Till Geochemistry, Indicator Mineralogy, and Surficial Geology of the Brazil Lake Pegmatite Area, Southwest Nova Scotia, Canada

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Introduction

During the summer and fall of 2020, surficial-geological mapping and till-geochemistry sampling were conducted around the Brazil Lake Li-Cs-Ta-(LCT) pegmatite district in southwestern Nova Scotia (Fig. 1), an area currently being explored for its critical mineral and rare-metal potential (Wightman, 2020). Although LCT-pegmatites occur elsewhere in the Appalachian orogen (Kings Mountain, North Carolina, and Peg Claims, Maine), the pegmatite veins at Brazil Lake are the only known occurrences in Nova Scotia (e.g. Kontak, 2004).

The pegmatites at Brazil Lake, collectively termed the Brazil Lake pegmatites (BLp) are not easily delineated because of their small size, poor geophysical response, and by extensive till cover that limits outcrop exposure. Here, and in much of southwestern Nova Scotia, glacial deposits blanket the region, a product of multiple glaciations throughout the Pleistocene. Thick glacial sediment cover and complex glacial dispersal patterns have made bedrock mapping and exploration for buried mineralization in the region challenging.

Additionally, this region is host to numerous Sn-W and related granophile mineral occurrences, which collectively make up the Southwest Nova Scotia Tin Domain (Chatterjee, 1983). These occurrences are associated with the Devonian-Carboniferous, peraluminous granitic rocks of the South Mountain Batholith (SMB), which intrude and underlie much of southwestern Nova Scotia and include both greisen-hosted Sn ± W ± base and precious metals (e.g. East Kemptville), and metasediment-hosted Sn-Cu-Zn-Pb-In (e.g. Dominique) occurrences. Several of these rare metals (Ta, Li, Be, Cs, Rb, Nb, and Sn) were named to Canada's critical mineral list in 2021 (Natural Resources Canada, 2021).

A detailed till geochemical study was conducted to (1) determine anomalous and background trace element signatures and indicator mineralogy in till, (2) define local geochemical and glacial dispersal patterns, and (3) determine the appropriate sampling protocols and analytical techniques to employ in future till geochemistry surveys. This detailed geochemical study is part of an ongoing regional surficial geological program in southwestern Nova Scotia that included surficial geological mapping, sediment thickness modelling, till fabric and clast lithology analyses, and detailed studies on glacial stratigraphy. The goal of these activities is to better understand the effects of multiple glaciations on till composition, deposition, and glacial dispersal in the region and to assess the potential for additional base- and rare-metal mineralization in the pegmatites and peraluminous granites of the southwestern SMB. The ultimate goal is to develop exploration models that can be applied to areas with thick glacial overburden, such as southwestern Nova Scotia. This study was a collaborative effort between the Geological Survey Division of the Nova Scotia Department of Energy and Mines and the Geological Survey of Canada.

Previous Work

The BLp has been the focus of exploration and petrological studies since it was first identified from pegmatite float in 1960 (e.g. Taylor, 1967) and several surficial geochemical surveys have been conducted since then. In a regional lake sediment study of the Meguma terrane, lakes in the vicinity of the Brazil Lake pegmatites did not show any pronounced geochemical signature in Li, Rb, W, Nb or F (Rogers et al., 1985; 1990). Regional till geochemical surveys by the Department of Natural Resources in the early 1980s did not display any rare metal geochemical signature; however, no samples were taken within 3 km of the Brazil Lake pegmatites and the survey did not

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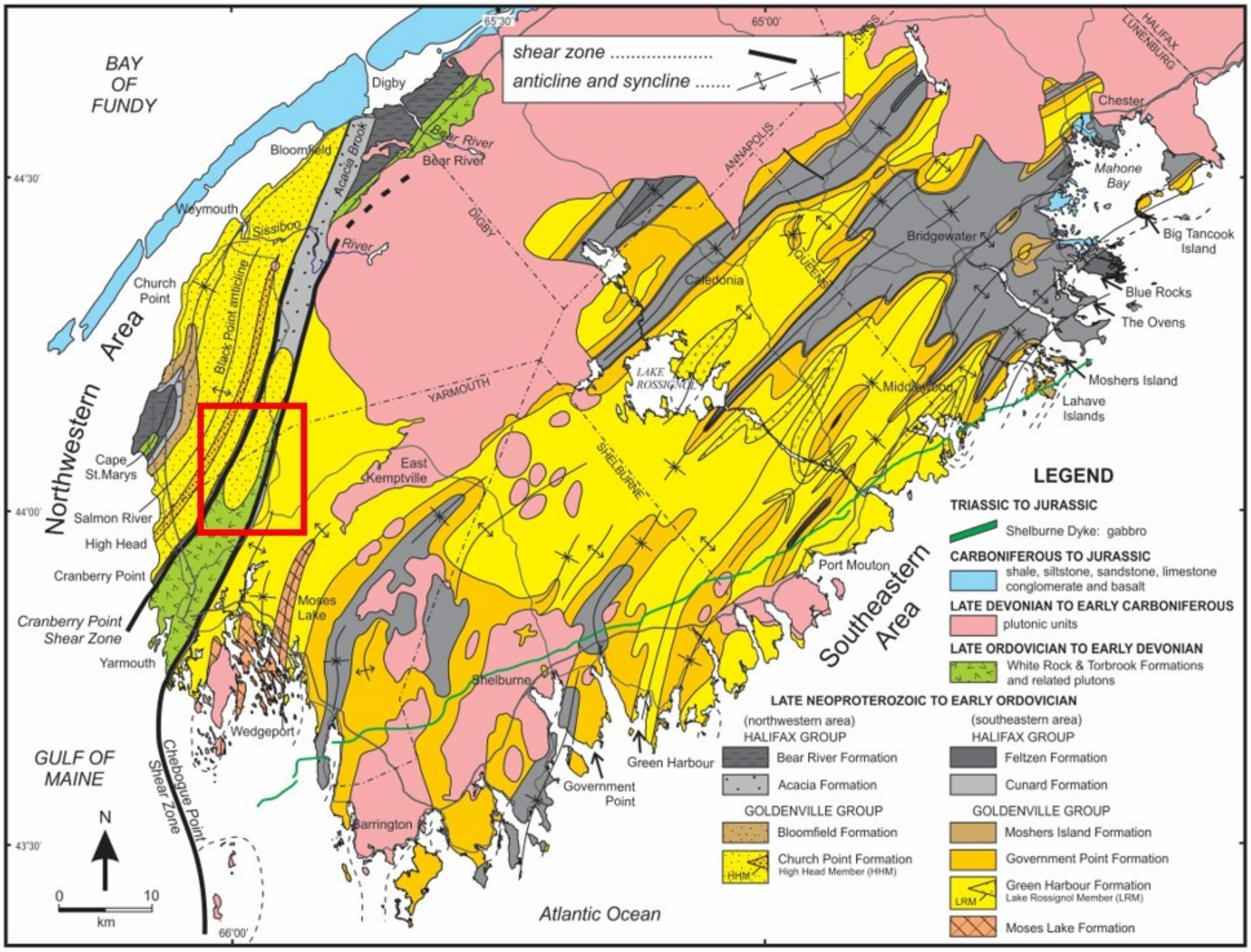

Figure 1. Bedrock geology of southwestern Nova Scotia (modified from White, 2010; White et al., 2012, 2018). Location of study area is indicated by the red box.

analyze for many of the granophile elements that are found to be enriched in the BLp (Stea and Grant, 1982). Elevated levels of Li (≤275 ppm), Cs (≤100 ppm), Sn (≤177 ppm), and Ta (≤95 ppm) were identified in till sampling by Palma et al (1982). A multi-media geochemical study (till, Balsam fir, and humus) over a 600 x 600 m sampling grid (~50 m sample spacing) overlying the BLp by MacDonald et al. (1992), showed elevated but variable geochemical response in several LCT-pegmatite pathfinder elements, including Li, Cs, Ta, P, Sn, Nb, and F. A till orientation survey of the pegmatite area (Lundrigan, 2008) reported anomalous Li (≤777 ppm) overlying the pegmatite and elevated Li up to 400 m southeast, but only in the coarse-grained (1-2 mm) till fraction. No other Li-bearing pegmatite geochemical signatures (Be, Rb, Cs, Nb, Sn, and Ta) were detected in either the fine (63 µm) or coarse fraction.

Geology

Geological Setting

The study area is underlain by rocks of the Meguma terrane, the most easterly component of the northern Appalachian orogen. The Meguma terrane in the area is characterized by a thick sequence of Early 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 et al., 2018). Subsequent deformation and variable metamorphism (greenschist to amphibolite facies) occurred during the Early to Middle Devonian Neoacadian orogeny (ca. 405–365 Ma) resulting in NE- to NNE-trending, upright regional-scale folds. These rocks were intruded by numerous late syntectonic to post-tectonic, Middle to Late Devonian, peraluminous granitic plutons, such as the South Mountain Batholith (SMB; White, 2010); the western edge of which occurs some 20 km east of the Brazil Lake area (Fig. 1).

Geology of the Brazil Lake Pegmatite

The Brazil Lake study area is underlain by the metavolcanic and shallow marine metasedimentary rocks of the Silurian White Rock Formation, which are cut by the BLp and the Brenton Pluton (Fig. 2; White, 2010; White et al., 2018). Rock types within the study area include slate of the Halifax Group, metasandstones of the Goldenville Group, metamorphosed metavolcanic rocks/amphibolite, dark green actinolite gneiss and schist, grey biotite ± garnet ± staurolite phyllite and schist, and fine-grained tourmaline-bearing, buff to white quartzite adjacent to the pegmatite lenses (White, 2010).

The bedrock geology of the BLp is briefly summarized below from Kontak (2004, 2006) and Kontak et al. (2005), and based on studies of two separate NE-trending, steeply-dipping pegmatite sheets, each ≤20–25 m width and extending a few hundred metres in length. Subsequent drilling by Champlain Resources has reported additional pegmatite lenses at depth (Black, 2011). The lensoid morphology is likely due to deformation associated with movement along the regional Chebogue Point shear zone (White 2010; White et al., 2018).

The Brazil Lake pegmatites are an albite-spodumene-type of pegmatite, characterized by abundant coarse spodumene, K-feldspar, quartz, and two varieties of albite occurring as fine-grained, sacchroidal-textured albite or euhedral platy cleavelandite. Muscovite occurs throughout the pegmatite, most of which is of secondary origin and generally associated with albitized zones (Kontak et al., 2003). Accessory minerals include tourmaline, Nb-Ta oxides (columbite and tantalite), garnet, triplite, amblygonite, apatite, beryl, cassiterite, chlorite, carbonate, wolframite, sphalerite, zeolite, zircon, epidote, topaz, biotite, titanite, and phosphate minerals (lithophillite, fillowite, montebrasite and crandallite). Much of the tantalite and apatite are related to the albitized zones (Kontak et al., 2005; Kontak, 2004). The southern pegmatite vein has yielded a U-Pb crystallization age of 378 ± 1 Ma (concordant tantalite) (Kontak et al., 2005).

Pleistocene Geology

The glacial history of southwestern Nova Scotia is largely derived from thick Quaternary sections along the coastal Yarmouth-Digby area, where evidence for four major ice-flow phases and interglacial marine phases have been identified (Grant, 1980; Stea and Grant, 1982). The oldest glacial event, the Northumberland Phase, (marine isotope stage (MIS) 6; ~190-130 ka) is recorded by the Little Brook Till, a grey compact till that occurs locally at the base of coastal sections and contains both local and far travelled clasts (Stea and Grant, 1982; Stea et al., 2011).

Regional southward ice flow from New Brunswick during the Caledonia Phase (~75-50? ka) produced a thick blanket of a distinctive reddish shell-rich till (Red Head Till), which often contains a high percentage of far-traveled till clasts with transport distances of 80 km or more, and generally forms the cores of drumlins (Finck and Stea, 1995; Stea et al., 2011). The following regional Escuminac phase (MIS 2; 25-20 ka) is marked by a shift in ice flow from southeastward (during Caledonia Phase) to southward and southwestward and associated with the hybrid ‘Saulnierville Till’, with basal phase containing predominantly local clast lithologies and an upper phase with far-traveled clasts from the Cobequid Highlands and New Brunswick (Stea and Finck, 2001; Stea et al., 2011).

During the following Scotian phase (~20-17 ka), regional ice centres shifted, and Nova Scotia was cut off from external ice centres due to ice streaming in marine channels (Stea et al., 2011; Shaw et al., 2006). The resultant “Scotian Ice Divide” formed lengthwise down the centre of the province such that ice flow varied from southwest to southeast in southwestern Nova Scotia. The Beaver River Till formed under the Scotian Ice Divide and is characterized by a loose sandy matrix, rubbly texture, and angular clasts that are more than 90% locally derived. Clast fabrics are usually poorly developed due to the loose sandy texture of the till and a lack of elongated clasts. Additionally, the presence of washed zones around

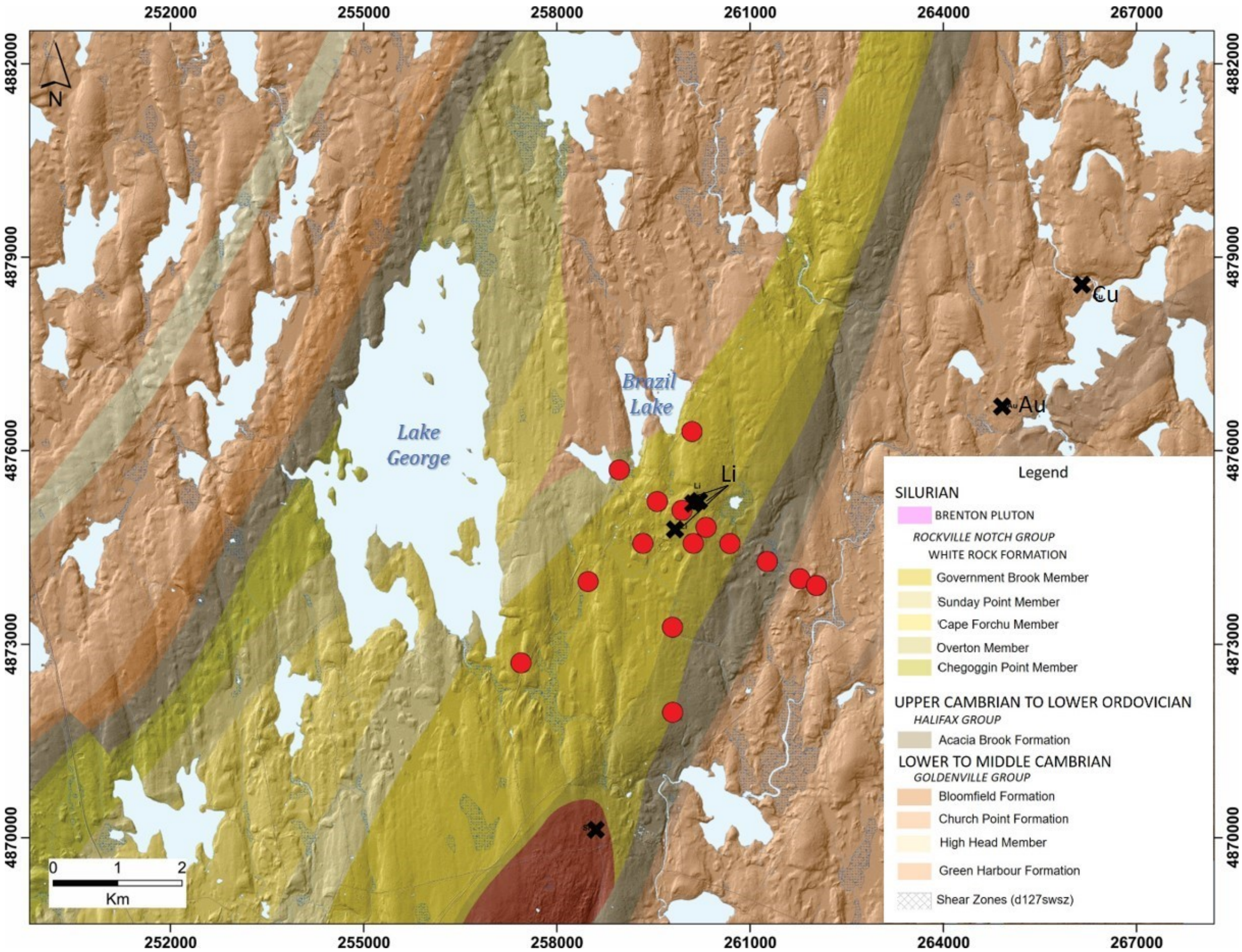

Figure 2. Bedrock geology of the Brazil Lake study area (superimposed on lidar hillshade image) showing the location of till samples collected in 2020 (red dots) and mineral occurrences (black x's). Brazil Lake pegmatites are marked by the Li symbol.

boulders and lenses of washed sediments support an ablation origin (Stea and Finck, 2001; Finck and Stea, 1995).

Methods

Fifteen sites were selected for till sampling at varying distances from the BLp: one site was between the north and south pegmatite veins, two sites were up-ice (north and northwest) of the deposit, and five sites were down-ice (southeast) of the pegmatites (Fig. 2). Till samples were collected from hand-dug holes and roadcuts along local roads averaging 150 cm depth.

In total, 16 till samples were collected from 15 sites following the Geological Survey of Canada till sampling protocols (Spirito et al., 2011; Plouffe et al., 2013). At each site, a small sample (~3 kg) was taken from unoxidized till (C-horizon) for geochemical analysis of till matrix and archiving. One large (~15 kg) till sample was taken for sufficient recovery of indicator minerals. Samples were collected in 6 mm clear plastic bags, secured with cable lock ties, then stored and shipped in 20 L plastic pails. Field data collected at each site included GPS coordinates, general site description, sample description (soil horizon, texture, Munsell colour, clast types, relative percentages of clasts, matrix description [i.e. percent sand, silt, clay] and sample depth), and the description and measurement of any ice-flow indicators.

Till samples were submitted to Bureau Veritas Commodities (Vancouver, British Columbia) for geochemical analyses. For more details on analytical methods see: https://commodities.bureauveritas.com/metals-minerals/exploration-and-mining/geoanalytical-services. Samples were dried and sieved to three sized fractions: -2.0 + 1.0 mm, < 0.063 mm (-230 mesh) silt + clay, and < 0.002 mm clay. These were analyzed by the following methods: aqua regia digest (AQ252-EXT+REE/ ICP-MS), lithium metaborate/tetraborate fusion /nitric acid digest/ ICP-ES, -MS with a full suite of REE (LF200-GSC), and multiacid digest/ICP-ES (MA250).

One large till sample and six bedrock samples of the Brazil Lake pegmatite were submitted to the commercial lab Overburden Drilling Management Limited for processing using a combination of tabling, panning, and heavy liquids to recover potential indicator minerals. All size fractions will be examined for gold, metallic oxide, and silicate indicator minerals. The indicator mineral signatures of mineralized bedrock will be used for comparisons with the mineralogy and geochemistry of the till.

Results to Date

Surficial Mapping

As bedrock outcrops are rare throughout much of southwestern Nova Scotia, an understanding of the surficial geology is critical for drift prospecting. Surficial studies of coastal sections, initiated in the summer of 2020, are ongoing. Here, multiple till units reflect several phases of glacial deposition, and shifting ice-flow directions. These results, including till composition, Quaternary stratigraphy, and clast fabric studies will be included in a future comprehensive report of the region's surficial geology.

To aid in surficial mapping of this area, lidar data and sediment thickness modelling are being used. Lidar data for southwestern Nova Scotia were released in October 2020 through the Nova Scotia LiDAR Acquisition Project, currently funded by the Nova Scotia Department of Lands and Forestry (Forestry Division) and the Department of Internal Services (Geographic Information Services). Lidar data for many areas of the province are now available (and updated as more data are released) through the Nova Scotia Geospatial Infrastructure (NSGI) and their DataLocator application: https://nsgi.novascotia.ca/datalocator/elevation/. Lidar data were processed in house during spring 2021 into hillshade DEMs with multiple illumination angles to avoid azimuth bias.

In general, most of the landscape is covered by till of variable thickness, from thin veneers (<2 m) over the BLp to thick coastal sections and drumlin ridges over 40 m thick (Fig. 3). South- to southeast-trending drumlins are the dominant glacial landform present. Drumlins to the east of the BLp also display more parabolic forms, reflecting more complex ice flow on a local scale. Megaflutings and mega-scale glacial lineations, indicative of faster-flowing ice (i.e. ice streaming) were also identified. Moraines (major and minor), ribbed moraine, ice-thrust ridges, and eskers were also recognized. Together, these landforms exhibit a more complex record than previously recognized. Preliminary comparison of lidar data with previous surficial geological maps show a much greater extent of glaciofluvial deposits and marshlands; these commonly occur in the topographic lows between drumlin ridges and are shown by the flat textures in the lidar data. These observations hold important implications for till geochemical surveys and highlights the importance of using the appropriate sample media as sampling in glaciofluvial deposits should be avoided due to the possibility of sediment reworking, and the difficulty in defining distances and directions of transport.

Sediment Thickness Mapping

Sediment thickness mapping was conducted to aid in surficial geological and surficial aquifer mapping, and further our understanding of the distribution and thickness of surficial sediments across southwestern Nova Scotia. A surficial thickness map was generated using ESRI ArcGIS kriging analysis functions. Depth to bedrock data from four sources were used: The Nova Scotia water well logs database (669 records; NSE, 2019), Nova Scotia Drillholes database (1698 records; O'Neill and Poole, 2016), and bedrock outcrop points from bedrock mapping (6962 records, White et al., 2012), and the surface elevation data extracted from the lidar digital elevation model. Data were filtered to remove georeferencing errors and incorrect geological descriptions.

A preliminary version of this map showing its full extent and for the BLp area is shown in Figure 4. Based on this model, the sediment thickness ranges from 0 to 76 m. Within the BLp area, the thickest sediment occurs in the many drumlin ridges with thicknesses exceeding 40 m. Much of the area between these ridges is characterized by shallow bedrock with a surficial cover less than 5 m; these zones are commonly mantled by glaciofluvial and fluvial sand and gravels. Using this model, areas with lower till sampling suitability and potential

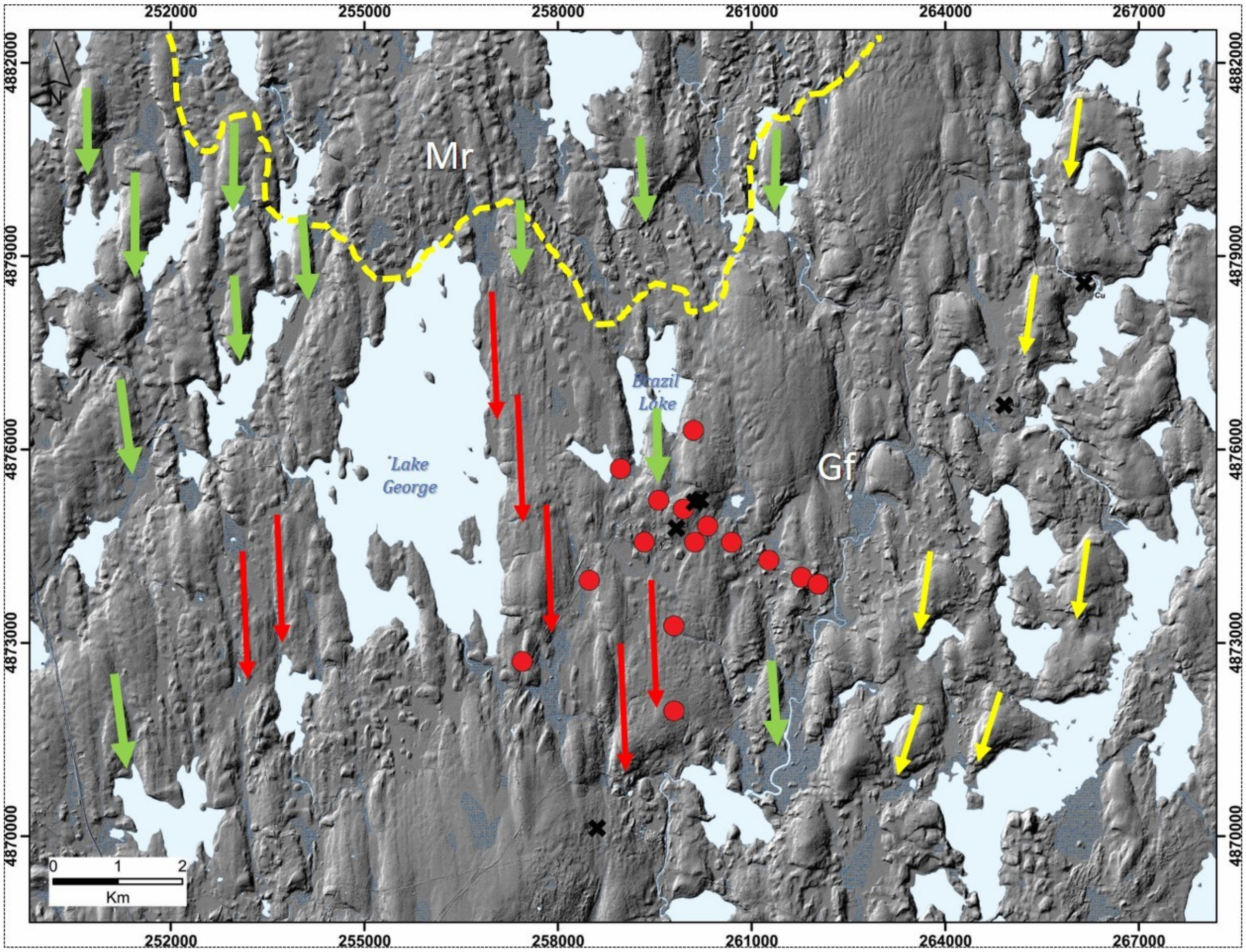

Figure 3. Lidar hillshade image of the Brazil Lake study area (illumination angle of 315°). Till sample locations are indicated by red dots. Mineral occurrences are indicated by black x's. The study area is characterized by S- to SE- trending drumlins (examples indicated by green arrows) and in places transition to more elongate (> 4:1 elongation ratios) megaflutings and mega-scale glacial lineations (examples indicated by red arrows). More parabolic drumlin forms are present to the east of Brazil Lake, reflecting more complex ice flow, including the influence of local southward-flowing ice (yellow arrows). Glaciofluvial (Gf), fluvial and organic materials are common in the topographic lows between drumlins. Areas of moraine and ribbed moraines (Mr) also occur, in places overriding drumlins.

can be identified, and these generally correspond to areas of thickest overburden, where thicker, pre-existing cover may have covered underlying bedrock, inhibiting direct contact and quarrying of mineralized bedrock. Where drift cover over bedrock is thin, till is more likely to be locally derived as a result of glaciers having been in direct contact with the underlying bedrock.

The sediment thickness map will be released as a digital publication. The detailed methodology and applications to surficial aquifer mapping will be discussed in a separate report.

Future Work

Research to date, combined with the availability of new lidar data, has shown that previous interpretations of the glacial history in southwestern Nova Scotia requires significant update and re-interpretation. Geochemical results are expected in spring 2021 and will be used to refine the sampling and analytical techniques to employ in further regional till sampling surveys of the area. These results, together with lidar imagery and sediment thickness modeling, will be used to guide regional- and local-scale till sampling, (till

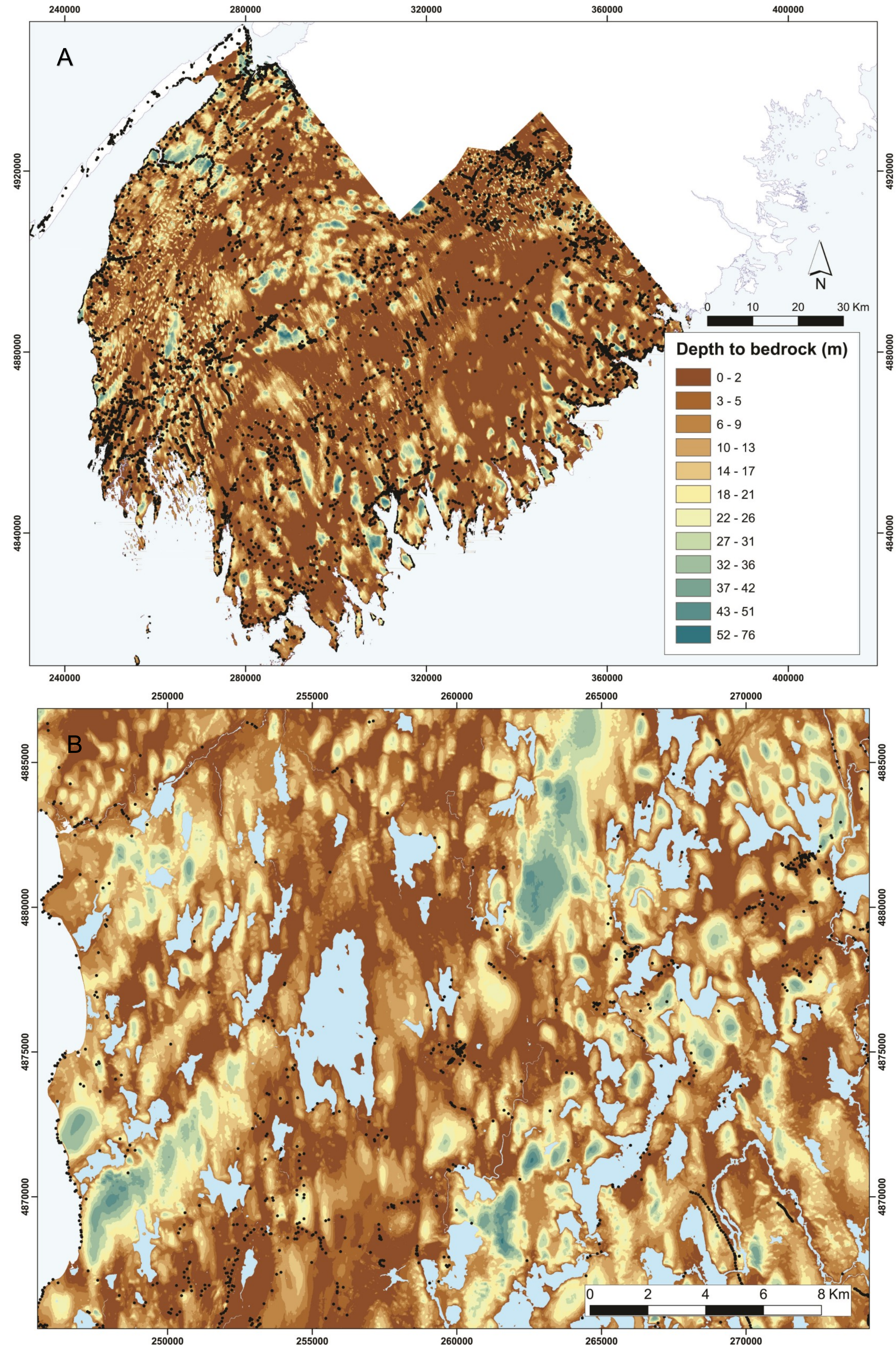

Figure 4. (a) Preliminary sediment thickness map for southwestern Nova Scotia, covering Kings, Queens, Yarmouth and Shelburne counties. (b) Preliminary sediment thickness map for the Brazil Lake study area. Black dots show the location of well logs, drillholes, and bedrock outcrop points used to constrain the model.

geochemistry and indicator mineralogy) and detailed till compositional and stratigraphic studies, planned for the region in summer 2021.

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