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Canada

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TABLE OF CONTENTS

ABSTRACT 6
INTRODUCTION 6
LOCATION AND ACCESS 8
GEOLOGY 8
Bedrock geological setting *8*
Local bedrock geology and mineralization *10*
Pegmatite discovery *11*
Surficial geology *13*
Till characteristics *16*
PREVIOUS SURFICIAL GEOCHEMICAL AND MINERALOGICAL STUDIES 19
Pegmatite studies *19*
Gold studies *20*
METHODS 20
Bedrock sample collection *20*
Till sample collection *20*
Sample processing *27*
Pebble lithology determinations *28*
Data plotting *31*
RESULTS 32
Quality assurance/quality control *32*
Indicator mineralogy *32*
Pebble lithology data *39*
DISCUSSION 44
Size fraction comparison *44*
Density fraction comparison *45*
Spodumene dispersal fan *45*
Comparison to other heavy mineral studies *45*
Comparison to till geochemistry *48*
Gold potential *48*
Future work *49*
CONSIDERATIONS FOR LITHIUM EXPLORATION 49
CONSIDERATIONS FOR GOLD EXPLORATION 51
ACKNOWLEDGEMENTS 51
REFERENCES 51

APPENDIXES (digital data files)

Appendix A Metadata for 2020, 2021 and 2022 bedrock and till samples

Appendix B Field data for bedrock and till samples

Appendix B1 Bedrock sample field observation and location data
Appendix B2 Photographs of bedrock sample sites and hand specimens
Appendix B3 Till sample field observation and location data
Appendix B4 Sample locations, weight data, and gold grain abundances for five till samples collected in the Kemptville Gold District in 2005 (from Goodwin, 2006)

Appendix C Unedited (raw) sample processing sample weights and indicator mineral counts reported by Overburden Drilling Management Ltd. for bedrock and till samples

Appendix C1 Heavy mineral data for one bedrock sample collected in 2020.
Appendix C2 Heavy mineral data for four bedrock samples collected in 2022.
Appendix C3 Heavy mineral data for one till sample collected in 2020.
Appendix C4 Heavy mineral data for Batch 1 of 2 for till samples collected in 2021.
Appendix C5 Heavy mineral data for Batch 2 of 2 for till samples collected in 2021.
Appendix C6 Heavy mineral data for Batch 1 of 2 for till samples collected in 2022.
Appendix C7 Heavy mineral data for Batch 2 of 2 for till samples collected in 2022.

Appendix D Selected indicator mineral data (number of grains) for till heavy mineral samples including in-house standards and field duplicates: a) raw data and b) data normalized to a 10 kg sample weight (-2 mm table feed)

Appendix E Selected indicator mineral abundance data (number of grains for only the field duplicates and in-house GSC standards Bathurst Blank and Almonte Till: a) raw data and b) data normalized to a 10 kg sample weight (-2 mm table feed)

Appendix F Proportional dot maps of selected indicator mineral abundances plotted on a bedrock geology base (White et al., 2012a,b). Bedrock geology legend is shown in Figure 2. Percentile ranges are reported in brackets to the right of the grain abundance ranges in the legend.

Map 1. Proportional dot map of spodumene abundance in the 2.8-3.2 SG 0.25-0.5 mm fraction
Map 2. Proportional dot map of spodumene abundance in the 2.8-3.2 SG 0.5-1.0 mm fraction
Map 3. Proportional dot map of spodumene abundance in the 2.8-3.2 SG 1.0-2.0 mm fraction
Map 4. Proportional dot map of spodumene abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 5. Proportional dot map of spodumene abundance in the >3.2 SG 0.5-1.0 mm fraction

Map 6. Proportional dot map of spodumene abundance in the >3.2 SG 1.0-2.0 mm fraction
Map 7. Proportional dot maps of spodumene abundance in the 2.8-3.2 and >3.2 SG fractions for all 3 size fractions in the area proximal to the Brazil Lake pegmatites. The central location of the Brazil Lake pegmatites and Army Road pegmatite (Critical Raw Materials, 2023) are indicated by the gray stars. Black dashed lines outline the areas of stripped bedrock outcrop exposing each pegmatite.
Map 8. Relative proportions of spodumene in the 2.8-3.2 SG fraction between 3 size fractions portrayed as proportional pie symbols
Map 9. Proportional dot map of apatite abundance in the 2.8-3.2 SG 0.25-0.5 mm fraction
Map 10. Proportional dot map of tourmaline abundance in the 2.8-3.2 SG 0.25-0.5 mm fraction
Map 11. Proportional dot maps of tourmaline abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 12. Proportional dot map of cassiterite abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 13. Proportional dot map of scheelite abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 14. Proportional dot map of pyrite abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 15. Proportional dot map of goethite abundance in the >3.2 SG 0.25-0.5 mm fraction
Map 16. Proportional dot map of gold grain abundance in the pan concentrate fraction (black dots) and in the >3.2 SG 0.25-2.0 mm fraction (green dots).

Appendix G Pebble lithology data for selected till samples

Appendix G1 Pebble lithology data listing:
Worksheet 1 >8 mm fraction pebble lithology data
Worksheet 2 Spodumene abundance in 2-4 mm, 4-8 mm, and >8 mm fractions
Appendix G2 Pebble lithology photographs 1 to 5
Appendix G3 Relative abundance of spodumene fragments in 3 different size fractions of >2 mm clasts and pegmatite clasts in till samples plotted as pie diagrams on a bedrock geology base (White et al., 2012a,b). Bedrock geology legend is shown in Figure 2.

LIST OF FIGURES

Figure 1. Bedrock geology of southwestern Nova Scotia.

Figure 2. a) Bedrock geology of the Brazil Lake study area (White et al., 2012a,b) showing the locations of all till samples collected in 2020 (green dot), 2021 (black dots), and 2022 (red dots) with samples collected specifically for heavy mineral analysis shown with a white dot in the center of the symbol. This regional map also shows mineral occurrence locations indicated by the black asterisk symbols.

Figure 2. b) Bedrock geology of the Brazil Lake study area (see inset map in Figure 2a) of the location of the Brazil Lake and Army Road pegmatites indicated by the gray stars. Black dashed lines outline the areas of stripped pegmatite bedrock at the North and South dykes.

Figure 3. a) Coarse-grained (≤0.5 m in length) white spodumene crystals exposed on the weathered subcropping surface of the South Dyke; b) fresh unweathered spodumene boulder (1.5 in length and 1.0 m in height) extracted from the South Dyke; c) black columbite/tantalite crystals in quartz at the North Dyke; d) cross-section of the South Dyke in contact with the metavolcanic country rocks. At the outer contact of the pegmatite, abundant black tourmaline is observed, which formed as a result of the exsolution of boron-rich fluids from the pegmatite.

Figure 4. Abundant spodumene-bearing float boulders are exposed on the surface south and east of the North Dyke, such as the boulder shown here.

Figure 5. Colourized LiDAR hillshade image (azimuth of 315°) showing the streamlined glaciated landscape of the Brazil Lake region. Generalized ice flow phases, based on regional ice flow history by Stea and Grant (1982) and Finck and Stea (1995), are indicated by arrows with one being the oldest flow.

Figure 6. Generalized ice-flow chronology of southern Nova Scotia summarized from Stea and Grant (1982), Finck and Stea (1995) and Stea et al. (2011). The oldest documented ice-flow phase, prior to the last interglacial, is not shown here.

Figure 7. Examples of subglacial traction (lodgement) till sampled at various sites in the Brazil Lake area. Note the compaction of the till as demonstrated by fissility and overconsolidation; b) site 22MPB036, overconsolidated chunks of till on the shovel. Note the white spodumene clast indicated by the yellow arrow; c) site 22MPB027 after sampling and showing well developed A, B, and C soil horizons; d) 22MPB027 overconsolidated chunk of till on shovel; and e) site 22MPB038 after sampling showing subhorizontal fissility behind the shovel.

Figure 8. Spodumene clasts eroded from the pegmatites were readily visible while sampling tills in backhoe trenches just down-ice of the North and South dykes. White spodumene fragments from till at site 22MPB044 are shown in this photograph.

Figure 9. a) Figure 9. a) Subglacial melt out till (outlined by a yellow dashed line) observed as a thin (<2 m) horizon containing well sorted lenses and layers of sand in a coastal section (Beaver River till type locality). b) Close-up view of upper melt-out till facies from the Salmon River coastal section showing pale sandy till with abundant local, mostly angular clast lithologies, and c) A thin upper melt-out till horizon was only identified on the southeastern flank of a drumlin from the Salmon River coastal section (refer to Brushett et al., 2024 for location).

Figure 10. Approximate locations of the North and South dykes (white dashed lines) and locations of GSC till samples collected in 2022 from backhoe trenches nearby. Regional ice flow directions are indicated by arrows in bottom right corner of figure: (1) older flow, (2) younger flow. Background image is SPOT satellite imagery with 0.5 m resolution, using Google Earth.

Figure 11. LiDAR hillshade DEM of the Raynardton Road borrow pit area. Large drumlins (outlined by white dashed polygons) occur throughout the area, many of which have been post-

glacially dissected or modified by glacial meltwaters. The tops of some of the drumlins have a 'pebbled' texture in the LiDAR image, indicating the presence of large greywacke boulders on the surface of the upper subglacial traction till. White arrows indicate the locations of some final ice flow phase glacially streamlined landforms.

Figure 12. a) A 10 m section of till exposed in a borrow pit on the north side of Raynardton Road, 15 km southeast of the Brazil Lake pegmatites; b) Abundant large bedrock boulders on or at its natural land surface resting on the upper till unit at the Raynardton Road borrow pit; c) The uppermost upper till in the section consists of compact very stony till with discontinuous lenses and layers of sorted sand and is considered to be a subglacial traction till deposited by streaming ice.

Figure 13. Two till samples (22MPB033, 22MPB034) were collected from the center of the Raynardton Road till section- refer to Figure 12a. The number of spodumene grains, normalized to 10 kg weight (table feed) and recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion are reported beside each sample site.

Figure 14. Till exposed in a backhoe trench pit just east of North Dyke and location of sample 22MPB043 and 22MPB044 collected within the trench. The number of spodumene grains, normalized to 10 kg weight (table feed) recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion/ICP-MS are reported beside each sample site.

Figure 15. Till exposed in a backhoe trench pit just east side of North Dyke and location of samples 22MPB047 and 22MPB048 collected within the trench. The number of spodumene grains, normalized to 10 kg weight, recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion/ICP-MS are reported beside each sample number.

Figure 16. Schematic flow sheet showing the processing steps for the preparation of heavy mineral concentrates and recovery of indicator minerals from bedrock samples from the Brazil Lake pegmatites.

Figure 17. Schematic flow sheet showing the processing steps for the preparation of heavy mineral concentrates and recovery of indicator minerals from till samples.

Figure 18. Colour photographs of LCT pegmatite indicator minerals recovered from bedrock sample 20DB-031 BDK: a) spodumene; b) spodumene on black background; c) black columbite/tantalite; d) blue apatite; e) zircon; f) uraninite with minor zircon; and g) orange (iron poor) sphalerite.

Figure 19. Photograph of large (0.5 mm wide) gold + quartz particle recovered from the 0.25-0.5 mm heavy mineral fraction of till sample 22MPB050.

Figure 20. Enlargement of inset map in top right corner of Figure 2 (red box) showing location of the Kemptville District gold workings south of Kempt Back Lake. Black squares indicate the location of five till samples that were collected by Goodwin in 2005 and processed to recover gold grains. Red star indicates the location of GSC till sample 22MPB050 collected as part of the

current study. The number of gold grains recovered from each till sample and normalized to 10 kg (table feed) are reported as red text.

Figure 21. Outline of spodumene dispersal train reported by Black (2012) in Brazil Lake pegmatite area. Spodumene grains were identified in the >2 mm fraction of large bulk till samples in nine till sample pits.

Figure 22. Comparison of proportional dot maps of spodumene grain abundance normalized to 10 kg (table feed) in the 0.25-0.5 mm fraction of till: a) 2.8-3.2 SG fraction, and b) >3.2 SG fraction. Interpreted dispersal fans are highlighted in pink.

Figure 23. Comparison of proportional dot maps and interpreted dispersal fans (pink polygons) of: a) spodumene abundance in the 0.25-0.5 mm 2.8-3.2 SG fraction of till samples (N=76) normalized to10 kg (table feed); and b) Li concentration in the 1.0–2.0 mm till fraction analyzed using Na-peroxide fusion followed by ICP-MS (N=104), and using dot size thresholds from Figure 14b in Brushett et al. (2024).

Figure 24. Enlargement of inset map in top right corner of Figure 2 (black box) showing location of the Kemptville District gold workings south of Kempt Back Lake. Stea (2012) reported a south-trending glacial dispersal train of gold grains in till (pink proportional dots) from gold workings (yellow lines) in the district. Data are plotted on a digital DEM with drumlins outlined in black. Gold grain abundances were determined using different methods from those used by GSC, therefore results are not directly comparable. The location of GSC till sample 22MPB050 is shown as a green star.

LIST OF TABLES

Table 1. List of file names, year of sampling, and the worksheets that contain raw heavy mineral abundance data.

Table 2. List of bedrock lithology categories for classifying pebbles that were recovered from the >2 mm fraction of heavy mineral till samples during sample processing.

Table 3. Potential indicator minerals of the Brazil Lake LCT pegmatites summarized from bedrock descriptions by Taylor (1967), Corey (1995), and Kontak (2004, 2006), and a listing of indicator minerals found in till samples in this study.

Table 4. Spodumene concentrations reported for other till indicator mineral studies compared to the concentrations reported in this study.

Table 5. Comparison of indicator mineral and trace element signatures of LCT pegmatites in the till samples from the Brazil Lake area.

Indicator mineral signatures of the Brazil Lake LCT pegmatites, southwest Nova Scotia (parts of NTS 20-O/16, 20P/13, 21A/04, and 21B/01)

ABSTRACT

This open file reports indicator mineral abundance data for 7-20 kg heavy mineral till samples collected as a part of an indicator mineral, till geochemistry, and surficial mapping project around the Brazil Lake lithium-cesium-tantalum (LCT-type) pegmatites in southwestern Nova Scotia (parts of NTS map sheets 20-O/16, 20P/13, 21A/04, 21B/01). The goals of the research are to increase lithium exploration success in regions covered by glacial sediments by documenting how critical minerals and associated elements are glacially dispersed in till from pegmatites in general, and specifically at the Brazil Lake property. Newly available LiDAR data from the Nova Scotia government assisted in deciphering ice flow trajectories, which in turn, allowed for targeted till sampling. A total of 84 till samples were collected for indicator mineral analysis in 2020, 2021 and 2022 and the data reported here are for both widely spaced regional till samples collected across southwest Nova Scotia, and local till samples collected immediately up- and down-ice of the Brazil Lake pegmatites. The widely spaced till samples provide the regional context for the interpretation of the closely-spaced samples and help in the assessment of the potential for discovery of additional pegmatites in the region. Data reported in this open file include sample descriptions, locations, heavy mineral data for the <2.0 mm fraction of till and bedrock samples, and till clast (pebble) lithology data for the >2 mm fraction of selected till samples.

The following indicator minerals in the Brazil Lake LCT pegmatites are visually distinct and were recovered from till samples down ice: spodumene, columbite-tantalite, apatite, tourmaline, cassiterite, and scheelite. Two density fractions of minerals should be recovered from till in order to maximize recovery of LCT pegmatite indicator minerals. Spodumene, apatite, and tourmaline are most abundant in the 2.8-3.2 specific gravity (SG) fraction and columbite-tantalite, cassiterite, and scheelite were recovered from the >3.2 SG fraction. Of the three size fractions examined, spodumene is most abundant in the finest 0.25-0.5 mm size range. The background concentration of spodumene in local till is zero, thus the presence of even one grain in a till sample is significant. Till samples immediately down ice of the pegmatites contain 100s to 1000s of spodumene grains per 10 kg of sample material (table feed) in the 0.25-0.5 mm fraction. Glacial dispersal of spodumene from the Brazil Lake pegmatites forms a broad fan-shaped and obvious exploration target at least 12 km down ice. In contrast, the fan defined by till matrix geochemistry (Li ppm) is a shorter (5 km) and narrower fan and forms a much smaller exploration target.

INTRODUCTION

In 2021 and 2022, the Geological Survey of Canada (GSC), in partnership with the Nova Scotia Department of Natural Resources and Renewables (NSDNRR), collected till samples around the Brazil Lake lithium-cesium-tantalum (LCT) type pegmatites in southwest Nova Scotia (Fig. 1) (Brushett and Tupper, 2021; McClenaghan et al., 2023a,b; Brushett et al., 2022, 2023a,b,c, 2024). This fieldwork was carried out as part of critical mineral exploration research funded by the GSC's Targeted Geoscience Initiative (TGI) program. The TGI Program is a national, collaborative, multidisciplinary geoscience research program that aims to improve mineral exploration effectiveness. It achieves these goals by developing next-generation geological models and knowledge, as well as cutting-edge tools and methods, to understand the processes that formed Canada's mineral deposits and identify and develop novel indicators and parameters to guide exploration in emerging and existing mining areas (https://natural-resources.canada.ca/earth-sciences/earth-sciences-resources/targeted-geoscience-initiative-tgi/10907).

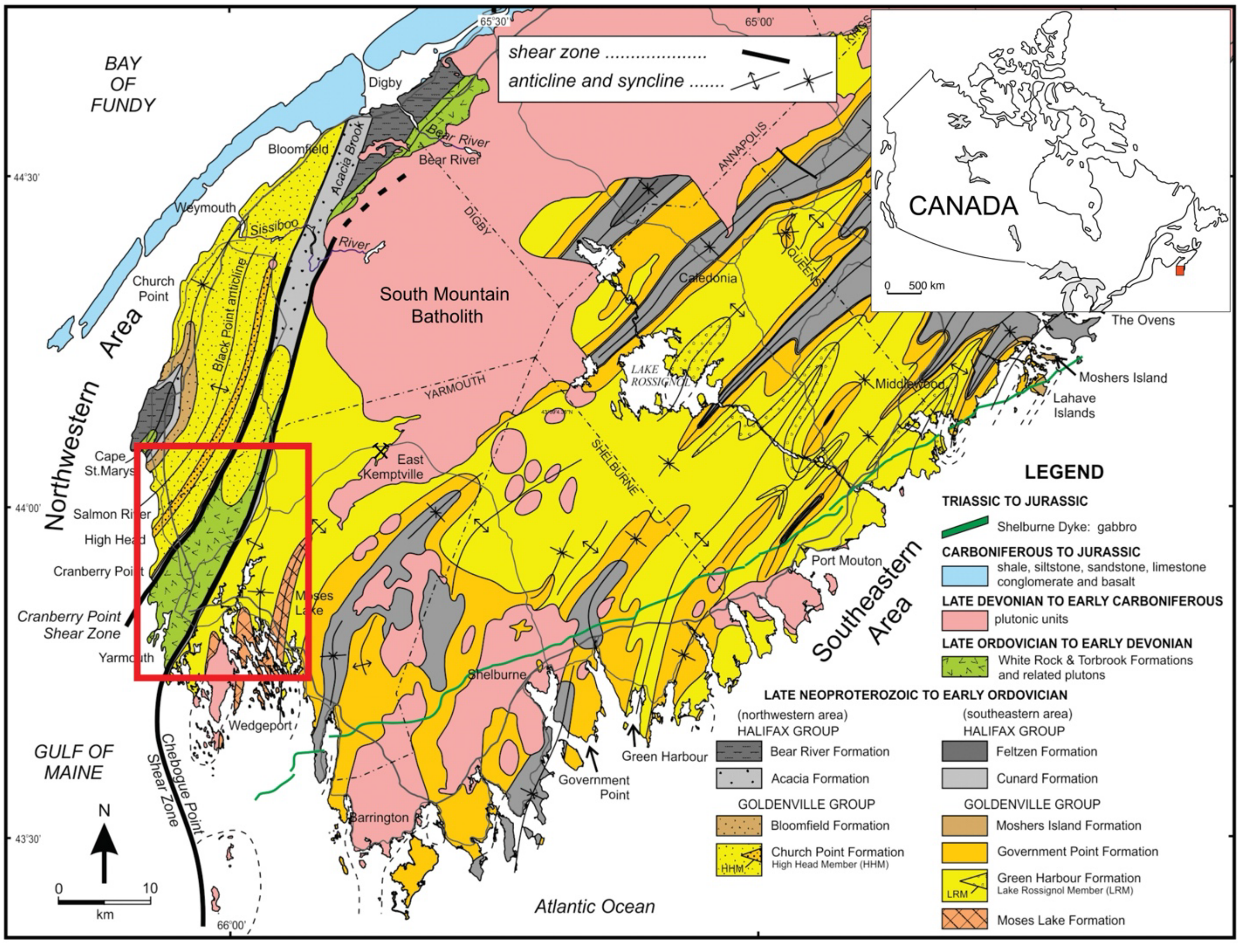

Figure 1. Bedrock geology of southwestern Nova Scotia (modified from White, 2010; White et al., 2018). Location of the study area is indicated by the red box.

Although there have been numerous studies focused on the use of indicator mineral methods to explore for a broad range of commodities (e.g., Au, PGE, Cu, Pb, Zn, U, W, Sn and diamonds; McClenaghan and Paulen, 2018 and references therein), only a few case studies have ever tested till indicator mineral methods for discovering lithium-bearing pegmatites (e.g., Nikkarinen and Björklund, 1975; Black, 2012; Hodder and Martins, 2023). To address this research gap, a detailed glacial sediment and bedrock study has been conducted around the Brazil Lake pegmatites to: (1) investigate how spodumene, the key ore mineral in the Brazil Lake deposit, is glacially dispersed in till and how it breaks down during glacial transport; (2) determine the geochemical signature of till from this style of mineralization; (3) define the net glacial dispersal pattern of the Li pegmatites; and, (4) define the appropriate sampling protocols and analytical techniques that can be used for lithium exploration, not only in southwest Nova Scotia, but in recent (last 2 million years) glaciated terrain worldwide. In support of this research, regional-scale surficial geological mapping, sediment thickness modelling, till fabric measurement, clast lithology analyses, till geochemistry, indicator minerals, and studies of glacial stratigraphy are being carried out in order to provide the regional context for interpreting results from the Brazil Lake case study.

This study focuses on two pegmatites, the North and South Brazil Lake pegmatites, in which lithium is hosted in the mineral spodumene. Other lithium occurrences/deposits globally also contain other Li-silicates including lepidolite, petalite, and eucryptite (e.g., Steiner, 2019). Spodumene ($LiAlSi_2O_6$) is a clinopyroxene and is the most 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).

LOCATION AND ACCESS

The study area is located approximately 25 km northeast of Yarmouth (Fig. 1) within the southwestern portion of the Atlantic Uplands of Nova Scotia, part of the Appalachian Region (Williams et al., 1974) in eastern Canada. The topography consists of gently rolling hills with a near continuous cover of glacial sediments that is characterized by drumlin fields. The internal structure of several of these drumlins is exposed in coastal sections along the Yarmouth-Digby coast. Bedrock was only observed where it is exposed in a few places along stream beds and around the edges of bedrock quarries. Sample sites were accessed by truck along numerous local and resource-access roads, and recreational trails.

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; Fig. 2). The Meguma terrane is characterized by a thick sequence of Cambrian to Early Ordovician metasedimentary rocks, comprising the metasandstone-dominated Goldenville Group and the overlying siltstone- and slate-dominated Halifax Group (White, 2010). Locally, the Meguma Group is unconformably overlain by a thin sequence of Silurian to Early Devonian slate, quartzite, and volcanic rocks of the Rockville Notch Group (White and Barr, 2017; White et al., 2018). The earliest deformation occurred during the Middle Devonian Neoacadian orogeny (ca. 405–365 Ma) resulting in NE- to NNE-trending, upright regional-scale folds. 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 southwest 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, 2003; 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. Of these shear zones, the Kemptville Shear

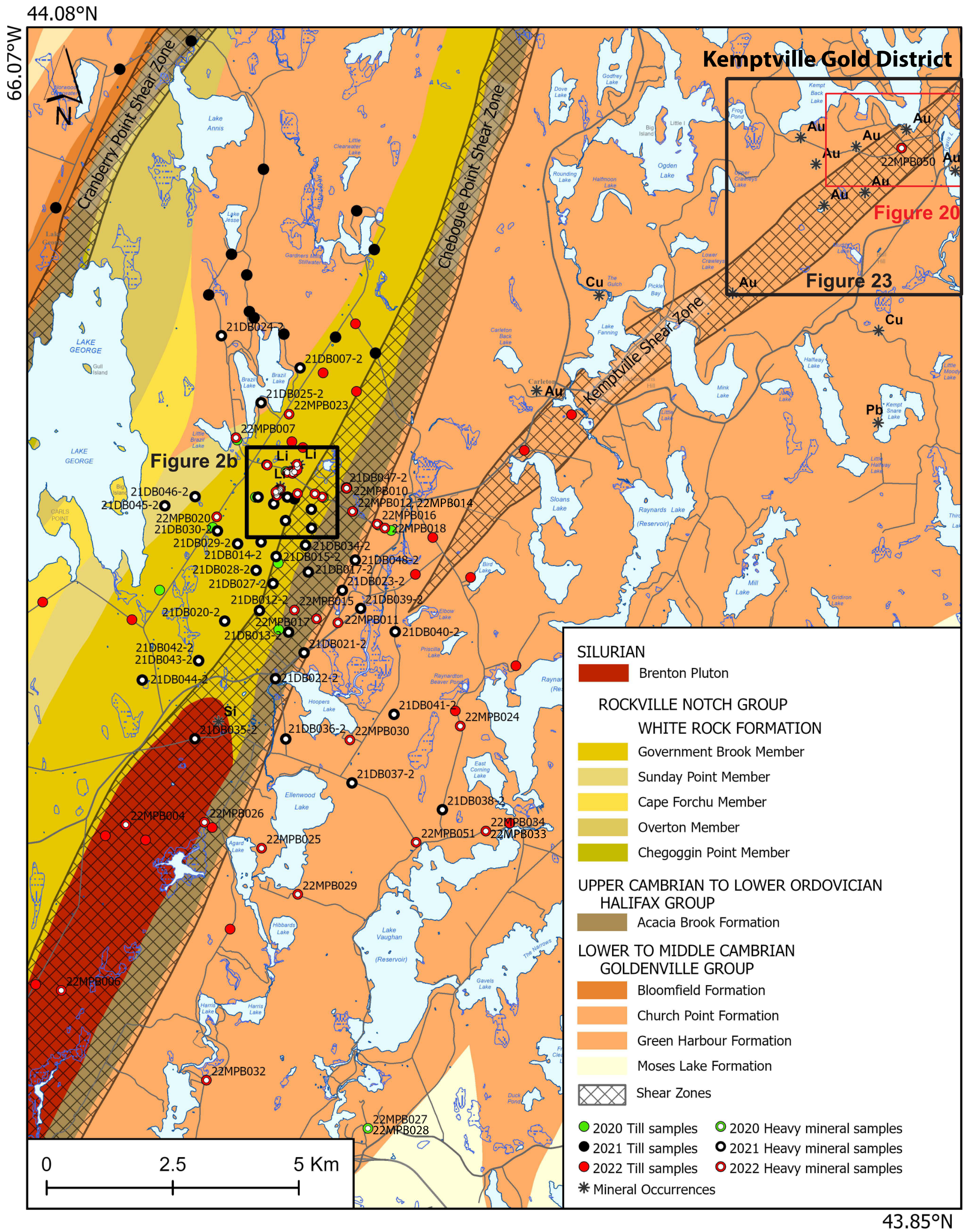

Figure 2a. Bedrock geology of the Brazil Lake study area (White et al., 2012a,b) showing the locations of all till samples collected in 2020 (green dot), 2021 (black dots), and 2022 (red dots) with samples collected specifically for heavy mineral analysis shown with a white dot in the center of the symbol. This regional map also shows mineral occurrence locations indicated by the black asterisk symbols.

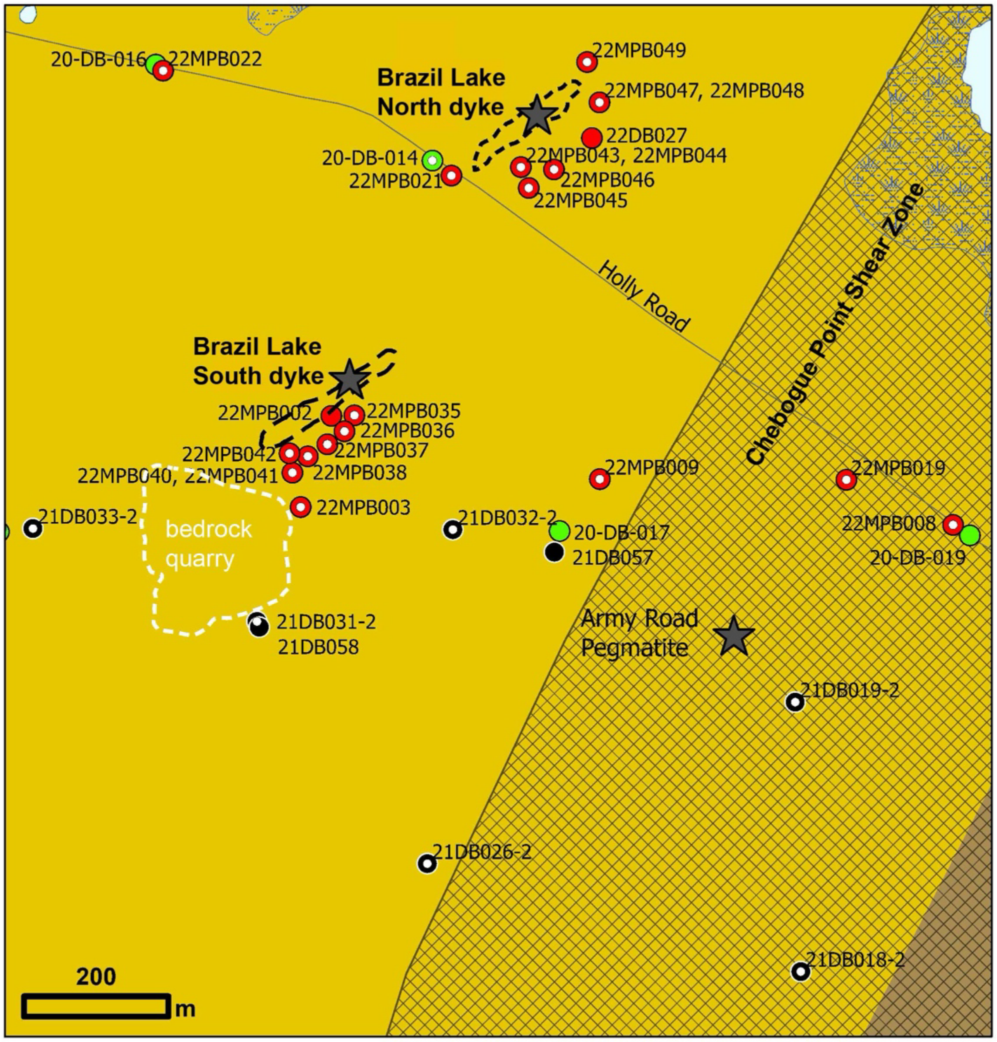

Figure 2b) Bedrock geology of the Brazil Lake study area (see inset map in Figure 2a) of the location of the Brazil Lake and Army Road pegmatites indicated by the gray stars. Black dashed lines outline the areas of stripped pegmatite bedrock at the North and South dykes.

Zone is a distinct zone that extends northeast from Elbow Lake, just south of Kemp Back Lake (Fig. 2) and eastward towards East Kemptville. The shear zone is host to several Au-bearing quartz vein deposits in Goldenville metasedimentary rocks (O'Reilly and Kontak, 1992). Historically, gold was mined from the Kemptville, Carleton and Kempt Back Lake areas (see gold occurrences on Figure 2; Gillespie-Wood, 1987). The nature of gold mineralization here differs significantly from other Meguma-style gold deposits, where Au-bearing quartz veins, alteration, and sulphide mineralization are related to the development of the Kemptville Shear Zone but the gold paragenesis is uncertain (Horne et. al., 2006).

Local bedrock geology and mineralization

The Brazil Lake deposit is hosted by the Silurian White Rock Formation (Rockville Notch Group), comprising shallow marine metasedimentary rocks interbedded with minor mafic metavolcanic units, which locally include quartzite, amphibolite, and pelitic schist (Figs. 1, 2;

White, 2010; White and Barr, 2017). The Brenton Pluton, a syenogranite to monzogranite intrusion related to the White Rock Formation, is in fault contact with both the White Rock Formation and Halifax Group and occurs ~3 km southwest of the Brazil Lake deposit (Kontak, 2006). It is inferred to be Silurian based on a U/Pb zircon age of 439 ±4 Ma (Keppie and Krogh, 2000). Numerous shear zones crosscut the area with the metamorphic grade increasing abruptly towards these shear zones. At the southeast margin of the White Rock Formation, staurolite-grade, typically schistose rocks are in faulted contact with slate of the Halifax Group that has been metamorphosed to amphibolite facies. The fault is inferred to be a brittle structure within the broader Chebogue Point Shear zone (previously termed the Deerfield shear zone). At its northwest margin, the Halifax Group and White Rock Formation are deformed along the Cranberry Point shear zone; cooling ages of muscovite indicate the deformation to be middle Carboniferous (Alleghanian) (Culshaw and Reynolds, 1997; Culshaw and Liesa, 1997; White and Barr, 2017). Field observations by Kontak (2006) suggest 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 Dyke indicate that pegmatite crystallization occurred at ca. 395 Ma (Kontak et al., 2005; Kontak and Keyser, 2009).

The bedrock geology of the Brazil Lake pegmatites is summarized below from studies of two separate northeast-trending, steeply dipping (to the southeast) pegmatite dykes. The dykes are named and described with respect to their location north or south of Holly Road (Fig. 2 inset map; Kontak, 2004, 2006; Kontak et al., 2005). Drilling and surface trenching indicate that the North and South dykes, which are separated by about 300 m, 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° (Cullen et al., 2022).

The pegmatites are of albite-spodumene type and are characterized by coarse crystals of spodumene and K-feldspar, with intergranular spodumene (Fig. 3a), muscovite, albite, and quartz (Fig. 3b). Accessory phases include tantalite (Fig. 3c), black tourmaline (Fig. 3d), apatite, beryl, sphalerite, and cassiterite. Spodumene ($LiAlSi_2O_6$), the most abundant lithium-bearing mineral in the pegmatites, is a light-coloured, relatively robust silicate mineral (H = 6.5–7) with two perfect cleavages, a vitreous luster that is pearly on its cleavage surface, and a moderate density of 3.18 g/cm^3. Key minerals in the pegmatites that could be useful indicator minerals for drift prospecting include black tourmaline, black tantalite, red garnet, blue apatite, green beryl, cassiterite, wolframite, sphalerite, zircon, epidote, topaz, titanite, and phosphate minerals. Similarly, key trace elements that are typically enriched in LCT-type pegmatites and may be useful pathfinder elements include Li, Be, B, Mn, Rb, Y, Zr, Nb, Sn, Cs, La, Ce, Ta, Th, and U (Černý and Ercit, 2005).

Pegmatite discovery

The Brazil Lake pegmatites have been the focus of exploration and petrological studies since they were discovered in 1960 by tracing the source of pegmatite boulders on surface near what was later discovered to be the South Dyke (Taylor, 1967; Kontak, 2004; Barr and Cullen, 2010). Numerous spodumene-bearing boulders are still evident on surface in the area immediately down

Figure 3. a) Coarse-grained (≤0.5 m in length) white spodumene crystals exposed on the weathered subcropping surface of the South Dyke (photograph by M.B. McClenaghan; NRCan photo 2022-571); b) fresh unweathered spodumene boulder (1.5 in length and 1.0 m in height) extracted from the South Dyke (photograph from Cullen et al., 2022); c) black columbite/tantalite crystals in quartz at the North Dyke (photograph by D. Archibald, St. Francis Xavier University); d) cross-section of the South Dyke in contact with the metavolcanic country rocks At the outer contact of the pegmatite, abundant black tourmaline is observed, which formed as a result of the exsolution of boron-rich fluids from the pegmatite (photograph by C. Beckett-Brown; NRCan photo 2023-484).

ice of the North Dyke (Fig. 4). The most recent resource estimate for the two pegmatites was reported as measured and indicated resources of 555 300 tonnes grading 1.30 % Li_2O and an inferred mineral resource of 381 000 tonnes grading 1.48 % Li_2O (Cullen et al., 2022; Canadian Mining Journal, 2022). Diamond drilling was initiated in October of 2022 to further define the Li resources at the South and North Dykes and to assess the Li potential of a third nearby pegmatite, the Army Road pegmatite (Fig. 2 inset map). At the time of writing of this report, drilling continued to expand the South Dyke down-plunge to the southwest with thicknesses up to 20 m and, identified spodumene in the Army Road pegmatite, 500 m to the east, that remains open down-plunge to the southwest (Critical Raw Materials, 2023).

Figure 4. Abundant white spodumene-bearing float boulders are exposed on the surface south and east of the North Dyke, such as the boulder shown here. Photograph by Beth McClenaghan, NRCan photo 2022-589.

Surficial geology

The current knowledge of the glacial history of southwestern Nova Scotia is largely derived from previous regional-scale (1:100 000) surficial mapping and till sampling conducted by Stea and Grant (1982) and Finck and Stea (1995) in the 1970s and 1980s. This mapping and sampling, together with the stratigraphic studies by Grant (1980), Grant and King (1984), and Stea et al. (1992), have led to a broad framework of the regional glacial history. This stratigraphic framework was based upon the traditional 'layer-cake model 'of till stratigraphy and should be re-examined in the context of the time-transgressive nature and evolution of the former ice sheet during its early growth, full extension, and decay. Drift thickness modelling (Brushett et al., 2023b,c*)* and new regional surficial mapping, aided by LiDAR data (Fig. 5), are ongoing by NSDNRR to update the stratigraphic and depositional history for the region.

The surficial geology of southwestern Nova Scotia is the product of multiple glacial advances and retreats throughout several glacial events (Stea, 2004; Stea et al., 2011). Multiple till units, identified in coastal sections in southwest Nova Scotia, reflect several phases of glacial deposition and shifting ice-flow directions (Grant, 1980; Stea and Grant, 1982), which are described below from oldest to youngest:

1) The oldest ice-flow phase (Northumberland phase; Marine Isotope Stage (MIS) 6: ca. 190–130 ka), identified from the lowermost grey silty till at the base of some coastal sections, was

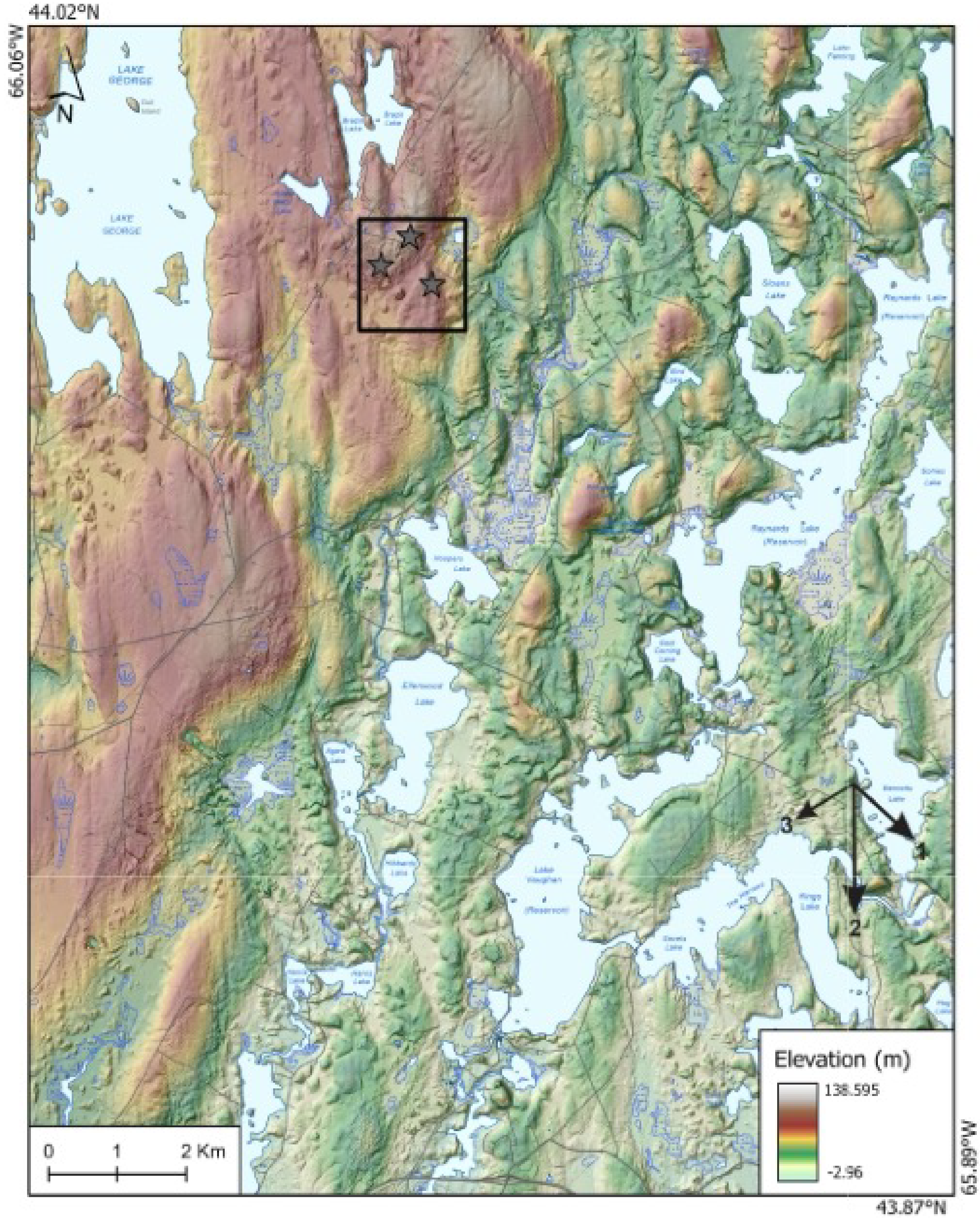

Figure 5. Colourized LiDAR hillshade image (azimuth of 315°) showing the streamlined glaciated landscape of the Brazil Lake region. Generalized ice flow phases, based on regional ice flow history by Stea and Grant (1982) and Finck and Stea (1995), are indicated by arrows with one being the oldest flow. LiDAR data provided by the government of Nova Scotia. Gray stars indicate the locations of the Brazil Lake pegmatites and the Army Road pegmatite (eastern most star).

interpreted to have been deposited by east to southeast ice-flow sourced from the northern Appalachian Mountains (Stea et al., 2011). This ice flow phase is not shown in Figure 6.
2) Regional east to southeastward ice-flow from New Brunswick during the Caledonia phase (MIS 4; ca. 75–50? ka) was responsible for the early formation of drumlins in southwest Nova Scotia. These drumlins are silt- and clay-rich (as well as shell-rich in coastal sections) and

contain a high percentage of foreign bedrock components with transport distances of >80 km (Stea and Finck, 2001; red arrows in Figure 6).

3) Subsequent southward regional ice-flow during the Escuminac phase (MIS 2; 22–18 ka; (Stea et al., 2011) modified older drumlins and formed new ones that reflect a more southward flow (blue arrows in Figure 6).

4) During the subsequent Scotian phase (ca. 20–17 ka), regional ice centres shifted and Nova Scotia was cut off from external ice centres (i.e., the Laurentide Ice Sheet) mainly due to ice streaming in marine channels (Shaw et al., 2006; Stea et al., 2011). The resultant Scotian Ice Divide formed lengthwise down the centre of the province such that ice-flow direction varied from southwest to southeast in southwestern Nova Scotia (Grant, 1980; Stea and Grant, 1982; purple arrows in Figure 6).

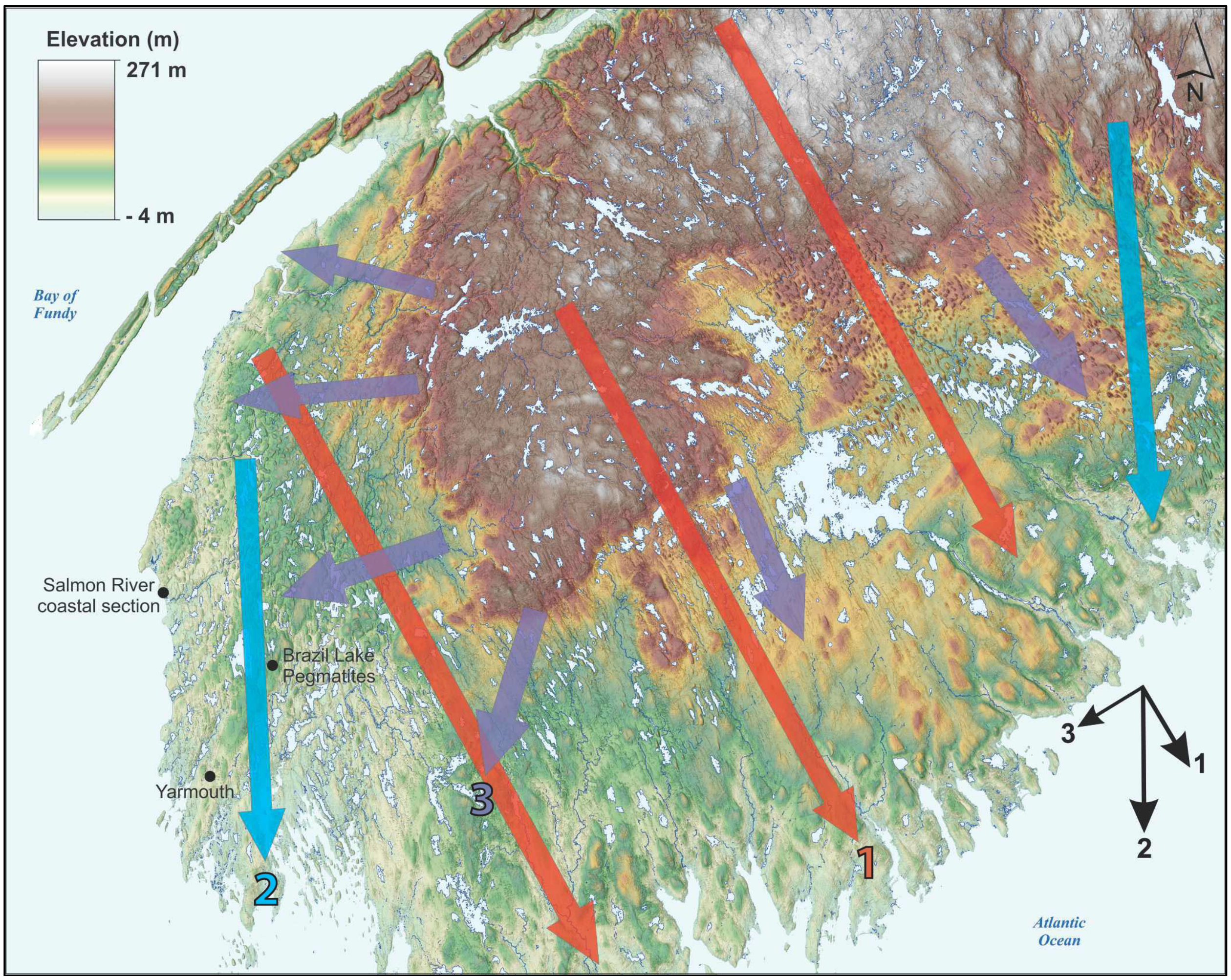

Figure 6. Generalized ice-flow chronology of southern Nova Scotia summarized from Stea and Grant (1982), Finck and Stea (1995) and Stea et al. (2011). The oldest documented ice-flow phase, prior to the last interglacial, is not shown here. Arrows superimposed on hillshade image LiDAR image from data published by the Government of Nova Scotia.

As a result of this complex glacial evolution, there is extensive till cover throughout much of southwestern Nova Scotia that has made bedrock mapping and exploration for buried mineralization challenging. As a result of the glacial sediment cover, the areal extent of the pegmatites at the Brazil Lake pegmatites is not well known. The study area underwent extensive glacial modifications through the late Wisconsin glaciation leaving highly variable glacial sediment thicknesses and complex landforms. Southeast- to south-trending drumlins are the predominant glacial landform over much of the region, with the orientation transitioning to south-trending drumlins close to the coastline.

Till thickness is variable, ranging from thin veneers (<2 m) over the pegmatites to thick drumlin ridges composed of over 40 m of till (Brushett et al., 2023b,c). In the Brazil Lake area, mega-scale glacial lineations were also identified in the LiDAR imagery of this drumlinized terrain (Fig. 5) and these are indicative of fast flowing ice during the latter phases of glaciation ((Flow 3 on Figure 6 ice streaming: Stokes and Clark, 2002). The area between these lineations (till ridges) is characterized by thin till overlying bedrock with sediment cover of <5 m. Glaciofluvial deposits commonly occur in topographic lows, which are now occupied by modern rivers and wetlands.

Till characteristics

Four main genetic properties were used to differentiate till facies: 1) matrix texture, 2) fissility and compaction, 3) clast lithologies, and 4) the proximity to geomorphic forms that could be identified using LiDAR imagery. Using these criteria, two till facies were identified in this study. The two facies are:

i) subglacial traction till: a silty sand that is over consolidated and sometimes displays subhorizontal fissility with visible jointing (Fig. 7). A typical till exposure (~1-2 m depth) shows a very compact light brownish grey silty-sandy till with angular to subrounded clasts, the majority of which reflect local bedrock lithologies, with numerous striated and faceted clasts. This till nomenclature supersedes the terms 'subglacial lodgement till' and 'basal till' in the modern literature (e.g. Evans, 2017; McClenaghan et al., 2020, 2023c). Pebbles and cobbles of spodumene were observed in this till facies (Fig. 7b, 8) in trenches just down-ice of the North and South dykes. A bedrock subcrop surface revealed by previous stripping of the South Dyke is glacially polished and striated (179°) and demonstrates that the bedrock here was in direct contact with southward-flowing ice (Figure 3 Flow 2). Therefore, this facies is the primary target sample medium.

ii) Subglacial melt-out till: a second till facies was identified, primarily in quarries and drumlin exposures where it is seen as a thin (<2 m) horizon on the drumlin flanks (area within the yellow dashed lines in Fig. 9a-c). This till is sandier, less indurated, less compact, and contains well sorted lenses and layers of sand. A higher proportion of clasts and larger range of clast sizes are observed within this unit, and clasts are generally more monolithic than those present in the subglacial traction facies. In some quarries or borrow pits, a boulder horizon was identified near and at the surface, generally composed of angular greywacke boulders. This till is classified as a subglacial melt-out till (e.g. Evans, 2017; McClenaghan et al., 2020, 2023c).

Note that no supraglacial tills (i.e. debris carried on top of the glacier during glacier during transport) or ablation tills (i.e. debris sheared up into the glacier and carried as englacial load) were observed anywhere in region.

Figure 7. Examples of subglacial traction (lodgement) till sampled at various sites in the Brazil Lake area. Note the compaction of the till as demonstrated by fissility and overconsolidation. Width of shovel head is 21 cm: a) site 22MPB026 after sampling (photograph by M.B. McClenaghan, NRCan photo 2023-061); b) site 22MPB036, overconsolidated chunks of till on the shovel. Note the white spodumene clast indicated by the yellow arrow (photograph by M.B. McClenaghan, NRCan photo 2023-062); c) site 22MPB027 after sampling and showing well developed A, B, and C soil horizons (photograph by M.B. McClenaghan, NRCan photo 2023-063); d) 22MPB027 overconsolidated chunk of till on shovel (photograph by M.B. McClenaghan, NRCan photo 2023-064); and e) site 22MPB038 after sampling showing subhorizontal fissility behind the shovel (photograph by M.B. McClenaghan, NRCan photo 2023-065).

Figure 8. Spodumene clasts glacially eroded from the pegmatites were readily visible while sampling tills in backhoe trenches just down-ice of the North and South dykes. White spodumene fragments from till at site 22MPB044 are shown in this photograph (photograph by M.B. McClenaghan, NRCan photo 2022-590).

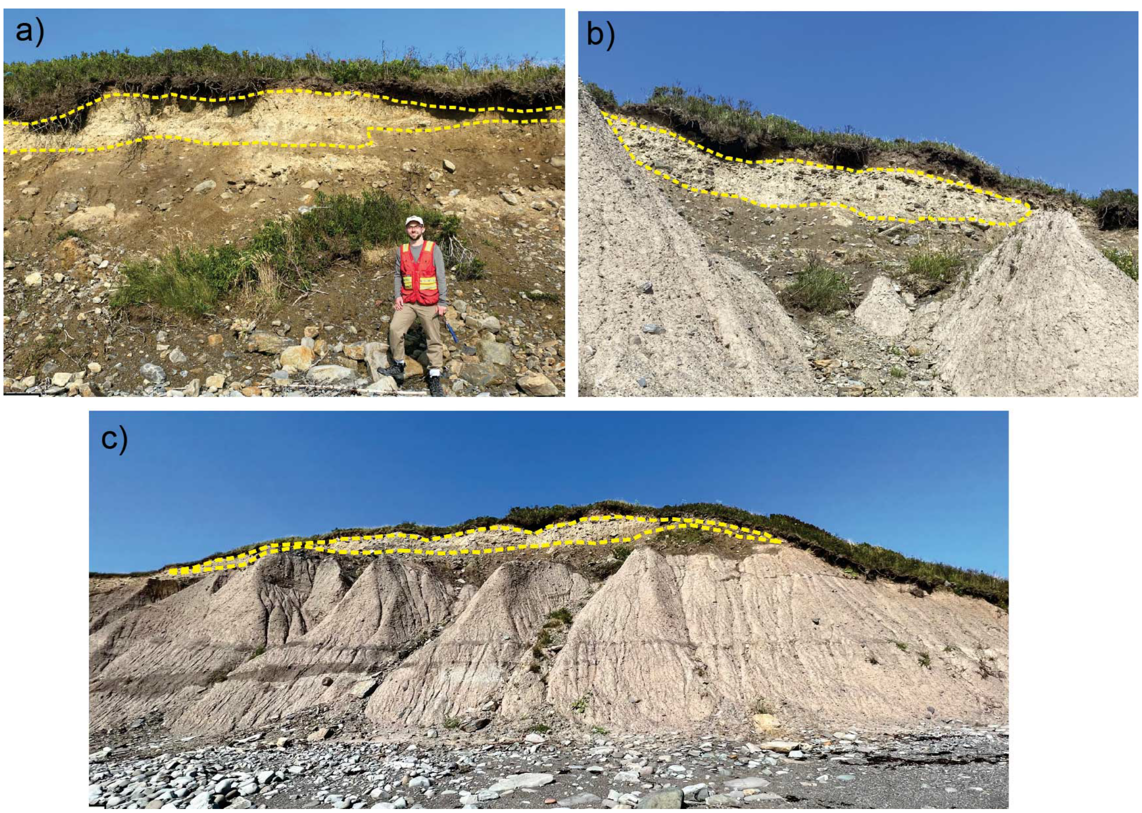

Figure 9. a) Subglacial melt out till (outlined by a yellow dashed line) observed as a thin (<2 m) horizon containing well sorted lenses and layers of sand in a coastal section (Beaver River till type locality). b) Close-up view of upper melt-out till facies from the Salmon River coastal section showing pale sandy till with abundant local, mostly angular clast lithologies, and c) A thin upper melt-out till horizon was only identified on the southeastern flank of a drumlin from the Salmon River coastal section (refer to Brushett et al., 2024 for location). Photographs by D. Brushett, Nova Scotia Department of Natural Resources and Renewables.

PREVIOUS SURFICIAL GEOCHEMICAL AND MINERALOGICAL STUDIES

Pegmatite studies

The first till geochemical study in the Brazil Lake area was conducted by Shell Resources in 1981 when till sampling (B-horizon) was conducted over the pegmatites at 50 m intervals on 100 m spaced east-west lines. The 2.0-0.177 mm (-10+80 mesh) fraction of till was pulverized to <0.074 mm and analyzed for Sn and Ta by XRF and Li by multi-acid digestion/atomic absorption spectrometry (AAS). The highest content of Li, Sn, and Ta reported was 228, 152, and 46 ppm, respectively (Palma et al., 1982). A regional-scale lake sediment geochemical survey of the Meguma terrane, including the area around Brazil Lake, did not show any pronounced geochemical anomaly for Li, F, Rb, Nb, Sn, or W (Rogers et al., 1985, 1990).

A multimedia geochemical study (till, balsam fir twigs, and humus) was conducted over a 600 x 600 m sampling grid (~100 m sample spacing for till, 50 m for twigs and humus) overlying the pegmatites by MacDonald et al. (1992). The <0.063 mm till fraction was analyzed by several methods, including instrumental neutron activation analysis (INAA), multi-acid digestions, a variety of fusions, and XRF for several pathfinder elements of rare-element pegmatites, including Li, B, Be, F, P, Fe, Rb, Nb, Cs, Ta, and Sn (*see* Table 4 *in* McDonald et al., 1992). The 0.063–0.25 mm >2.95 specific gravity (SG) heavy mineral fraction of the till was analyzed using the same methods. Variable geochemical responses between the different sample media with "spotty" zones of enrichment of limited areal extent were observed, which the authors attributed to the small size of the pegmatite veins and limited glacial dispersal. A contrast in Li and Cs concentrations, attributed to different mineralogical assemblages, was also noted, with higher concentrations of Li and Cs near the South Dyke, and only Li content in till was elevated near the North Dyke, suggesting different mineralogical assemblages.

Till sampling around the pegmatite conducted by Lundrigan (2008) included several till size fractions, which were digested using aqua regia, multi-acid, Li-metaborate fusion and Na-peroxide fusion methods and then analyzed using ICP-MS. Lundrigan (2008) reported that Li was the only pathfinder element identified, with anomalously high concentrations in till overlying, and up to 400 m southeast, of the pegmatites. The highest concentrations (>777 ppm) and greatest geochemical contrast between background and anomalous values was observed in the coarse-grained (-1.0 + 0.5 mm) till fraction.

Ongoing exploration by Champlain Mineral Ventures since 2002 has included several till and soil sampling programs (Black, 2011, 2012; Wightman, 2018, 2020). B-horizon soil sampling at 25 m spacing along 100 m spaced lines ((<177 µm fraction; multi-acid and Na-peroxide fusion/ ICP-MS), Soil Gas Hydrocarbon (SGH) soil sampling, and spodumene grain counts from bulk till samples were conducted to define new spodumene-bearing pegmatite targets. Spodumene grain counts recovered centimetre-sized spodumene grains, which were interpreted to indicate glacial dispersal from the north-northwest; however, grain counts were not normalized to a common sample weight (Black, 2012).

Till geochemical data for till samples collected in this GSC study are reported in a companion report to this publication, GSC Open File 9148 (Brushett et al., 2024).

Gold studies
Goodwin (2006) collected five, 10-kg heavy mineral till samples in the northeast part of the current study area as part of a case study around the Kemptville Gold District in 2005. Samples were collected from hand-dug surface pits between 1.0-1.5 m deep and were processed at the same heavy mineral lab that was used for the current study and using the same processing methods as the current study. Sample location data, sample weights, and gold grain abundance results are reported in Goodwin (2006) and in Appendix B4 of this report and are directly comparable to gold grain results reported below for this study.

METHODS
Bedrock sample collection
Bedrock samples were collected to provide reference material and insights into the types and abundances of LCT pegmatite indicator minerals present in the bedrock source rocks. General metadata information about the project and the bedrock samples are reported in Appendix A Location and other data for the bedrock samples are reported in Appendix B1. In 2020, one bedrock sample (20DB-031BDK) was collected by NSDNRR from the South Dyke for heavy mineral analysis. In 2022, one bedrock sample (22MPB511) and one float boulder sample 22MPB512) were collected from the North Dyke and two bedrock samples were collected from the South Dyke (22MPB513, 22MPB514). Photos of the 2022 bedrock and boulder sample sites and hand specimens are included in Appendix B2.

Till sample collection
In 2020, 2021, and 2022, a total of 84 bulk heavy mineral till samples were collected from 77 sites, including four field duplicate samples at four sites (Fig. 2a,b). Sites consisted of hand-dug pits, and till exposures in borrow pits or along local roads. Some of the samples were also collected from fresh backhoe trenches dug on the down-ice (SSE) side of both the North and South Dykes where C-horizon (unoxidized to moderately oxidized) till was targeted (Fig. 10). Till samples were collected by NSDNRR (DB series sample numbers, e.g. 21DB001-2) and the GSC (MPB series sample numbers, e.g. 22MPB003) following the Geological Survey of Canada till sampling protocols described in McClenaghan et al. (2020, 2023c).

At three sites, two till samples were collected from vertical till sections to document compositional variability with depth:
1) In a borrow pit on Raynardton Road, 13 km southeast of the Brazil Lake pegmatites and on the north side of Lake Vaughan (Fig. 2), two till samples were collected from a 10 m till section exposing the core of a south-trending drumlin (Fig. 11). The E-W oriented vertical face in the borrow pit (Fig. 12a) exposes two sandy subglacial tills. The uppermost upper till in the section consists of dense, very stony till with discontinuous lenses and layers of sorted sand (Fig. 12b) and is considered to be a subglacial traction till. It mantles the drumlin feature, is approximately 3.5 m thick, and is was deposited by southward ice streaming that actively eroded and streamlined the landscape (Fig. 5- ice flow 2, blue arrows). This uppermost till contains abundant large bedrock boulders on or at its natural land surface (Fig. 12c). The underlying till is estimated to be >6 m thick and forms the core of the drumlin and was deposited by southward flowing ice, as indicated by till fabric data collected from the section in this study. The strong pebble fabric, greater compaction, and lack of sorted sand lenses indicates that this till is a subglacial traction till.

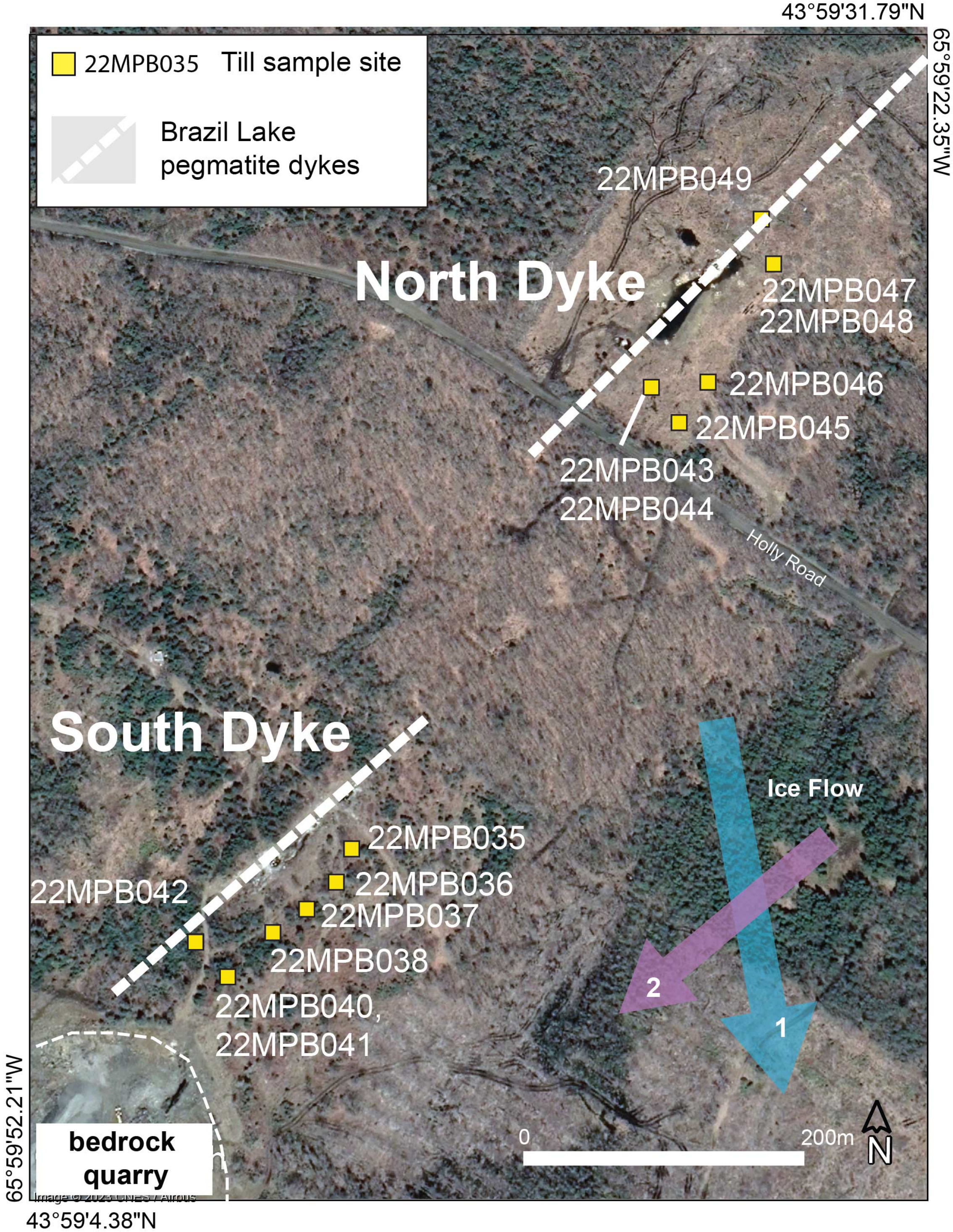

Figure 10. Approximate locations of the North and South dykes (white dashed lines) and locations of GSC till samples collected in 2022 from backhoe trenches nearby. Regional ice flow directions are indicated by arrows in bottom right corner of figure: (1) older flow, (2) younger flow. Modified from McClenaghan et al. (2023b). Background image is SPOT satellite imagery with 0.5 m resolution, using Google Earth.

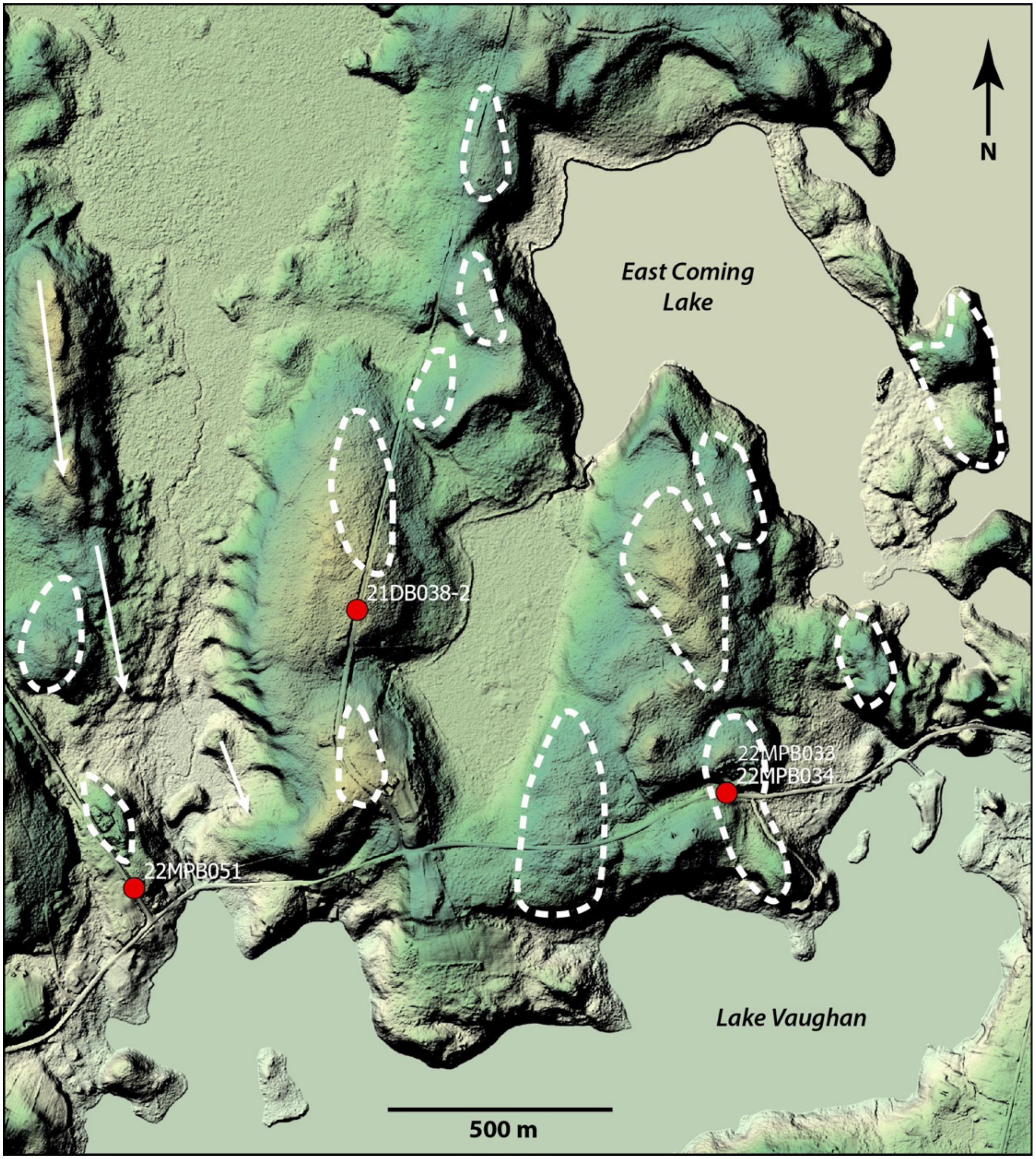

Figure 11. LiDAR hillshade DEM of the Raynardton Road borrow pit area (sample site 22MPB033-22MPB-034). Large drumlins (outlined by white dashed polygons) occur throughout the area, many of which have been post-glacially dissected or modified by glacial meltwaters. The tops of some of the drumlins have a 'pebbled' texture in the LiDAR image, indicating the presence of large greywacke boulders on the surface of the upper subglacial traction till. White arrows indicate the locations of some final ice flow phase glacially streamlined landforms. LiDAR image from provincial dataset published by the Government of Nova Scotia.

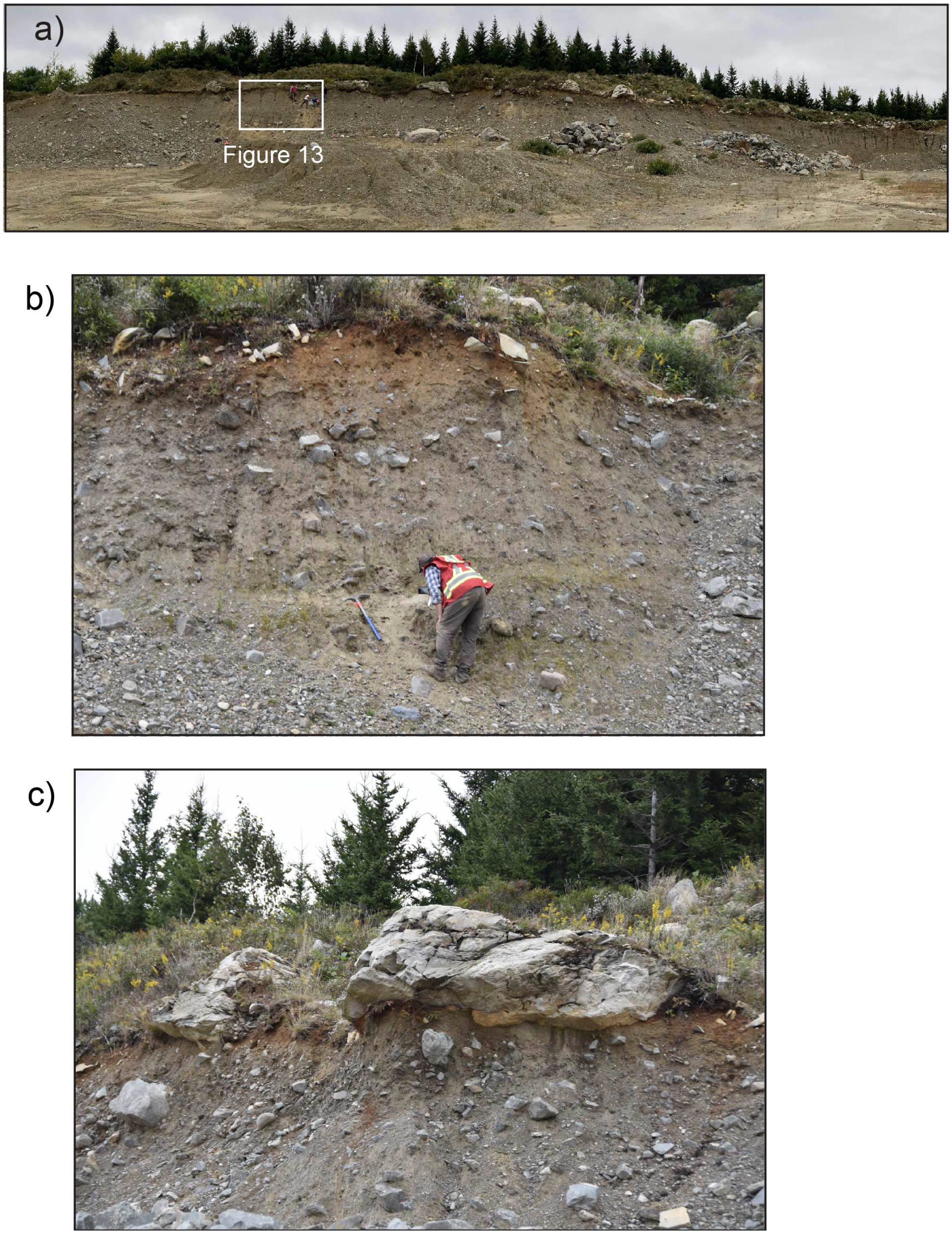

Figure 12. a) A 10 m section of till exposed in a borrow pit on the north side of Raynardton Road, 15 km southeast of the Brazil Lake pegmatites (Photograph by Roger Paulen, NRCan photo 2023-485); b) Abundant large bedrock boulders on or at its natural land surface resting on the upper till unit at the Raynardton Road borrow pit (Photograph by Roger Paulen, NRCan photo 2023-487); c) The uppermost upper till in the section consists of compact very stony till with discontinuous lenses and layers of sorted sand and is considered to be a subglacial traction till deposited by streaming ice (Photograph by Roger Paulen, NRCan photo 2023-486).

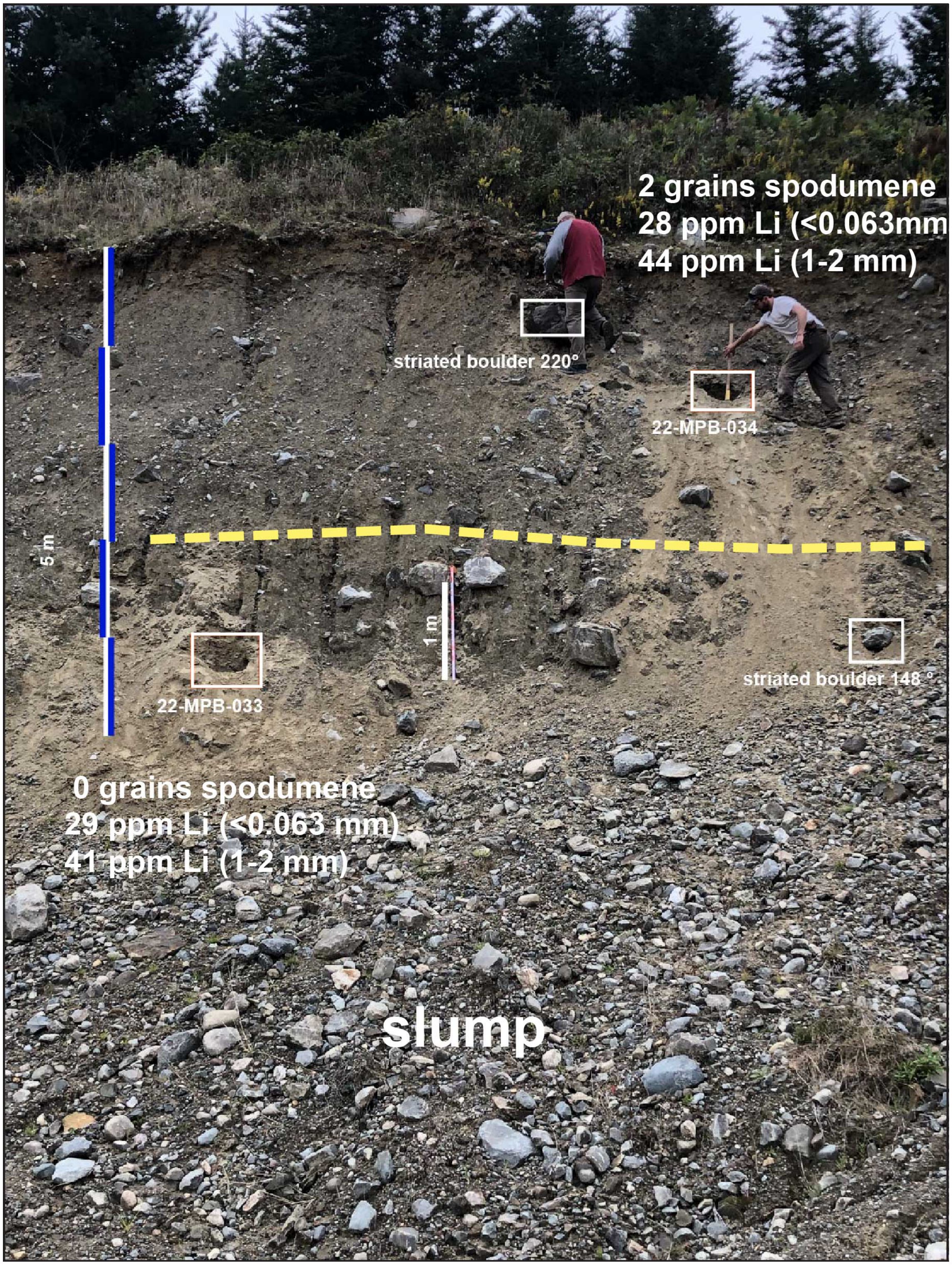

Figure 13. Two till samples (22MPB033, 22MPB034) were collected from the center of the Raynardton Road till section; refer to Figure 12a for location in pit. Yellow dashed line marks boundary between upper and underlying till units. The number of spodumene grains, normalized to 10 kg weight (table feed) and recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion are reported beside each sample site. (Photograph by Beth McClenaghan, NRCan photo 2023-461).

Figure 14. Till exposed in a backhoe trench pit just east of North Dyke and location of sample 22MPB043 and 22MPB044 collected within the trench. The number of spodumene grains, normalized to 10 kg weight (table feed) recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion/ICP-MS are reported beside each sample site. (Photograph by Beth McClenaghan, NRCan photo 2023-462).

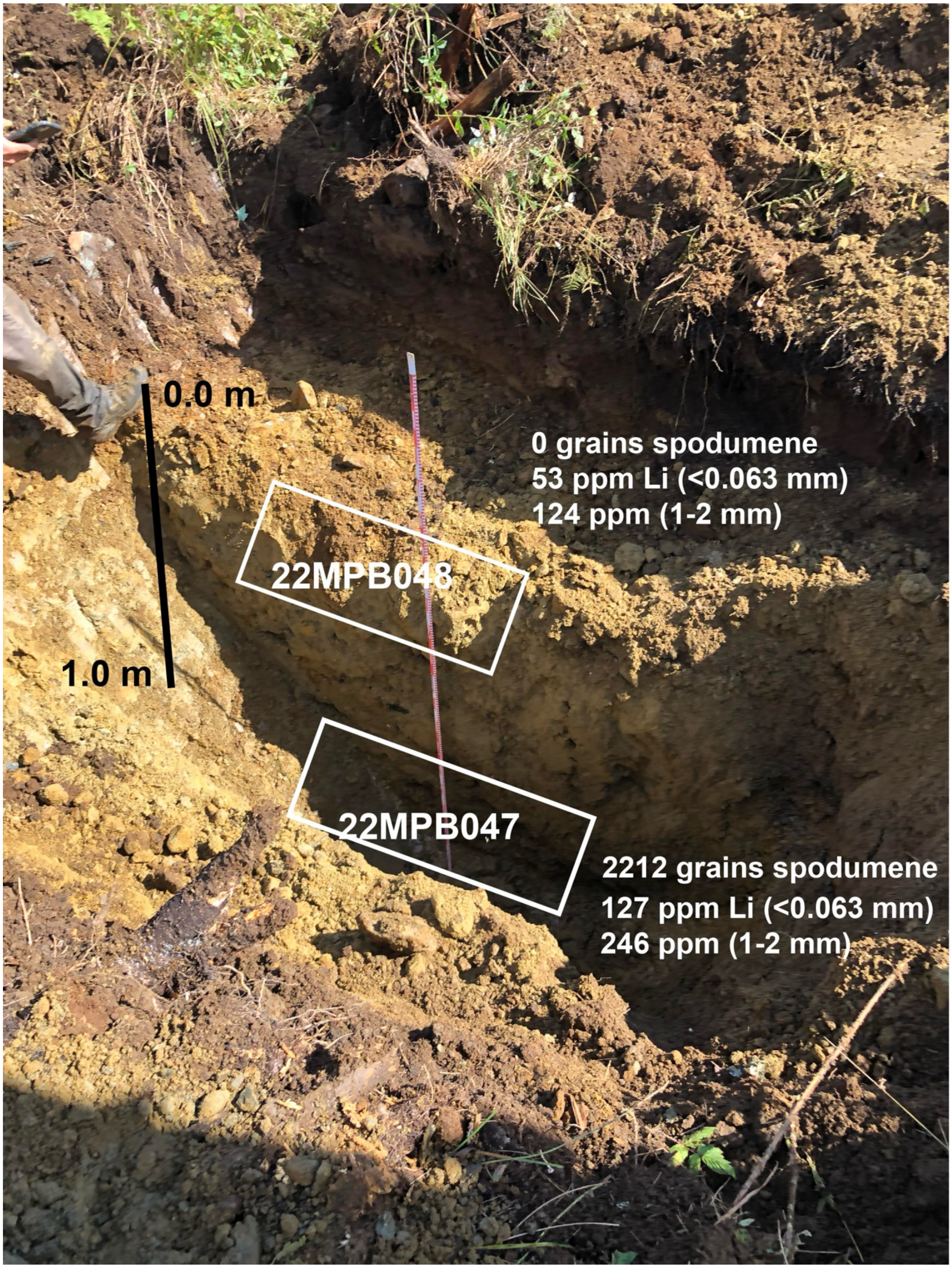

Figure 15. Till exposed in a backhoe trench pit just east of the North Dyke and location of samples 22MPB047 and 22MPB048 collected within the trench. The number of spodumene grains, normalized to 10 kg weight, recovered from the 2.8-3.2 SG fraction of till and the Li contents in 2 size fractions determined by Na-peroxide fusion/ICP-MS are reported beside each sample number. (Photograph by Beth McClenaghan, NRCan photo 2023-463).

Sample 22MPB033 was collected from 4.3 m depth in the underlying till and sample 22MPB034 was collected at 1.4 m depth from the uppermost till unit (Fig. 13). Bedrock was not exposed at the bottom of the section or on the pit floor.

2) In a backhoe trench 50 m south of the northeast-trending North Dyke (Fig. 10), sample 22MPB043 was collected at 1.1 m depth and 22MPB044 was collected at 2.1 m depth (Fig. 14). Bedrock was not reached in this trench.

3) In a second backhoe trench overlying the northeast-trending North Dyke (Fig. 10), till sample 22MPB047 was collected at 1.9 m depth and 22MPB048 was collected at 1.0 m depth (Fig. 15). Bedrock was not reached in this trench.

At each sample site, a large 7-20 kg till sample was collected for processing and recovery of indicator minerals for LCT pegmatites and other ore systems (i.e., gold grains) and the recovery of the pebble-sized fraction for lithological analysis (>2.0 mm fraction). Field data collected at each site are reported in Appendix B3, which includes GPS coordinates, general site description, and sample description (e.g. soil horizon, texture, colour, sample depth). Site photos for till samples collected in 2021 and 2022 are included in GSC Open File 9148 (Brushett et al., 2024). No site photos are available for the one till sample collected in 2020.

Sample processing

The large bulk (~7-20 kg) till samples and small fist-sized (0.5-1.3 kg) bedrock samples were shipped to Overburden Drilling Management Limited (ODM) in Ottawa, Ontario, for sample processing to produce 0.25-2.0 mm mid-density (2.8-3.2 specific gravity (SG)) and heavy-density (>3.2 SG) mineral concentrates from which indicator minerals were counted and selected minerals removed for further study.

Bedrock samples were processed and examined to establish the suite of indicator minerals that best reflect the Li pegmatites according to the flow sheet outlined in Figure 16. ODM in-house barren quartz blank (‘blk’) samples were inserted at the start of each bedrock batch and between each bedrock sample. Each bedrock or blank sample was disaggregated using a custom-built CNT Spark-2 electric pulse disaggregator (EPD; Rudashevsky et al., 1995; Cabri et al., 2008), instead of using a conventional rock crusher, in order to preserve natural grain boundaries, sizes, textures, and shapes. The mass of <2.0 mm material that was produced by disaggregation ranged from 434 g to 1427 g and each sample was processed using a shaking table to produce a preconcentrate. The table preconcentrate was panned to determine if any fine-grained (<0.25 mm) gold, sulphides, cassiterite or other indicator minerals were present. The table concentrate was then further refined using heavy liquid and ferromagnetic separations to produce two fractions: a) 2.8-3.2 specific gravity (SG) and, b) >3.2 SG (Fig. 16).

Till samples were processed and examined for Li indicator minerals, gold grains, and indicator minerals of other types of mineralized bedrock in the region according to the process outlined in Figure 17. Geological Survey of Canada in-house blanks were inserted into the 2021 and 2022 samples batches by GSC personnel prior to shipping samples to the mineral processing and picking lab, to monitor the recovery of indicator minerals and the potential for sample contamination. Blanks included both the 'Bathurst blank' and 'Almonte till blank' and each blank is clearly identified in Appendix B4. The Bathurst blank consists of weathered Silurian-Devonian granite (grus) of the South Nepisiguit River Plutonic Suite (Wilson, 2007) and was collected approximately 66 km west of Bathurst, New Brunswick (Plouffe et al., 2013; McClenaghan et al., 2020, 2023c) as a series of 200 buckets of weighing about 20 kg each. The Almonte blank consists of bulk till collected from a borrow pit in Almonte county, Ontario. It has the typical texture and color of Shield-derived till, and is used as an in-house standard and as a base material for spiking (Plouffe et al., 2013). In 2022, two Almonte till blanks were spiked with a known quantity of spodumene grains (samples 22MPB052 and 22MPB-53). Indicator mineral results for the in house-blanks are reported along with the routine till samples in Appendixes C4 to C7. The individual blank bucket numbers used are listed in Appendix B. For some blank samples, the material in an individual bucket was split to create two 10-kg blank samples and these splits are labelled as A or B.

After the insertion of blanks, the till samples were shipped to ODM for sample processing and production of heavy mineral concentrates and grain picking, as outlined in the flowsheet in Figure 17. Samples were first processed using a shaking table to prepare a <2.0 mm preconcentrate. The table preconcentrate was micro-panned to recover fine-grained (<0.25 mm) gold, sulphides, or other indicator minerals that might be present. The minerals in the panned concentrates were counted, their size and shape characteristics recorded, and then returned to the concentrate. Gold grains in the pan concentrate were sized and their shape classified using the pristine-modified-reshaped classification scheme of DiLabio (1990) that relates shape to transport distance. Mineral abundance data reported in the pan concentrate is listed in the "Detailed VG" worksheet in all raw data files in Appendix C.

The preconcentrate was subsequently subjected to two heavy liquid separations and ferromagnetic separations (Fig. 17) to produce 2.8-3.2 SG and >3.2 SG non-ferromagnetic heavy mineral concentrates for visual identification and counting of indicator minerals. The 0.25-0.5, 0.5-1.0, and 1.0-2.0 mm non-ferromagnetic >3.2 SG fraction 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.

Pebble lithology determinations

The >2.0 mm fraction from a selection of 30 till samples collected in 2021 or 2022 were shipped to C. White (consultant) in Nova Scotia, for examination of pebble lithologies. The 2-4 mm (granules) and 4-8 mm (small pebbles) clasts were scanned solely for the presence of spodumene and the abundance is reported in Appendix G- worksheet "spodumene counts 3 fractions". The >8 mm clast size fraction was examined in detail and the major and minor bedrock lithologies were counted. In some instances, a Malvern Panalytical benchtop (portable) X-ray fluorescent (pXRF) spectrometer has been used to verify the presence or absence of specific minerals. In addition, a handheld ultraviolet (UV) light (both long and short wave length) was used to aid in the identification of spodumene and/or any tungsten-bearing minerals in the till fractions. All samples were split using a cone and quarter method to partition the sample into 4 quarters and then opposite diagonal quarters were examined. However, to achieve a minimum of 300 pebbles all clasts in samples 21DB004, 21DB004, and 22MPB038, 043, 045, 046, and 049 were examined and counted. The data are reported in Appendix G-worksheet ">8 mm lithologies". Lithological categories are listed at the bottom of the appendix worksheet and in Table 2.

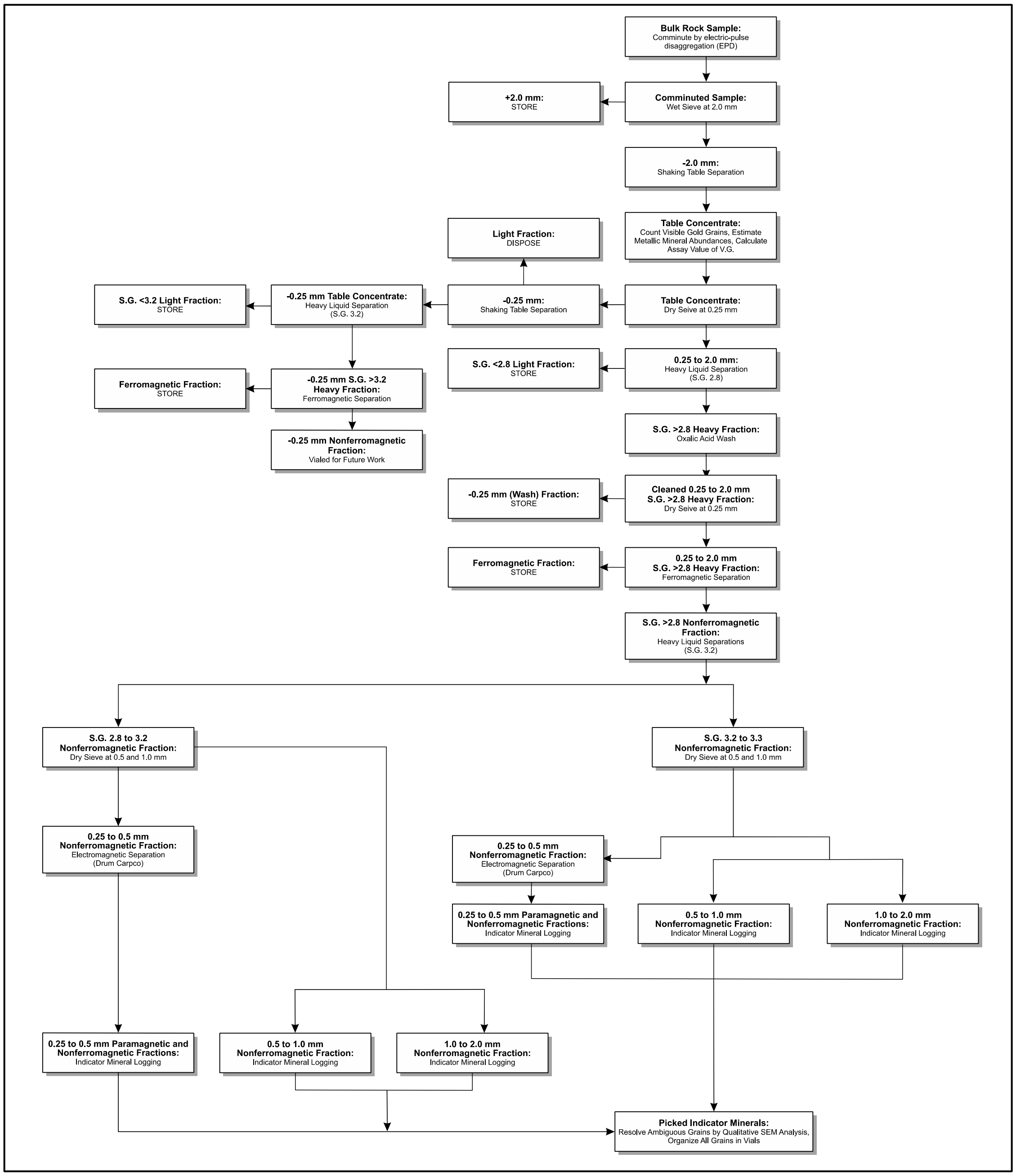

Figure 16. Schematic flow sheet showing the processing steps for the preparation of heavy mineral concentrates and recovery of indicator minerals from bedrock samples from the Brazil Lake pegmatites. From Overburden Drilling Management Limited.

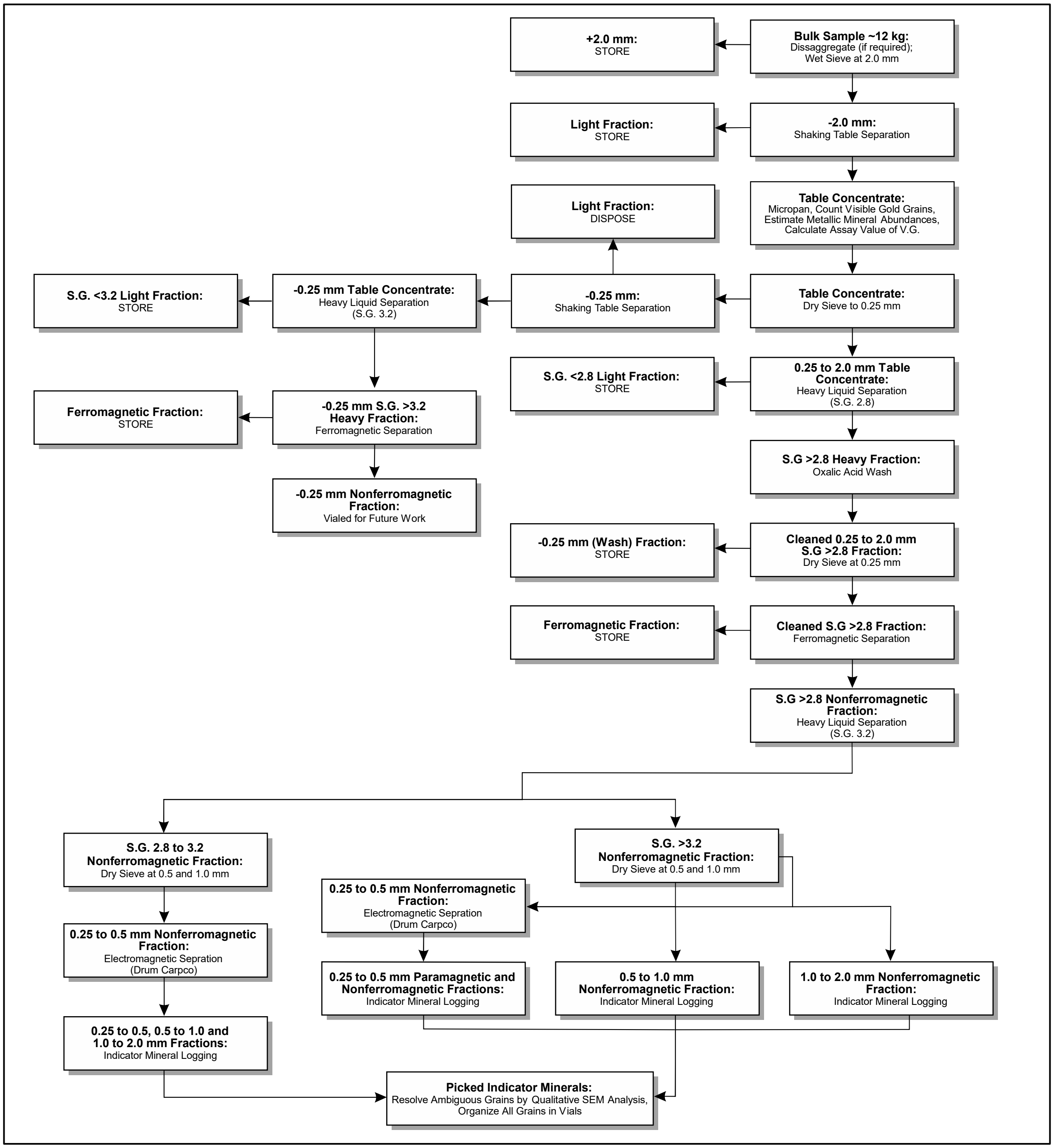

Figure 17. Schematic flow sheet showing the processing steps for the preparation of heavy mineral concentrates and recovery of indicator minerals from till samples. From Overburden Drilling Management Limited.

Table 1. List of appendix files, year of sampling, and the worksheets that contain raw heavy mineral abundance data.

Appendix File	Material	Year	Pan cconcentrate mineal abundance data worksheet name	>3.2 SG Columbite, cassiterite, and sphalerite mineral abundance data worksheet name	2.8-3.2 SG Spodumene, apatite and tourmaline indicator mineral abundance data worksheet name
Appendix C1	bedrock	2020	Detailed VG	MMSIM Counts1	MMSIM Counts2
Appendix C2	bedrock	2022	Detailed VG	MMSIM	2 Mid Density
Appendix C3	till	2020	Detailed VG	MMSIM Counts1	PCIM Counts2
Appendix C4	till	2021	Detailed VG	MMSIM Counts1	PCIM Counts2
Appendix C5	till	2021	Detailed VG	MMSIM Counts1	PCIM Counts2
Appendix C6	till	2022	Detailed VG	MMSIM Counts1	Mid Density
Appendix C7	till	2022	Detailed VG	MMSIM Counts1	Mid Density

Table 2. List of bedrock lithology categories for classifying pebbles that were recovered from the >2 mm fraction of heavy mineral till samples during sample processing.

Category number in Appendix G	Lithology	Group	Formation	Description
1	metasandstone	Goldenville Group	Green Harbour Fm	grey, blocky, subangular to subrounded, v.f.g-f.g
2	metasandstone	Goldenville Group	Green Harbour Fm	grey, tabular to blocky, angular, v.f.g.-f.g
3	metasiltstone	Goldenville Group	Green Harbour Fm	mainly grey, tabular, subangular to subrounded
4	muscovite-biotite phyllite/schist	Rockville Notch Group		grey to rust brown, tabular to elongate, subangular, +/- garnet, staurolite, chloritoid porphyroblasts
5	metasandstone	Rockville Notch Group		lt grey to white, subrounded
6	metasiltstone	Rockville Notch Group		mainly grey, blocky to elongate, subrounded to rounded, (+/- <1 mm porphyroblasts of biotite, muscovite, chloritoid)
7	amphibolite	Rockville Notch Group		black, mainly elongate, angular to subangular, f.g.-m.g.
8	salt&pepper amphibolite	Rockville Notch Group		salt and pepper, blocky, subrounded, f.g.-m.g.-c.g.
9	quartzite	Rockville Notch Group		grey to dark grey to brown, blocky, rounded,
10	felsic crystal tuff or porphyry (rhyolite)	Rockville Notch Group		grey, blocky, rounded,
11	basalt	Rockville Notch Group		brown to grey, blocky, rounded, mafic flow
12	porphyry (plagioclase)	Rockville Notch Group		grey to purple to brown, blocky, rounded,
13	monzogranite to syenogranite	Rockville Notch Group		pale, well foliated, blocky to tabular, subangular, f.g.-m.g.,(Brenton Pluton)
14	pegmatite	Rockville Notch Group		pale, blocky, subangular
15	spodumene	Rockville Notch Group		cream, tabular, angular,
16	vein quartz	unknown		rounded to angular,
17	granite	unknown		pink to grey, subangular, elongate to blocky, f.g.

f.g. - fine grained
m.g. - medium grained
c.g. - coarse grained

Data plotting

Proportional dot maps showing the abundance of selected indicator minerals, normalized to 10 kg sample weight (weight of <2 mm table feed fraction) or pebble lithologies were plotted using the ESRI ArcMap™ (v. 10.8.1) desktop application. Data classes for each dot size were determined using percentiles calculated in ArcMap.

RESULTS

Bedrock sample grain counts in the 0.25-0.5 mm >3.2 SG and 2.8-3.2 SG fractions are reported as raw values in Appendix C1 and C2. Till sample grain counts are reported as raw mineral counts in Appendix C3 to C7. Raw mineral abundance data reported for the pan concentrate, >3.2 SG concentrate, and the 2.8-3.2 SG fractions are found in the worksheets listed in Table 1.

For selected minerals including gold, the mineral abundance data for till samples were normalized to the weight of the <2 mm (Table Feed) fraction. The weight of this fraction is reported in the worksheets that are listed in Table 1. Normalized grain counts for selected mineral species are reported in Appendix D. Mineral distributions in till samples that are described and discussed below and plotted on maps as the normalized 0.25-0.5 mm fraction data. Because no regional indicator mineral survey data have been previously published for the Brazil Lake area, background values were established using till samples farthest up ice (north) from the pegmatites and that contained the fewest indicator minerals.

Quality assurance/quality control

Raw, unedited indicator mineral data for the pan concentrate and 0.25-0.5 mm heavy mineral fraction of the Bathurst blank, Almonte till, and field duplicates are listed along with the routine till sample data in Appendixes C4 to C7. Normalized mineral abundance data for the 0.25-0.5 mm mid-density and heavy mineral fractions of the Bathurst Blank (green highlighting), Almonte till (yellow highlighting) and four field duplicates (blue highlighting) are summarized for selected key minerals in Appendix E.

The only indicator mineral of note recovered from three of the five the Bathurst blanks is goethite. Previous data reported for the Bathurst blank indicates that it can contain the occasional pyrite and goethite grain (Oviatt et al., 2013; Plouffe et al., 2013, McClenaghan et al., 2020, 2023c). In this study, the Almonte till contains the occasional gold grain (up to 2 grains), abundant apatite, a few 100s of tourmaline grains, and 10s of grains of goethite and pyrite. These values are similar to values reported for this till blank in other GSC studies (Plouffe et al., 2013; McClenaghan et al., 2017). These results for both blanks indicate that no external or carryover contamination between samples has been detected. Two Almonte till blanks were spiked with known spodumene gains prior to shipping of the samples to ODM. These grains (2 and 14 grains) were recovered from the two samples. Spodumene counts are similar between duplicate pairs of samples, most notably for the 2.8-3.2 SG fraction, where spodumene is most abundant.

Indicator mineralogy

Potential LCT pegmatite indicator minerals are listed in Table 3 along with their density, hardness, who first reported their presence in the Brazil Lake pegmatites, and whether they were recovered in bedrock and till samples in this study.

Selected mineral count data normalized to a 10-kg sample weight are reported in Appendix D. Mineral distribution maps, plotted using the normalized data in the form of proportional dot maps, are included in Appendix F. The maps for gold grains, pyrite, and goethite include one extra sample (22MPB050) than the other mineral maps in Appendix F because they include sample 22MPB050. This sample was collected in the extreme northeast corner of the study area, in the Kemptville Gold District, specifically to investigate the gold signature in till. It does not contain any spodumene.

Spodumene

Spodumene is the main Li-bearing mineral of LCT pegmatites (Bradley and McCauley, 2013; Černy, 1991; Černy and Ercit, 2005; Groves et al., 2022) and its presence in the Brazil Lake pegmatites is well documented (Corey, 1995; Kontak, 2004, 2006). Spodumene has a specific gravity of 3.1-3.2 and a hardness of 6.5-7. It was identified in bedrock and till mid-density and heavy mineral fractions in this study by its white colour, prismatic, generally flattened and elongated, striated, commonly massive crystal habit, and brittle fracture (Fig. 18a,b) and, at times, it is fluorescence under UV light. All three size fractions of the mid-density and heavy mineral fractions were examined for spodumene and background abundance in both density fractions and both size fractions is zero grains. Spodumene abundance is summarized as follows:

1) Mid-density (2.8-3.2 SG) fraction: Spodumene is most abundant in the mid-density fraction as compared to the heavy mineral fraction, and in the smallest size fraction (0.25-0.5 mm) with the most anomalous samples containing 100s to 1000s of grains/10 kg (Appendix F map 1). It is present but less abundant in the 0.5-1.0 mm fraction, with the most anomalous samples containing 10s to 100s of grains/10 kg (Appendix F map 2), and it is absent to scarce in the 1.0-2.0 mm fraction, containing a maximum of 1s to 10s of grains (Appendix F map 3).

2) Heavy mineral (>3.2 SG) fraction: Similar to the mid-density fraction, spodumene is most abundant in the smallest size fraction (0.25-0.5 mm) of the heavy mineral fractions with the most anomalous samples containing 1s to 10s of grains/10 kg (Appendix F map 4). It is much less abundant in the 0.5-1.0 mm fraction containing up to a maximum of 12 grains/10 kg (Appendix F map 5), and absent in the 1.0-2.0 mm fraction except for a single sample that contains 3 grains/10 kg (Appendix F map 6).

In this study, spodumene in the 2.8-3.2 SG fraction is most abundant in till immediately south of the North and South Dykes (max 2212 grains) and in sample 21DB027 that is 3 km south of the South Dyke (1705 grains) (Appendix F Map 1). Abundances decrease southward but are still detectable in till 12 km to the south. The farthest down ice sample is 22MPB027, 12 km south of the pegmatites and just south of Lake Vaughan (Appendix F Map 1) and contains 2 grains.

Spodumene abundances in each of the three size fractions for both density fractions of till samples for the immediate area around the Brazil Lake pegmatites are shown in six maps in Appendix F Map 7. These maps show a similar distribution pattern for spodumene as that visible in the larger-scale map for the study area (Appendix F maps 1-6): i) spodumene is most abundant in the mid-density fraction in comparison to the heavy mineral fraction, and ii) spodumene is most abundant in the smallest (0.25-0.5 mm) fraction.

The relative proportions of spodumene in each of the three size fractions of the 2.8-3.2 SG fraction are compared in Appendix F Map 8 to further demonstrate that the finest size fraction contains the most spodumene. Also readily apparent from the map is that coarsest spodumene grains in till samples are closest to the pegmatites, thus the presence of coarse grains can be an indicator of close proximity to an LCT pegmatite.

Table 3. Potential indicator minerals of the Brazil Lake LCT pegmatites summarized from bedrock descriptions by Taylor (1967), Corey (1995), and Kontak (2004, 2006), and a listing of indicator minerals found in till samples in this study.

Mineral	Formula	Specific gravity (SG)	Hardness (H)	In bedrock HMC in this study?	In till HMC in this study?	First reported presence in deposit	Fractions that indicator minerals were recovered from in this study
spodumene	$LiAlSi_2O_6$	3.1 - 3.2	6.5-7	yes	yes	Taylor (1967); Kontak (2004)	2.8-3.2 SG 0.25-0.5 mm
tourmaline-schorl/dravite	$Na(Fe,Mg)_3Al_6Si_6O_{18}(BO_3)_3(OH)_2$	3.03 - 3.22	7	yes	yes	Taylor (1967); Kontak (2004)	2.8-3.2 SG 0.25-0.5 mm
green beryl	$Be_3Al_2Si_6O_{18}$	2.63 - 2.9	7.5-8	no	no	Taylor (1967); Kontak (2004)	NA
columbite	$(Mn,Fe)(Nb,Ta)_2O_6$	5.3-7.3	6	yes	yes	Taylor (1967); Kontak (2004)	>3.2 SG 0.25-0.5 HMC
tantalite	$(Fe,Mn)Ta_2O_6$	8.1-8.2	6-6.5	yes	yes	Taylor (1967); Kontak (2004)	>3.2 SG 0.25-0.5 HMC
blue apatite	$Ca_5(PO_4)_3(OH,F,Cl)$	3.16 - 3.22	5	yes	yes	Taylor (1967); Kontak (2004)	2.8-3.2 SG 0.25-0.5 mm
triplite	$(Mn,Fe)_2(PO_4)(F,OH)$	3.5-3.9	5-5.5	no	no	Kontak (2004)	NA
montebrasite	$LiAlPO_4(OH)$	5.5-6	2.98 - 3.04	no	no	Kontak (2006)	NA
crandallite	$CaAl_3(PO_4)_2(OH)_5 \bullet (H_2O)$	2.78 - 2.92	4	no	no	Kontak (2006)	NA
goyazite	$SrAl_3(PO_4)_2(OH)_5 \bullet (H_2O)$	3.16 - 3.28	4-5	no	no	Kontak (2006)	NA
lithiophilite	$LiMnPO_4$	3.29 - 3.50	4	no	no	Corey (1995); Kontak (2004)	NA
fillowite	$Na_3CaMn_{11}(PO_4)_9$	3.43	4.5	no	no	Kontak (2006)	NA
variscite	$Al(PO_4) \bullet 2(H_2O)$	2.5 - 2.52	4-5	no	no	Corey (1995)	NA
florencite	$(La,Ce)Al_3(PO_4)_2(OH)_6$	3.46 - 3.71	5-6	no	yes	this study (in till only)	>3.2 SG 0.25-0.5 HMC
heterosite	$(Fe,Mn)PO_4$	4-4.5	3.4	yes	no	this study	>3.2 SG 0.25-0.5 HMC
uraninite	UO_2	6.5 - 10.95	5-6	yes	no	this study	pan conc, >3.2 SG 0.25-0.5 HMC
zircon	$Zr(SiO_4)$	4.6 - 4.7	7.5	yes	yes	Corey (1995); Kontak (2004)	>3.2 SG 0.25-0.5 HMC
cassiterite	SnO_2	6.8 - 7	6-7	yes	yes	Corey (1995); Kontak (2004)	pan concentrate
wolframite	$(Fe, Mn)WO_4$	7-7.5	4-4.5	no	no	Kontak (2004)	NA
scheelite	$CaWO_4$	5.9–6.1	4.5-5	no	yes	this study (in till only)	>3.2 SG 0.25-0.5 HMC
sphalerite	$(Zn,Fe)S$	3.9–4.2	3.5–4	yes	yes	Kontak (2004)	>3.2 SG 0.25-0.5 HMC
pyrite	FeS_2	4.8 - 5	6-6.5	yes	yes	this study	pan conc, >3.2 SG 0.25-0.5 HMC
arsenopyrite	FeAsS	6	5.5-6	yes	no	this study	pan concentrate
loellingite	$FeAs_2$	7.43	5-5.5	yes	no	this study	pan concentrate
pyrolusite	MnO_2	5	2-6.5	yes	no	this study	>3.2 SG 0.25-0.5 HMC

HMC = heavy mineral concentrate
NA = not applicable
SG = specific gravity

At three sites, two till samples were collected from vertical till sections to document compositional variability with depth. Spodumene content in till does vary with depth at two of the three sites sampled:

1) Samples 22MPB033 and 22MPB034, Raynardton Road borrow pit: The lower till sample collected at 4.3 m depth does not contain spodumene grains (Fig. 13). The upper till sample, collected at a similar depth (1.4 m) to the routine surface samples that were collected in the survey area, contains 2 grains of spodumene (Fig. 13).

2) Samples 22MPB043 and 22MPB044, 25 m south of the south end of the North Dyke (Fig. 10): Both the upper and lower samples in this trench contain similar abundances of spodumene (>2000 grains/10 kg) (Fig. 14). Such high values close to the pegmatite are not unexpected and show that the upper 2 m of till at this site is spodumene-rich. Collecting a routine surface till sample at this site would have been sufficient to detect glacial dispersal from the North Dyke.

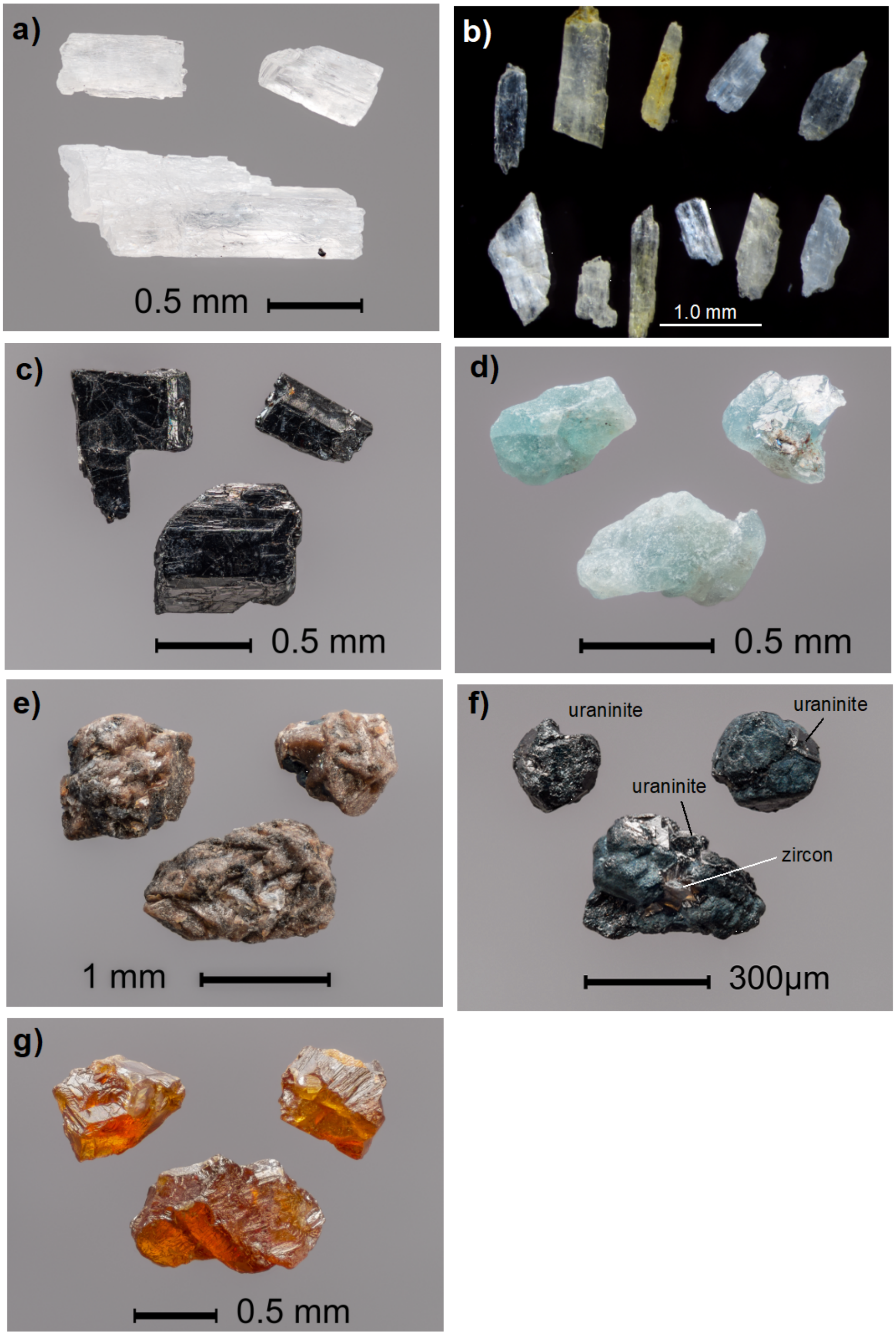

Figure 18. Colour photographs of LCT pegmatite indicator minerals recovered from bedrock sample 20DB-031 BDK: a) spodumene; b) spodumene on black background; c) black columbite/tantalite; d) blue apatite; e) zircon; f) uraninite with minor zircon; and g) orange (iron-poor) sphalerite. Photographs provided by Michael J. Bainbridge Photography, except Photo (b) that was provided by Overburden Drilling Management Limited.

3) Samples 22MPB047 and 22MPB048, 25 m south of the middle section of the North Dyke (Fig. 2): These two till samples contain very different amounts of spodumene (Fig. 15). The lower sample (1.9 m depth) contains 2212 grains/10 kg and the upper sample (1.0 m) depth contains zero grains. Collecting a routine surface till sample at this site would not have detected glacial dispersal from the North Dyke. In this case, the upper till immediately adjacent to the pegmatite is derived from bedrock up-ice of the pegmatite, and did not re-entrain the lower till containing the spodumene.

Columbite-Tantalite

Kontak (2004, 2006) has described the occurrence of columbite/tantalite in the Brazil Lake pegmatites, whereas Kontak et al. (2005) specifically refers to the mineral tantalite in their study of the geochronology of the pegmatites and describes it as being dark brown tabular crystals that are 1-2 cm in length (Fig. 3c). Columbite/tantalite has a combined specific gravity range of 5.3 to 8.2 and a hardness range of 6 - 6.5 (Table 3). It was identified in bedrock heavy mineral fractions by its black colour and blocky crystal habit (Fig. 18c) and selected grains were confirmed by ODM using an SEM. Identifying it can be challenging because it is visually similar to hornblende and ilmenite. For the 2020 bedrock sample, ODM reported results for "columbite/tantalite" in Appendix C1 worksheet "MMSIM Counts1". For the 2022 bedrock samples, ODM reported results for "columbite" in Appendix C2, worksheet "MMSIM". The only till sample found to contain columbite/tantalite grains is 22MPB047 (50 m south of the North Dyke). These grains were recovered only after re-examination (May, 2024) of the 0.25-0.5 mm heavy mineral fraction. Four other till samples (22MPB009, 22MPB006, 22MPB035, and 21DB033) that were proximal to the Brazil Lake pegmatites and that had elevated Nb and Ta values in the <0.063 mm fraction were also re-examined, but no grains were found.

Apatite

The Brazil Lake pegmatite contains abundant apatite (Kontak, 2004, 2006). Appendix F Map 9 shows the abundance of all colours of apatite in the mid-density (2.8-3.2 SG) 0.25-0.5 mm fraction of till. It is most abundant in till samples that are approximately 2 km south to southwest of the South Dyke. A light blue variety of apatite is a distinct indicator mineral in the Brazil Lake pegmatites (Fig. 18d). The presence of blue apatite in bedrock samples was noted in the raw data files in Appendix C, however blue apatite was not observed in the till samples.

Tourmaline

Tourmaline in the Brazil Lake pegmatite occurs as brown-black, green-brown and dark blue crystals in the margins of and within the pegmatite (Corey, 1995; Kontak, 2004). The tourmaline in the pegmatites is dravite-schorl (Kontak, 2004) and has a specific gravity of 3.18 - 3.22 and a hardness of 7. It was identified in bedrock and till mid-density and heavy mineral fractions in this study by its dark brown to black colour, prismatic crystal habit, and parallel striations on crystal surfaces. Most tourmaline grains in the bedrock samples in this study are black to dark brown. Some blue tourmaline grains were reported in bedrock sample 22MPB513 and till samples 22MPB009 and 22MPB047.

Tourmaline is most abundant in the mid-density (2.8-3.2 SG) fraction of till samples (100s to 1000s grains/10 kg) and the highest values in till are: i) just south of the South Dyke

(22MPB037) and the Army Road pegmatite (22MPB009), ii) between the South Dyke and the Army Road pegmatite (21DB032), and iii) 2 km north of the North Dyke (22MPB023) (Appendix F map 10). Elevated values also occur in till 5 km east and 5 km south of the Brazil Lake pegmatites. Abundances are much less (100s of grains) in the >3.2 SG fraction, and these values are highest in till around the North and South Dykes (Appendix F Map 11).

Florencite

Florencite is a hydrated phosphate of aluminum. It is not known to occur in the Brazil Lake pegmatites. It was identified only in till heavy mineral concentrates in this study by its red-brown to ochre in colour, rounded shape, resinous, greasy lustre and cherty appearance and confirmed by SEM. Its abundance in till samples varies from a background of zero grains for most till samples to a high of two grains. Till samples that contain florencite are proximal to the North and South Dykes and up to 5 km down ice.

Heterosite

Heterosite is a secondary mineral formed by oxidation of iron and/or manganese in combination with the leaching of lithium from primary phosphate minerals such as lithiophilite or triphylite. (https://www.mindat.org/min-1887.html). One grain was recovered from the heavy mineral concentrate of bedrock sample 20DB-031 BDK and was identified by ODM using an SEM. Its presence has not previously been reported in the Brazil Lake pegmatites.

Uraninite and zircon

Zircon was identified in bedrock and till heavy mineral concentrates by its brownish red colour and short wave ultraviolet light colour (yellow, green, orange colour). Its presence was documented in bedrock sample 20DB-031 BDK (Fig. 18e). Grains of uraninite intergrown with zircon were recovered from bedrock samples 20DB-031 BDK and 22MPB513. Uraninite was identified by its black submetallic luster and its intergrowth with zircon (Fig. 18f).

Cassiterite

The presence of cassiterite in the Brazil Lake pegmatites is known from previous studies by Corey (1995) and Kontak (2004). Cassiterite has a specific gravity of 6.8-7 and a hardness of 6-7 and was identified in bedrock and till heavy mineral concentrates in this study by its bright luster, brown color, and prismatic crystal habit. Cassiterite grains varying in size from 0.25 to 2.0 mm were recovered from the >3.2 SG fraction of the bedrock samples. Fine-grained cassiterite (25-250 µm) was recovered from the pan concentrate of three bedrock samples (22MPB511, 22MPB 512, and 22MPB 514.)

In till samples, cassiterite was recovered from the 0.25-0.5 mm size of the >3.2 SG fraction. Abundance varies from a background of zero grains in most till samples to a high of six grains in sample 22MPB046, immediately east of the South Dyke (Appendix F map 12).

Scheelite

The presence of scheelite has not been reported in the Brazil Lake pegmatites however it can be an accessory mineral in pegmatites (Poulin et al., 2018). It has a specific gravity of 5.9 - 6.12, a hardness of 4 to 5 and has never been observed in the Brazil Lake pegmatites. It was identified in till heavy mineral fractions by its pale yellow to white colour under normal light, by its bright whitish blue to yellow fluorescence under short wave UV light, and by its cleavage. Most till samples contains zero grains with a few samples containing between one and three grains. The highest values are in till 2 km south of the South Dyke (Appendix F map 13).

Sphalerite
Kontak (2006) reported the presence of Fe-poor sphalerite in the Brazil Lake pegmatites. Orange sphalerite grains were identified in the >3.2 SG HMC of bedrock samples 20DB-031 BDK and 22MPB513 (Fig. 18g). Sphalerite is present in both the 0.5-1.0 mm and the 0.25-0.5 mm heavy mineral faction of bedrock samples. No sphalerite was recovered from till samples.

Pyrolusite
The presence of pyrolusite has not previously been reported in the Brazil Lake pegmatites. Pyrolusite (MnO_2) is a secondary mineral formed from the oxidation of Mn-bearing minerals, and potentially tantalite. It has a specific gravity of 4.4 to 5.1 and a hardness of 6 to 6.5. It was identified in the >3.2 SG 0.25-0.5 mm fraction of bedrock sample 22MPB513 by its dull black amorphous appearance. It was not recovered from any till samples.

Pyrite
Corey (1995) noted the presence of pyrite in the wall rocks of the North Dyke and was identified in heavy mineral concentrate by its pale yellow metallic luster and crystal habit. It was recovered from the pan concentrate fraction of bedrock samples 22MPB512 and 22MPB513 and in whih it ranges from 25 to 150 µm in diameter (Appendix C2 "Detailed VG" worksheet). It was also recovered from the >3.2 SG 0.25-0.5 mm heavy mineral fraction of till samples. Most till samples have background concentrations of between 0 and 1 pyrite grains. Two till samples are noteworthy for their elevated pyrite content; i) sample 22MPB027 south of the Lake Vaughan reservoir contains 91 grains, and ii) sample 22MPB030 southeast of Hoopers Lake contains 141 grains (Appendix F map 14). These two samples are not proximal to the pegmatite; they are 5-10 km to the south overlying the Green Harbour Formation.

Arsenopyrite
Arsenopyrite was identified in bedrock sample 22MPB513 by its light steel grey metallic colour and moderate hardness (H=5). One grain was recovered from the pan concentrate and was initially picked because it looked like loellingite. Its presence has not previously been reported in the Brazil Lake pegmatites and no arsenopyrite was recovered from till samples.

Loellingite
Loellingite ($FeAs_2$) grains (25-150 µm) were identified in the pan concentrate of bedrock sample 22MPB513 by their light steel grey metallic colour and moderate hardness (H=5) and confirmed by SEM (Appendix C2 "Detailed VG" worksheet). No grains were recovered from till samples. Its presence had not previously been reported in the Brazil Lake pegmatites.

Goethite
Goethite is a secondary Fe-rich mineral that forms from the oxidation of other Fe-rich minerals. It has a hardness of 5 to 5.5 and a specific gravity 3.3 to 4.3. It was identified in till heavy mineral concentrates by its dark orangey brown colour and earthy appearance. Goethite ranges in abundance from 0 to more than 2600 grains per till sample. Samples with the greatest amount of

goethite are southeast of the pegmatites, overlying the Green Harbour Formation, and in sample 22MPB050 (Appendix F map 15) which is in the Kemptville gold district to the northeast (O'Reilly, 2003; Goodwin, 2006).

Gold

Gold grain counts that area reported here are the abundance of grains recovered from the pan concentrate of each till sample prior to heavy liquid separation and normalized to 10 kg <2 mm material (Table feed). Gold has not been reported in the Brazil Lake pegmatites and none was recovered from any pegmatite samples. Till samples contain between between 0 and 161 grains, with most till samples containing no gold grains (background) (Appendix F map 16). Values of >4 gold grains are considered to be anomalous based on the distribution pattern on the map. Till samples in the area southeast of the Brazil Lake pegmatites (samples 22MPB030, 032, 033, 034) contain between 6 and 46 gold grains and this area is underlain by metasandstones and metasiltstones of the Goldenville Group (Green Harbour Formation).

The highest number of gold grains (161 grains/10 kg) is in sample 22MPB050, 13 km northeast of the Brazil Lake area (Fig. 2) and within the former Kemptville gold district (Malcom, 1976; O'Reilly, 2003; Goodwin, 2006; Stea, 2012). This sample also contained one >0.5 mm (gold + quartz) particle (Fig. 19). Gold grains in till sample 22MPB050 range in size from 15 to 150 µm, with most grains between 15 and 50 µm in diameter (Appendix C7 Detailed VG worksheet) and are mostly pristine in shape, i.e. short distance of glacial transport (DiLabio, 1990).

Goodwin (2006) collected five surface till samples in 2005 in the same general area as sample 22MPB050. Goodwin's samples were processed at the same heavy mineral lab as the current till samples (ODM) and using the same methods, thus the older gold grain abundance data are directly comparable with the results of this study. The raw gold grain counts, sample weights and values normalized to 10 kg for the 2005 till samples are reported in Appendix B4 and plotted in Figure 20. The gold grain abundances in till in this small area south of Kempt Back Lake varies from 28 grains north of the former gold workings to 659 grains 500 m to the south. The gold grain abundance in our sample 22MPB050 is similarly elevated.

Pebble lithology data

Pebble lithology data are reported in Appendix G1. Surprisingly, the pebble lithologies in the >8 mm fraction of till samples directly reflect the underlying bedrock geology. This similarity between bedrock and till suggests little to no distal source contribution, with 20 of the 30 samples having a 100% local bedrock sources. The remaining 10 till samples have a greater than 98.5% local source.

A handheld UV light was used to identify potential spodumene and tungsten-bearing minerals. Note that spodumene can fluoresce bright orange under UV light. Unfortunately, pebbles in the >8 mm, 4-8 mm, and 2-4 mm fractions did not fluorescence under long- or shortwave light. The lack of fluorescence does not mean that spodumene is not present in the till samples, as not all species of spodumene will fluoresce. An absence of fluorescence is also true for the several spodumene-bearing bedrock hand samples from the Brazil Lake pegmatite—no fluorescence. The UV light also failed to identify any tungsten-bearing minerals (e.g., scheelite) in any of the pebble fractions.

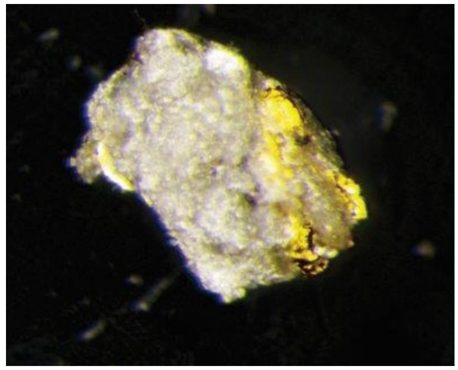

Figure 19. Photograph of large (0.5 mm wide) gold + quartz particle recovered from the 0.25-0.5 mm heavy mineral fraction of till sample 22MPB050. Photograph provided by Overburden Drilling Management Limited.

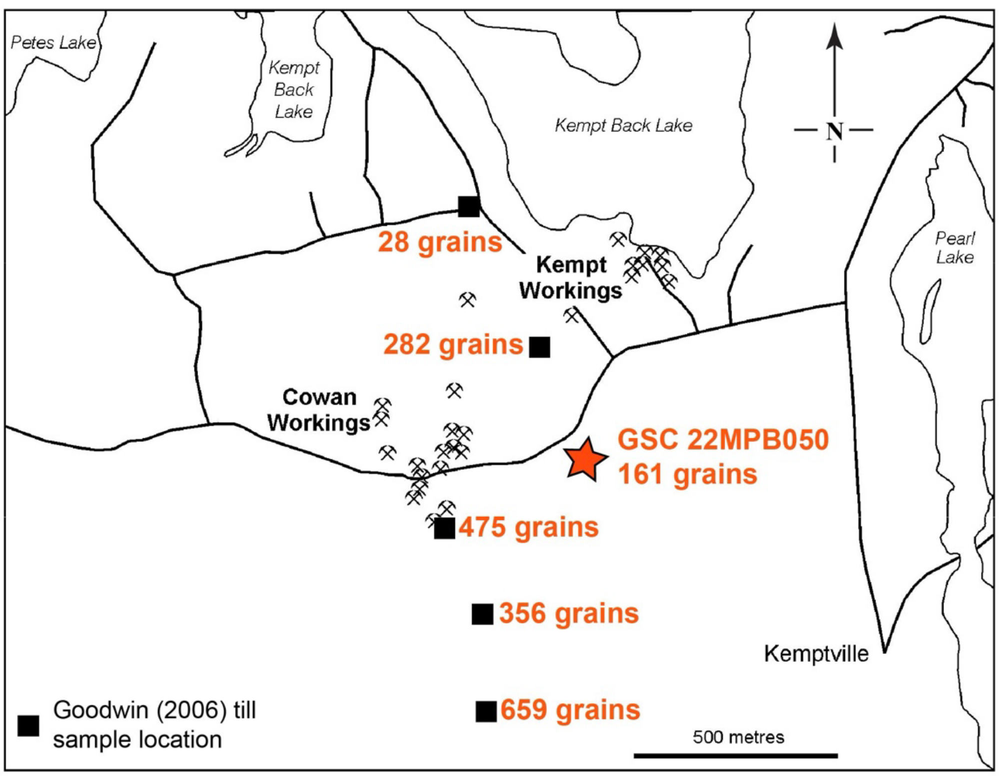

Figure 20. Enlargement of inset map in top right corner of Figure 2 (red box) showing location of the Kemptville District gold workings south of Kempt Back Lake. Black squares indicate the location of five till samples that were collected by Goodwin in 2005 and processed to recover gold grains. Red star indicates the location of GSC till sample 22MPB050 collected as part of the current study. The number of gold grains recovered from each till sample and normalized to 10 kg (table feed) are reported as red text. Map is modified from Goodwin (2006).

Overall, 15 distinct pebble lithologies were distinguished along with vein quartz and spodumene. Of the 15 lithologies, 14 were assigned to a 'basement' group, formation, and some down to a member level (Table 2).

Goldenville Group lithologies
All the samples collected overlying the Goldenville Group (Green Harbour Formation) contain abundant grey, very fine- to fine-grained metasandstone and metasiltstone which accounts for 75 to 97% of the clasts. Although a rather monotonous lithological package, the rock types are easily recognized in the field and hand specimens. Samples 22MPB024, 027, 051, and 21DB037 contain blocky, subangular to subrounded metasandstone and grey, tabular, subangular to subrounded, metasiltstone (Appendix G2-Photo 1-bottom row). No till samples were collected over the Church Point Formation (Goldenville Group) exposed farther to the north (Fig. 2).

Samples 22MPB029, 030, 032, and 21DB041 contain a similar abundance of metasandstone clasts, however, they typically lack metasiltstone clasts and the shape of the metasandstone clasts vary from blocky to tabular, and are typically angular (Appendix G1) and some display a cataclastic texture with brown carbonate-filled fractures (Appendix G2-Photo 1-top row). These four samples form a northeast-trending linear distribution marked by a string of lakes that are subparallel to the trend of the Chebogue Point shear zone (Fig. 2). Based on the texture of these metasandstone clasts and the linear orientation, it is interpreted that these samples are sourced from a previously unrecognized fault in the Green Harbour Formation.

Samples 21DB023, 040, 047, and 22MPB011, 017 were collected over the Green Harbour Formation and Acacia Brook Formation (Halifax Group) and lie within a 2 km wide, northeast-trending belt adjacent to the Rockville Notch Group (Fig. 2). These samples contain grey, very fine- to fine-grained blocky, subangular to subrounded metasandstone and tabular, subangular to subrounded metasiltstone in a close to 50/50 split. These clasts accounts for 18 to 32% of the total clasts (Appendix G1), with the remainder of the clast population derived from the schistose rocks of Rockville Notch Group. Overall, there is a decrease in the source of metasandstone clasts of the Green Harbour Formation towards the northwest.

Other till samples which contain a noticeable amount of Goldenville Formation metasandstone and metasiltstone clasts include 21DB020, 21DB042, and 22MPB049. These samples contain grey, very fine- to fine-grained blocky, subangular to subrounded metasandstone and tabular, subangular to subrounded metasiltstone in a close to 50/50 split which accounts for 12 to 21% of the clasts (Appendix G1). However, these samples lie well within the Government Brook Member of the Rockville Notch Group (Fig. 2) and based on ice flow patterns should not have sourced the metasandstone units in the Green Harbour Formation exposed to the east. Hence, a more conceivable assumption is that these metasandstone clasts are derived from the Church Point Formation (Goldenville Group) exposed farther north in the Brazil Lake area.

Rockville Notch Group and Brenton Pluton lithologies
Most of the samples collected over the Rockville Notch Group (21DB020, 026, 027, 042, and 22MPB009, 023, 035, 037, 038, 040, 043, 045, 046, 049) overlie the Government Brook

Member of the White Rock Formation with one sample (22MPB015) in the Acacia Brook Formation (Fig. 2). With the notable exception of the samples 21DB020, 042, and 22MPB049 cited above, the remainder of the samples contain clasts that are 100% locally derived from the Government Brook Formation (Appendix G1).

Almost every sample has abundant clasts of (1) grey to rust brown, tabular to elongate, subangular, muscovite-biotite phyllite/schist, (2) light grey to white, subrounded, fine-grained, metasandstone, and (3) grey, blocky to elongate, subrounded to rounded, metasiltstone (Appendix G1; Appendix G2- Photos 2a, b, c). These three lithologies account for 59 to 91% of the clasts. Clasts have a unique mineral assemblage indicative of a source rock metamorphosed to amphibolite facies. Many of the clasts contain porphyroblasts of staurolite that range from 5 mm to >4 cm and garnet (< 1mm). The underlying Government Brook Formation contains similar if not identical mineral assemblages and lithologies (White and Barr, 2017). In addition, the grade of metamorphism in the Government Brook Formation drops to greenschist facies with chloritoid-bearing rocks towards the east (White and Barr, 2017). Clasts of these lithologies are also noted in these samples.

No kyanite- or sillimanite-bearing pebbles in the >8 mm fractions were observed. In fact, no kyanite or sillimanite grains were present in the 4–8 mm and 2–4 mm fractions. This is not surprising because the underlying bedrock units did not reach that high a grade of metamorphism. The highest grade metamorphic mineral present is andalusite (Hwang, 1985; Moynihan, 2003; White and Barr, 2017).

Fine- to coarse-grained, black to grey-black, elongate to blocky, angular to subrounded, amphibolite clasts are also abundant in these samples and range in abundance from 3 to 38% (Appendix G1; Appendix G2-Photo 3). The finer-grained amphibolite clasts represent metamorphosed mafic volcanic rocks, typically displaying amphibole crystals oriented in a uniform direction (lineated) whereas the coarser grained varieties represent either dioritic or gabbroic dykes (now sills) or basaltic flows. All these amphibolitic lithologies are widespread throughout the Government Brook Formation and associated with the Brazil Lake pegmatites (c.f., Kontak, 2004; Kontak et al., 2005).

Also of note is that many of the pebbles appear to be striated. This is a structural feature from the basement rocks and not glacial in origin. Most of the underlying Government Brook Formation lies within a major, relatively high-grade metamorphic shear zone. The rocks are typically strongly foliated (banded on a mm-scale) and lineated with elongate metamorphic minerals (amphibole, staurolite, and andalusite). Many of the thin bands are mica-rich and easily weathered compared to the adjacent quartzofeldspathic laminations which can leave an apparent 'groove' on the pebble.

Almost every till sample, including those over the Goldenville Group, contains minor (<7.5%) clasts of quartzite, volcaniclastic and coherent lava flow units ranging in composition from basaltic to rhyolitic, and plagioclase porphyry (9–12, Table 1). These clasts tend to be blocky and rounded, and appear to have travelled some distance, however, these are all common lithologies found within the White Rock Formation, and particularly the Government Brook Member.

A significant number (46 to 59%) of pale, well foliated, blocky to tabular, subangular, fine- to medium-grained monzogranite pebbles is present in samples 22MPB004 and 22MPB026 (Appendix G1; Appendix G2-Photo 4) mostly because the till samples were collected on or adjacent to the Brenton Pluton (Fig. 2). In addition, sample 22MPB032, collected about 2 km to the east of the pluton, contains up to 23% of similar monzogranite clasts. However, the difference between these samples and those collected over the pluton is that the former samples also contain abundant Government Brook Formation clasts, whereas the latter samples have abundant Green Harbour Formation clasts. Six other samples scattered throughout the sample area contain trace amounts (<2%) of monzogranite clasts that look similar to the Brenton pluton.

Pegmatite and Spodumene

As noted above, pegmatite and spodumene-bearing pegmatite dykes/sills are associated with the Brenton Pluton and Rockville Notch Group, respectively. Based on the field mapping and follow-up studies, no pegmatite dykes/sills were observed in the adjacent Acacia Brook or Green Harbour formations of the Goldenville Group (White 2012a, b; White and Barr, 2017), White et al. 2018).

Pegmatite clasts and spodumene grains in the >8 mm till fraction are not common (Appendix G1). The pegmatite clasts are typically pale, blocky, and subangular and, where present, represent <1% of the total clasts. The two samples that contain close to 1% are 21DB026 and 21DB 027 overlying the Government Brook Formation and appear to be down-ice from the known pegmatite locations. The pebbles consist of coarse-grained K-feldspar and quartz ± plagioclase. Some clasts are single crystals/grains that likely represent a pegmatitic origin.

What are believed to be spodumene grains have been recovered from a few of the >8 mm fractions from samples 22MPB043, 22MPB 045, 22MPB 046 (Appendix G2 Photo 5), and 21DB023. The grains are cream-coloured, tabular with a bladed appearance and angular. Samples 22MPB043, 22MPB045, and 22MPB 046 are very close to the Brazil Lake spodumene-bearing pegmatite outcrops (Fig. 10) and spodumene fragments were noted in the till where these samples were collected (Brushett et al., 2024). However, sample 21DB023 is 2 km southeast (Fig. 2) of the pegmatites and overlies the Green Harbour Formation.

It should be noted that during the first pass examination of spodumene grains from the >8 mm fraction, potential spodumene clasts could easily be confused with K-feldspar grains. Both minerals have a similar cleavage and cream colour. The use of a pXRF was helpful in distinguishing the two minerals but in some cases (i.e., sample 21DB023), the pXRF analysis was inconclusive. This may be due to inclusions in the grain that ‘dilute’ the analyses.

Vein Quartz

Clasts of light grey to milky-white to translucent, angular to rounded quartz grains are present in every sample, up to 6% (Appendix G1). Some of the quartz in samples collected from down ice of the spodumene-bearing pegmatite locations are likely sourced from the pegmatite but others, especially from samples in the Goldenville Group, are likely sourced from quartz veins. The rounded quartz clasts are probably sourcing a distal area. It should be noted that quartz veins are abundant in all units in southwestern Nova Scotia and on their own not useful in provenance studies.

Fine-Grained Granite
Pink to grey, elongate to blocky, subangular, fine-grained granite clasts are not common. However, in samples where they are present, they can reach up to 1.6% of the clast population (Appendix G1). No such granitoid rock is present in the local area and hence the source is more likely to be distal. Given that all the other clasts are of local origin, it is probably the case that these granitoid rocks are local as well.

Spodumene in 2–4 mm and 4–8 mm fractions
The 2–4 mm and 4–8 mm fractions of each till sample contained 1000s of grains and very few spodumene grains were recovered (Appendix G1 worksheet 2; Appendix G2- Photo 5). Similar to the spodumene grains in the >8 mm fraction, it was difficult to distinguish spodumene from the feldspar. Based on the bladed crystal habit, some spodumene grains were identified and distinguished from the feldspar using the pXRF. However, because of the small sizes of the grains, obtaining a representative pXRF analysis was an issue.

2–4 mm and 4–8 mm fractions (other minerals)
Present in both size fractions were jet black glassy-textured, prismatic minerals that displayed a conchoidal fracture on the broken surfaces. Initially, these grains were thought to be tantalite because they lacked striations on the cleavage planes which is typical of tourmaline. Although the pXRF does not analyze accurately for Ta or Nb, it can used to test the abundance of other elements typical of each tantalite and of tourmaline. Running the Omnion software function on the pXRF shows that several of these black crystals contain about 31 wt.% SiO_2, 36 wt.% Al_2O_3, and 12 wt.% Fe_2O_3 (tantalite does not contain, SiO_2 or Al_2O_3) hence, these grains are likely tourmaline. Also of note is the elevated Zn content in these tourmaline crystals, which can be up to 1000 ppm.

Tourmaline has been observed in the Brazil Lake pegmatites (Kontak, 2004; Kontak et al., 2005) and it should therefore not be surprising that was recognized in the till fractions. However, it is abundant in the 4–8 mm fraction of sample 21DB023 and the 2–4 mm fraction of sample 22MPB011 (Appendix G2- Photo 6). Both samples are 2.5 to 3.0 km south of the known Brazil Lake pegmatites. Unfortunately, tourmaline was not recognized early-on in the picking process as efforts were focused on identifying spodumene crystals/grains in the smaller fractions. Hence, there could be significantly more of these grains in the till. A preliminary scan shows that tourmaline grains may be present in the 2–4 mm fraction in till samples 22MPB004, 009, 011, 017, 023, 024, 035, 037, 043, 045, and 046.

DISCUSSION
The aims of this study were to investigate effective methods for Li exploration in glaciated terrain, including indicator mineral methods, and to identify cost effective methods for Li exploration.

Size fraction comparison
Three size fractions were investigated in this study: 1) 0.25-0.5 mm fraction, the most common size fraction examined when indicator mineral methods are used for mineral exploration (McClenaghan and Paulen, 2018; McClenaghan et al., 2020, 2023c); 2) 0.5-1.0 mm fraction; and

3) 1.0–2.0 mm fraction. An impetus for examining coarser size fractions is Black's (2012) report of a south-trending 1.2+ km dispersal train of spodumene grains in the >2 mm fraction of till south of the combined area of Brazil Lake-Army Road pegmatites (Fig. 21). In our study, abundance is greatest in the smallest size fraction examined, the 0.25-0.5 mm fraction.

Density fraction comparison

Two mineral density fractions were investigated in this study: 1) 2.8-3.2 SG fraction; and 2) >3.2 SG fraction. Two fractions were investigated because spodumene has a specific gravity of 3.1 - 3.2, which means that it should be most abundant in the 2.8-3.2 SG fraction but could also be present in the >3.2 SG fraction. In addition to spodumene, apatite (3.16 - 3.22 SG) and tourmaline (dravite-schorl; 3.18 - 3.2 SG) have similar SG ranges and thus could be recovered in both density fractions. As expected spodumene, apatite, and tourmaline are most abundant in the 2.8-3.2 SG fraction. If both density fractions of the 0.25-0.5 mm are compared side by side (Fig. 22), it is readily apparent that the spodumene dispersal patterns are similar but most obvious and well developed for the 2.8-3.2 SG fraction. In future till sampling programs for Li exploration, ODM recommends heavy liquid separation be carried out at S.G. 3.0-3.2 in order to optimize spodumene recovery and eliminate some of the lighter minerals which resemble spodumene or apatite.

Spodumene dispersal fan

The threshold between background and anomalous concentrations of spodumene in till is zero grains. Any spodumene grains in a till sample are significant. Spodumene abundance is highest in a central corridor trending southward from the Brazil Lake pegmatites for 12 km (Fig. 22a). However, the overall pattern of spodumene dispersal is fan-shaped (see pink polygon in Figure 23a. The central core of the fan (0.25-0.5 mm 2.8-3.2 SG) contains the highest concentrations of spodumene and is oriented southward along the trend of the dominant and most vigorous (erosive) ice flow phase. The fan geometry is interpreted to be the net result of three phases of ice flow (Fig. 6; southeast, south, and southwest) eroding, transporting, and depositing glacial debris from the Brazil Lake pegmatites, the Army Road pegmatite, and possibly other unknown LCT pegmatites in the local area.

Comparison to other heavy mineral studies

Over the past 60 years, exploration for LCT pegmatites in glaciated terrain has been initiated and guided by the presence of pegmatite boulders (e.g. Schultz, 1971; Nikarinnen and Björklund, 1975; Steiger, 1977; Sarappää et al., 2015; Barros et al., 2022), including those found around the Brazil Lake pegmatites. In contrast to commodities such as Cu, Pb, Zn, and Au (e.g. McClenaghan and Paulen, 2018 and references therein), only a few case studies have been conducted to evaluate the effectiveness of indicator minerals for Li exploration (Table 4). These case studies include those reported by Nikkarinen and Björklund (1975) and Hodder and Martins (2023), and studies around the Brazil Lake pegmatites (Black, 2012; Fig. 21). For all these studies, the highest spodumene abundances in till are summarized in Table 4 to allow for comparison with results of our recent Brazil Lake study. In our study, the highest spodumene count in a single till sample is 2212 grains/10 kg.

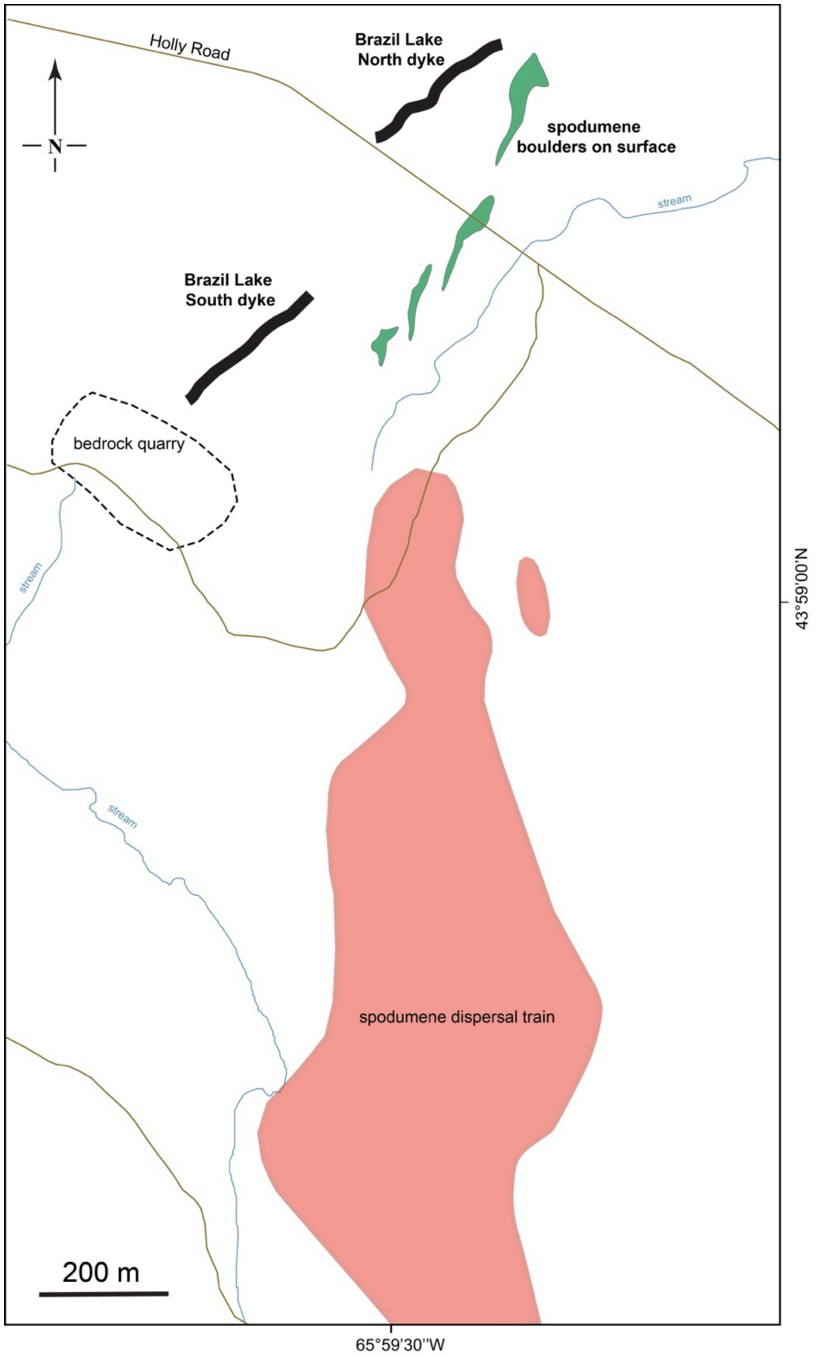

Figure 21. Outline of spodumene dispersal train reported by Black (2012) in Brazil Lake area. Spodumene grains were identified in the >2 mm fraction of large bulk till samples in nine sample pits. Modified from Black (2012).

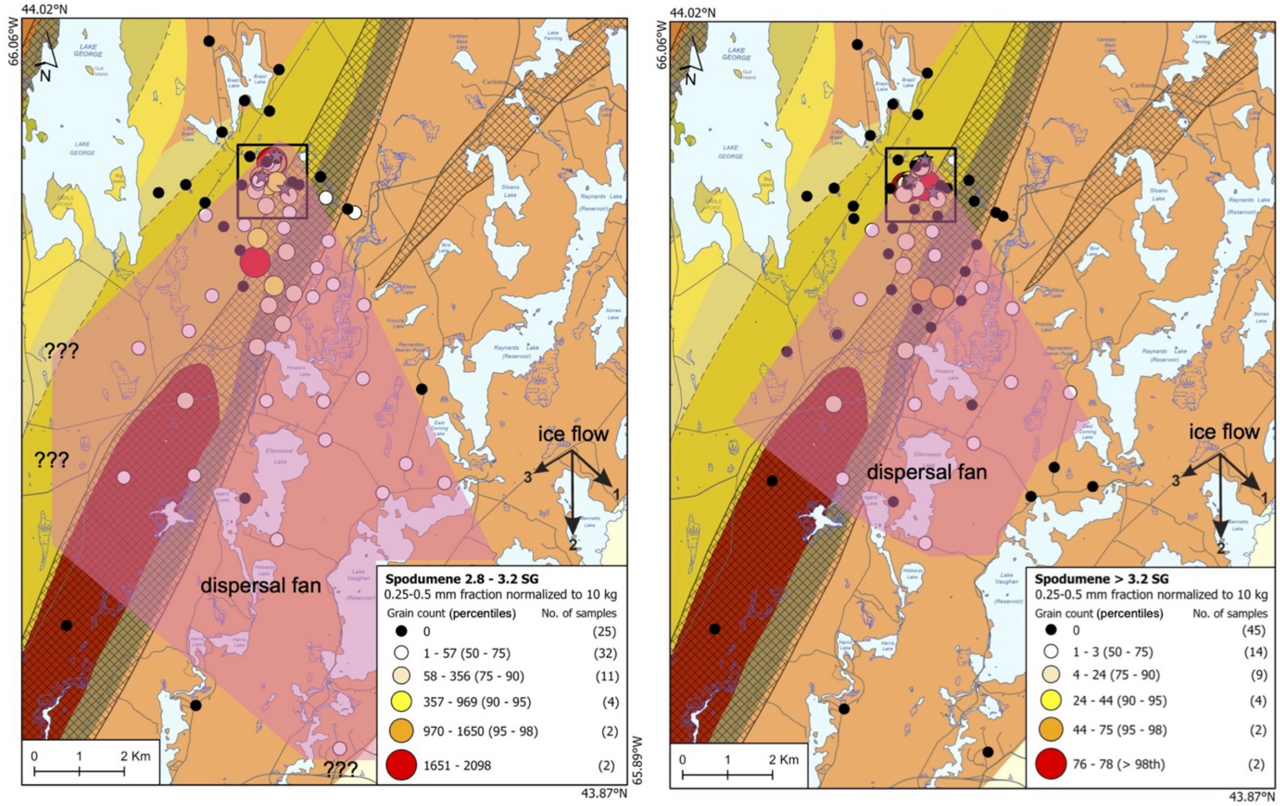

Figure 22. Comparison of proportional dot maps of spodumene grain abundance normalized to 10 kg (table feed) in the 0.25-0.5 mm fraction of till: a) 2.8-3.2 SG fraction, and b) >3.2 SG fraction. Interpreted dispersal fans are highlighted in pink. Gray stars indicate the location of the Brazil Lake pegmatites (western most stars) and the Army Road pegmatite (eastern most star). Bedrock geology legend shown in Figure 2. Black arrows in bottom right corner indicate regional ice flow phases, 1= oldest.

Table 4. Spodumene concentrations reported for other till indicator mineral studies compared to the concentrations reported in this study.

Location	Country	Source of information	Sample weight	Size fraction	Density (specific gravity, SG) fraction	Highest spodumene grain abundance per sample	Indicator minerals
Brazil Lake, Nova Scotia	Canada	this study	10 kg	0.25-2.0 mm	2.8-3.2 SG	2212	spodumene, apatite, tourmaline, cassiterite, sphalerite, scheelite
Brazil Lake, Nova Scotia	Canada	Black, 2012	unknown	>2 mm	NA	>1000	spodumene
western Finland	Finland	Nikkarinen and Björklund, 1975	200 g	0.15-0.25 mm	2.8-3.2 SG	>20	spodumene
southeast Manitoba	Canada	Hodder and Martins, 2023	10 kg	0.25-2.0mm	2.8-3.2 SG	35	spodumene

NA not applicable

Comparison to till geochemistry

Figure 23 compares the spodumene abundance in the 0.25-0.5 mm 2.8-3.2 SG fraction with the strongest, most obvious glacial dispersal fan reported for Li (ppm) concentration in till as reported by Brushett et al. (2024). Glacial dispersal of spodumene from the Brazil Lake pegmatites is detectable in a fan-shaped pattern at least 12 km down ice (south of Lake Vaughan reservoir; Fig. 23a pink polygon). In comparison, glacial dispersal from the Brazil Lake pegmatites is detectable using Li content in the till matrix in a narrower and shorter fan-shaped pattern up to 5 km down ice (Fig. 23b pink polygon).

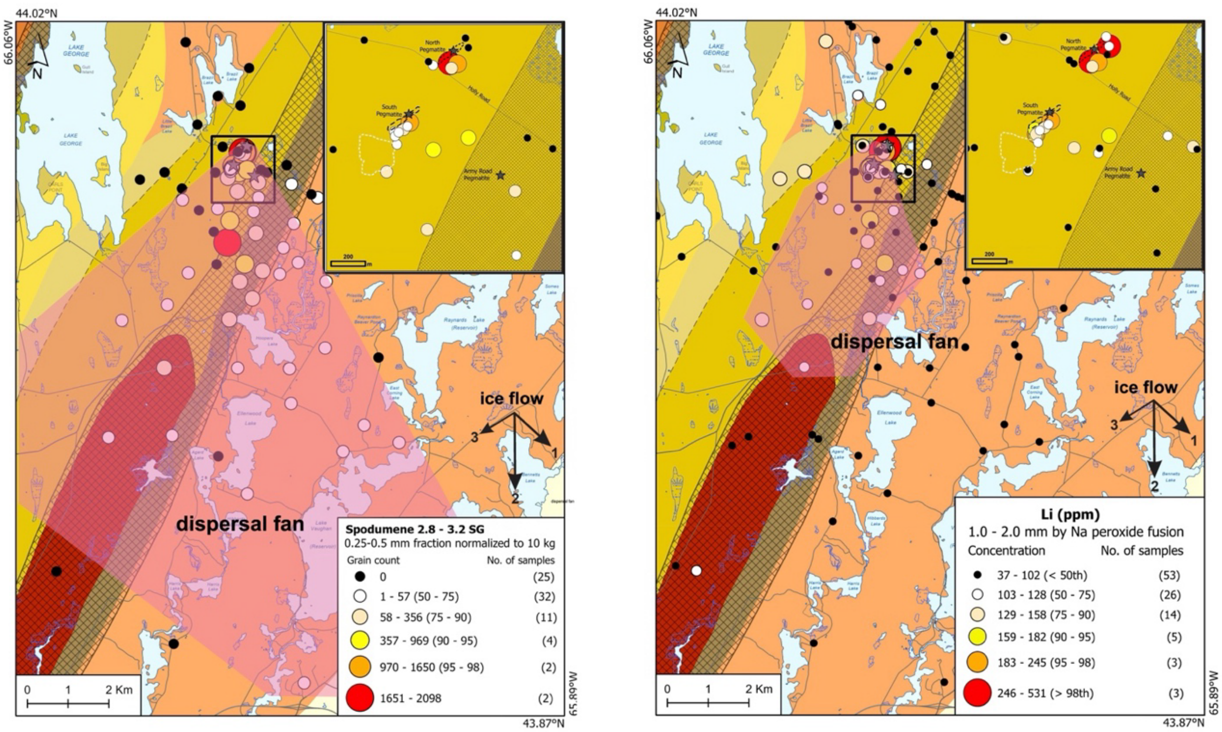

Figure 23. Comparison of proportional dot maps and interpreted dispersal fans (pink polygons) of: a) spodumene abundance in the 0.25-0.5 mm 2.8-3.2 SG fraction of till samples (N=76) normalized to10 kg (table feed); and b) Li concentration in the 1.0–2.0 mm till fraction analyzed using Na-peroxide fusion followed by ICP-MS (N=104), and using dot size thresholds from Figure 14b in Brushett et al. (2024). Bedrock geology legend is shown in Figure 2. Black arrows in bottom right corner indicate regional ice flow phases, 1= oldest.

Gold potential

Gold grains in till samples south and east of the Brazil Lake pegmatites and overlying Goldenville Group rocks (Green Harbour Formation) rocks indicate the area has potential to host gold mineralization. This is not unexpected since sample 22MPB050, purposely collected within in the heart of the known Kemptville Gold District, contains abundant gold grains. What is unexpected is the anomalous gold grain abundances in till samples to the southwest of the Kemptville Gold District, along the strike of the Kemptville shear zone and overlying the same favourable rock units. The high quantity of gold grain in till are accompanied by elevated pyrite and goethite abundances. The anomalous gold grain abundance in sample 22MPB050 is in the same area as the anomalous gold grain content in five till samples reported by Goodwin (2006) and a gold grain dispersal train reported by Stea (2012; inset map in Figure 2). Stea's gold dispersal train extends at least 3 km south from the former gold workings (yellow lines in Figure

24) on the south side of Kempt Back Lake (yellow lines in Figure 24). Till sample 22MPB050 is near the head of the train. The presence of such an obvious dispersal train indicates the gold-rich nature of the local bedrock and the usefulness of heavy mineral methods for detecting Meguma-style gold mineralization. It is worth noting that the Brazil Lake pegmatites and Kemptville gold district occur close together. Others have observed similar close spatial associations between LCT pegmatites and orogenic gold deposits in/near major bedrock structures (T. Cawood, pers. comm., 2024).

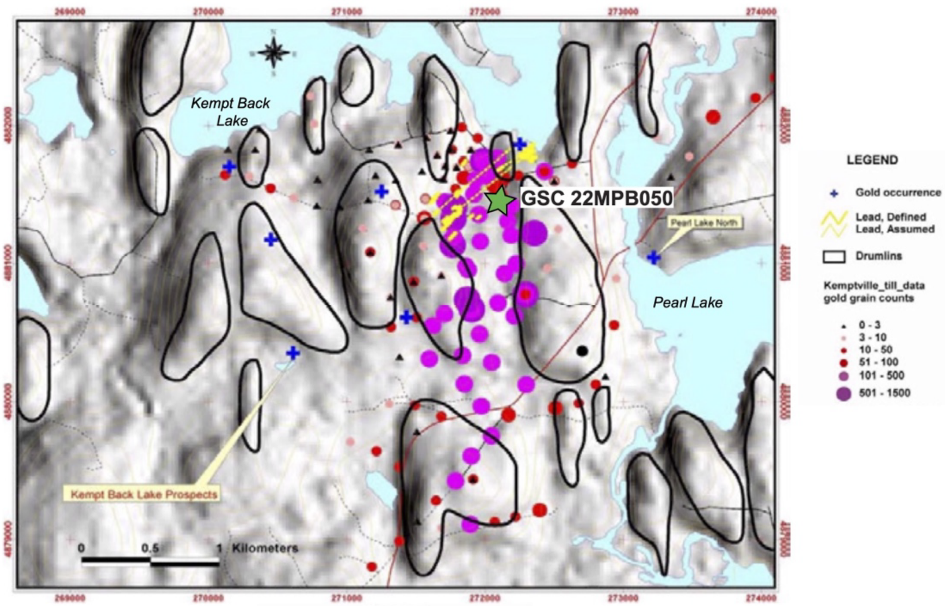

Figure 24. Enlargement of inset map in top right corner of Figure 2 (black box) showing location of the Kemptville District gold workings south of Kempt Back Lake. Stea (2012) reported a south-trending glacial dispersal train of gold grains in till (pink proportional dots) from gold workings (yellow lines) in the district. Data are plotted on a digital DEM with drumlins outlined in black. Gold grain abundances were determined using different methods from those used by GSC, therefore results are not directly comparable. The location of GSC till sample 22MPB050 is shown as a green star. Modified from Stea (2012).

Future work

This GSC publication is the second of two GSC reports to publish data from the Brazil Lake till study. The first report (Brushett et al., 2024) described the geochemistry results for till samples collected around the pegmatites. Mineral chemistry and lithium isotope signatures will be determined for selected 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 erosional depositional records of southwestern Nova Scotia.

CONSIDERATIONS FOR LITHIUM EXPLORATION

Although drift prospecting for Li-pegmatites is not new, it has garnered a resurgence of interest due to the demand for battery metals. Our study presents the first detailed investigation of the indicator mineral (this report) and geochemical (GSC Open File 9148) signatures of an LCT pegmatite in till. Understanding glacial flow paths and glacial transport are the two key aspects of understanding any glacial dispersal trains/fan. In this study, the orientations of the streamlined glacial landforms combined with till fabric data are the key indicators of ice flow directions. Spodumene is the key indicator of glacial transport direction and distance.

• **Indicator minerals:** The presence of spodumene grains in till is visual confirmation of the presence of an LCT pegmatite. The grains may be examined in detail, photographed, and chemically analyzed. In contrast, till geochemistry alone cannot be relied on to indicate the presence of a Li-bearing pegmatite because the Li could be derived from Li-rich mica or clays not related to a LCT pegmatite. At Brazil Lake, background abundance of spodumene in till is zero grains and thus the presence of just one spodumene grain in a 10 kg till sample is significant; this is the equivalent to ppb-level geochemical analyses. Glacial dispersal of spodumene from the Brazil Lake pegmatites forms a broad fan-shaped exploration target (12 km down ice) that is longer and wider than that defined by till matrix geochemistry. Additional indicator minerals of the Brazil Lake pegmatites in till samples include columbite-tantalite, apatite, tourmaline, cassiterite, and scheelite.

Table 5 (below) summarizes the indicator minerals and pathfinder elements for the Brazil Lake pegmatites and nearby Army Road pegmatite. Both methods should be used together to explore for LCT pegmatites in glaciated terrain.

Table 5. Comparison of indicator mineral and trace element signatures of LCT pegmatites in the till samples from the Brazil Lake area.

Pegmatite	Indicator minerals in till	Elements in till (Brushett et al., 2024)
Brazil Lake North Dyke	spodumene, apatite, tourmaline, cassiterite, scheelite	Li, Be, Cs, Nb, Rb, Ta, W
Brazil Lake South Dyke	spodumene, apatite, tourmaline, scheelite	Li, Be, Cs, Nb, Rb, Ta, W
Army Road	spodumene, apatite, tourmaline	Li, Cs, Rb, Sn, Ta

• **Mineral density:** Indicator minerals in two density fractions of till were examined in this study: 1) 2.8-3.2 SG; and 2) >3.2 SG. Spodumene, apatite, and tourmaline have a combined density range of 3.1-3.22 SG and thus examination of this mid-density fraction, in addition to the routinely used >3.2 SG fraction, is essential when exploring for LCT pegmatites. In future Li exploration programs, ODM recommends heavy liquid separation be carried out at S.G.3.0-3.2 in order to optimize spodumene recovery and eliminate some of the lighter minerals which visually resemble spodumene or apatite.

• **Size fraction:** Spodumene is most abundant in the smallest (0.25-0.5 mm) size fraction of till that is visually examined. To reduce time and cost, only this one size fraction could be recovered for Li exploration. Till samples immediately down ice of the pegmatites contain 100s to 1000s of spodumene grains per 10 kg sample in this size fraction.

• **Sample spacing and orientation**: Given the small size of the pegmatites (up to 21 x 700 m for the larger North Dyke) and the three phases of ice-flow, indicator mineral sampling could be conducted along parallel lines spaced 500 m or greater apart and oriented perpendicular to the dominant ice-flow direction.

• **Till facies**: Two till facies were observed in the study area and both are suitable for till sampling for geochemistry. The first is a silty sand till that has moderate to high compaction, subhorizontal fissility with visible jointing, angular to subrounded local bedrock clasts, and numerous striated and faceted clasts. This is a 'subglacial traction till', a term that has superseded the older commonly used term ‘subglacial lodgement till’ or 'basal till'. A second till facies that often occurs as a thin (< 2 m) unit on the drumlin flanks is sandier, stonier, less indurated, less compact, contains well-sorted lenses and layers of sand, and has more monolithic clasts lithologies. This is a subglacial meltout till, and is a term not be to confused with ‘ablation till’, which actually does not occur in this area.

CONSIDERATIONS FOR GOLD EXPLORATION

Gold grain anomalies in our till samples just south of the Kemptville shear zone, including the area of the known Kemptville Gold District, indicate that the shear zone is prospective for gold mineralization and that heavy mineral till sampling is a useful method for gold exploration in this region. Additional till sampling along this trend, both southwest and northeast of the Kemptville Gold District, could help to identify new gold exploration targets in the region.

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Two site visits were made to the Brazil Lake pegmatites with First Nation representatives in 2022. GSC and NSDNRR scientists met with Jeff Purdy (Councillor, Acadia First Nation), Greg Hart (NSPI Early Engagement Coordinator, Kwilmu'kw Maw-klusuaqn Negotiation Office), and Patrick Butler (Mi’kmaq Energy & Mines Advisor, Kwilmu'kw Maw-klusuaqn Negotiation Office) to explain the collaborative GSC-NSDNRR research at the site, the geology of the local lithium occurrence, answer questions, and address potential concerns about the impact of the field work. We thank the Acadia First Nation for their interest in the research.

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