumene clasts recovered while collecting till samples in backhoe trenches just down-ice of the pegmatites (photograph by M.B. McClenaghan, NRCan photo 2022-590).

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The 0.25–0.5 mm, 0.5–1.0 mm, and 1.0–2.0 mm non-ferromagnetic >3.2 SG fractions and the 0.25–0.5 mm non-ferromagnetic 2.8 to 3.2 SG fraction of bedrock and till samples were examined by ODM and potential indicator minerals were counted.

INDICATOR MINERALS

Raw mineral abundances were normalized to a 10 kg sample weight (table feed) and both raw and normalized counts are reported in McClenaghan et al. 2024) along with proportional dot maps for each of the key indicator minerals. Spodumene is the main Li-bearing mineral in the Brazil Lake pegmatites. It has a SG of 3.1–3.2 and a hardness of 6.5–7. It was identified in concentrates by its white colour, prismatic, generally flattened and elongated, striated, commonly massive crystal habit, and brittle fracture (Fig. 5) and, at times, its fluorescence under UV light. It is most abundant in the mid-density (2.8–3.2 SG) fraction as compared to the heavy mineral (>3.2 SG) fraction. It is most abundant in the smallest size fraction (0.25–0.5 mm), with the most anomalous till samples containing 100s to 1000s of grains/10 kg. In this study, spodumene is most abundant in till immediately south of the North and South pegmatites (maximum 2212 grains). Abundances decrease southward down ice, but spodumene is still detectable in till 12 km to the south. Other LCT indicator minerals recovered from till samples down ice include columbite/tantalite, apatite, tourmaline, cassiterite, and scheelite (McClenaghan et al. 2024).

Fig. 5. Colour photograph of spodumene grains from a bedrock sample of the North Brazil Lake pegmatite. Photograph taken by Overburden Drilling Management Ltd).

Brazil Lake dispersal train

The threshold between background and anomalous concentrations of spodumene in till is zero grains, thus the presence of any spodumene grains in a till sample is significant. Spodumene abundance is highest in a central corridor trending southward from the Brazil Lake pegmatites for 12 km (Fig. 2), however, the overall pattern of spodumene dispersal is fan-shaped. The central core of the fan is oriented southward along the trend of the dominant and most vigorous (erosive) ice flow phase. The fan shape is the net result of three phases of ice flow (southeast, south, and southwest) eroding, transporting, and depositing glacial debris from the Brazil Lake pegmatites, and possibly other LCT pegmatites in the local area. In comparison, glacial dispersal patterns for Li (ppm) in the 1–2 mm fraction of till (Na-peroxide fusion or 4-acid digestion) form a fan-shaped pattern that is much shorter, only 6 km down ice of the Brazil Lake pegmatites (Brushett et al. 2024).

The GSC has published a detailed reporting of the bedrock and till indicator mineral data for the Brazil Lake pegmatites in an open file report (McClenaghan et al. 2024). A second GSC report (Brushett et al. 2024) describes the till geochemistry results for the <0.063 mm and 1–2 mm fractions of till samples collected around the pegmatites, including a comparison of Na-peroxide fusion, 4-acid digestion, and aqua regia digestion. Mineral chemistry and lithium isotope signatures will be determined for selected bedrock and till indicator minerals from the Brazil Lake pegmatites. Till stratigraphic studies are currently in progress to provide a better understanding of the glacial history and stratigraphic context of the Quaternary depositional record of southwestern Nova Scotia.

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RECOMMENDATIONS FOR LITHIUM EXPLORATION

This GSC study presents the first detailed investigation of the indicator mineral signatures of an LCT pegmatite in till. Till samples immediately down ice of the pegmatites contain 100s to 1000s of spodumene grains per 10 kg sample. Indicator minerals of Brazil Lake LCT pegmatites that have been recovered from till samples include spodumene, columbite-tantalite, apatite, tourmaline, scheelite, and cassiterite.

Spodumene is the most obvious and direct indicator of the presence of LCT pegmatites. Background concentrations of spodumene in till are zero, thus even one grain in a till sample is significant. Grain abundance should be normalized to 10 kg of <2 mm material (table feed) in order to compare results between till samples of variable weight. Spodumene, apatite, and tourmaline have a combined density range of 3.1–3.2 SG. In future till sampling programs for Li exploration, heavy liquid separations can be carried to produce a mid-density fraction that is 3.0–3.2 SG, instead of 2.8–3.2 SG, in order to optimize spodumene recovery and eliminate some of the lighter indicator minerals. Spodumene is most abundant in the 0.25–0.5 mm size fraction of till. To reduce time and cost, only this one size fraction could be recovered and examined for Li exploration. For more information about this study, refer to McClenaghan et al. (2024) for a detailed description of the till sampling methods, sample processing and mineral identification methods, indicator mineral results and distribution maps, and high quality colour photographs of the indicator minerals.

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