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STRATIGRAPHY, STRUCTURE AND MINERAL POTENTIAL OF THE 3.0 Ga FLORENCE LAKE GREENSTONE BELT, LABRADOR

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ABSTRACT

A project of the collaborative efforts of the Geological Survey of Newfoundland and Labrador, the Nunatsiavut Government, and the Geological Survey of Canada (GEM GeoNorth program) in the summer of 2022, focussed on the geology of the 3.0 Ga Florence Lake greenstone belt (FLGB), its volcanic history, stratigraphy, and critical mineral potential. The FLGB project is a part of the overall effort to improve the geoscientific knowledge and support exploration in northeastern Labrador.

This project investigates the 3.1–3.0 Ga supracrustal rocks in the Hopedale Block, specifically the Hunt River and Florence Lake greenstone belts. These volcano-sedimentary rocks have been included in earlier, regional-scale mapping efforts and in mineral exploration, but earlier regional work indicated that more detailed geological observations were needed to characterize their structure and stratigraphy. A recent aeromagnetic survey covers the northern part of the FLGB and provides the framework for this project. This report summarizes the field observations and preliminary interpretations of the structure, stratigraphy and mineral potential of the Florence Lake greenstone belt. Previously unrecognized stratigraphic younging indicators and reconstruction of folding geometries will provide the basis for future investigations.

INTRODUCTION

The Florence Lake greenstone belt (FLGB) project is a collaborative initiative undertaken by the Geological Survey of Newfoundland and Labrador, the GEM GeoNorth program (Geological Survey of Canada/Natural Resources Canada), and the Nunatsiavut Government. As part of the broader effort to improve the geological understanding of northeastern Labrador, this project focuses on the supracrustal rocks preserved in the FLGB of the Hopedale Block (NTS 13N and 13K). The results of the mapping and associated research will help to unravel the geological history of the region and provide baseline information that can be utilized for mineral exploration for Ni–Cu–Co, Au, Cu–Zn and critical minerals in the belt.

The FLGB has been previously mapped by Ermanovics (1993) and James *et al.* (1996, 2002). These studies provide geological context, and characterized the lithologies and metamorphic history of the belt. However, much remains unresolved, such as the structural development and nature of folding in the FLGB, and how it relates to the structural–tectonic development of the Hopedale Block. Furthermore, the stratigraphy and timing of volcanic, intrusive, and metamorphic events also remain uncertain due to the limited availability of radiometric age dates. Smaller exposures of supracrustal rocks outside of the central zone of the FLGB host important mineral showings (*e.g.*, Baikie; cf. Brace and Wilton, 1989), but their origin and relationship to the FLGB are not well understood. Similarly, units of the Weekes amphibolite are geochemically similar to basalts in the other supracrustal belts in the region of the 3.1 Ga Hunt River volcanic belt (HRVB); however, the origin of these greenstone belt outliers and amphibolites, as well as contact relationships with their igneous and high-grade metamorphic host rocks, is unclear (H. Sandeman, personal communication, 2023).

Mapping in 2022 focused on the northernmost sub-belt of the FLGB, a 15 x 5 km peninsula between Adlatok Bay and Ugjuktok Bay south of Hopedale. Mapping the rest of the FLGB and its outliers will be completed in the coming field seasons. At the time of writing, no geochemical results or thin sections are available from the 2022 field season, so all the results and interpretations presented here are based on field observations and should be considered preliminary. The future objectives of the project include investigating:

- Origin, mode of emplacement and age of the greenstone belt outliers detached of the main belt,
- Age relationship of FLGB and other supracrustal rocks in the Hopedale Block *(i.e.*, 3.1 Ga Hunt River volcanic belt),
- Variability in the inferred basement Maggo gneiss, its age and metamorphic history,
- Contact relationships between FLGB, Maggo gneiss and Kanairiktok Plutonic Suite, and
- Economic and critical mineral potential of the FLGB.

REGIONAL GEOLOGY

The 3.3–2.8 Ga Hopedale Block forms the southern part of the Archean North Atlantic Craton in Labrador with the northern 3.8–2.5 Ga Saglek Block (Taylor, 1971; Ermanovics, 1993; Schiøtte *et al.*, 1993). The Hopedale Block is a granite–greenstone terrane, bound in the north by the Mesoproterozoic Nain Plutonic Suite. A Paleoproterozoic shear zone demarcates the Makkovik Province in the south. The Mesoproterozoic Harp Lake Intrusive Suite borders the approximately 150 x 100 km Hopedale Block in the east, with the exception of a small sliver northeast of the Harp Lake Intrusive Suite.

Supracrustal rocks of the 3.0 Ga FLGB (Figure 1) are in structural or depositional contact with 3.3–3.1 Ga orthogneisses (*i.e.*, Maggo gneiss), and intruded by syn- to posttectonic tonalities, granites, and granodiorites of the 2.9–2.8 Ga Kanairiktok Plutonic Suite (Loveridge *et al.*, 1987; Ermanovics, 1993). The distinction between gneisses and (foliated) granites is often ambiguous, as are their contact relationships with the FLGB (*cf.* Rayner, 2022). Structural overprints of the contact between the FLGB and its host rocks are common and preserved as mylonitic zones, indicating structural offset produced by mostly ductile deformation along its outer margins. It remains uncertain if the structural offsets only mask modified depositional contacts of FLGB rocks deposited on a basement of Maggo gneiss, or if they indicate larger offsets along structural boundaries. This deformation could be a product of the 3.0–2.8 Ga Fiordian metamorphic event that postdates volcanism in the FLGB (*cf.* Ermanovics *et al.*, 1982; Korstgård *et al.*, 1985; Brace and Wilton, 1989; James *et al.*, 2002).

The 3.1 Ga HRVB is a second supracrustal belt in the Hopedale Block and is of similar dimensions to the FLGB and of parallel extent, but located approximately 25 km northwest of the FLGB. Several 'outliers' or 'slivers' of volcanic rocks have been mapped, spatially between the two belts. Small, amphibolite-facies rocks hosted in the Maggo gneiss (*i.e.*, Weekes amphibolite) of uncertain protoliths may represent reworked and higher metamorphic-grade greenstone belt material (Ermanovics, 1993; James *et al.*, 1996, 2002).

FLORENCE LAKE GREENSTONE BELT

The FLGB is approximately 60 km long and up to 5 km wide, extending southwest from Adlatok Bay and Ugjuktok Bay south of Hopedale, Labrador. The main part of the FLGB consists of five structurally disconnected segments or sub-belts, from north to south: Adlatok-, Ugjoktok-, Schist Lakes-, Baikie- and Knee Lake. Mafic volcanic rocks are dominant in the FLGB, having variable amounts of felsic, ultramafic, and tuffaceous to pelagic sedimentary material. Minor syn-volcanic to syn- and posttectonic intrusive rocks are common, with individual intrusive bodies ranging in size from a few centimetres to kilometre scale. The younger intrusive rocks intruding the volcanic successions are syn- to posttectonic (Fiordian), 2.8–2.7 Ga granite and tonalite plutons of the Kanairiktok Plutonic Suite (Wasteneys *et al.*, 1996; James *et al.*, 2002). All rocks in the FLGB have been subjected to upper greenschist- to amphibolite-facies metamorphism, and locally retrograde metamorphism after contact metamorphic events related to the emplacement of Kanairiktok intrusives (meta- prefix for all rock types omitted for brevity).

Ermanovics (1993) classified the belt as a stratigraphic group, divided into the Schist Lakes-, Adlatok-, Lise Lake- and Ultramafic formation. James *et al.* (1996) later rejected this classification due to the lack of definite characteristics and greater variability than originally captured and instead introduced a descriptive, lithology-based classification distinguishing mafic-, ultramafic-, felsic-, mafic to intermediate-, sedimentary- and intrusive rocks. A complex history of folding and deformation has been reported previously (Ermanovics, 1993; James *et al.*, 1996), with up to four stages of deformation recorded locally (McLean and Butler, 1993). The resulting folding pattern on the belt scale and continuity of horizons along strike and between sub-belts remain unconstrained and is one of the main objectives for this part of the GSNL–GEM GeoNorth project.

METHODS AND PRELIMINARY RESULTS

The following results are a summary of field observations collected during the field season in August 2022. Lithologies and structures have been recorded in 140 individual outcrops and 98 samples obtained for lithogeochem-

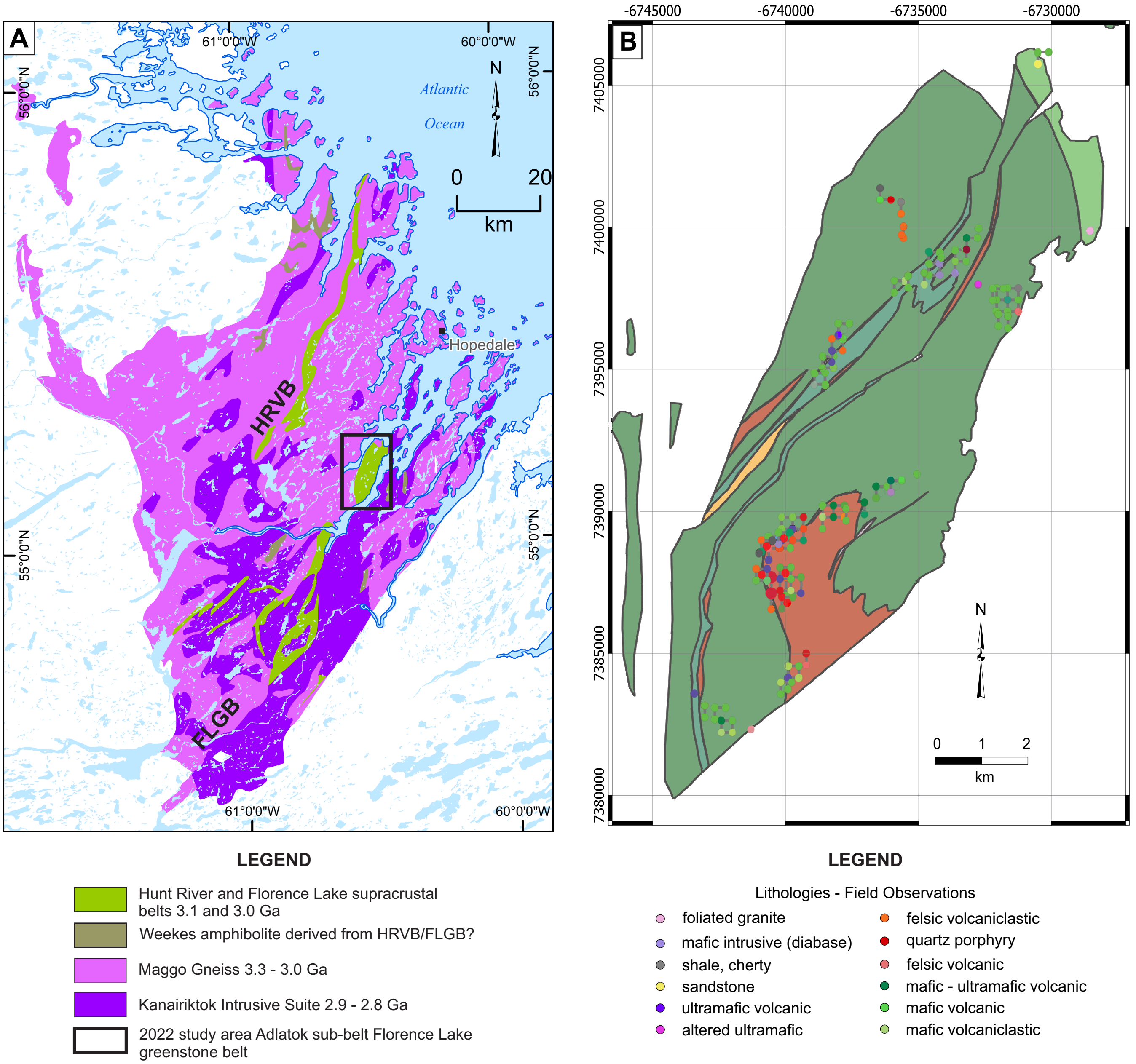

Figure 1. *Geological overview of the project area. A) Simplified geological overview of the Hopedale Block (Wardle* et al.*, 1997). The Florence Lake greenstone belt (FLGB) and Hunt River volcanic belt (HRVB) are two supracrustal units in the area. The ASB (outlined box) is the northernmost segment of the FLGB and was the focus of the 2022 field season. The ASB falls in NTS sheet 13N; B) Overview of the ASB with field stations overlain on the geology by James* et al. *(1996).*

ical analysis and thin sections (*see* Figure 1B for locations and recorded lithologies). Two additional samples were taken for U–Pb geochronology. Field data were collected using a Panasonic ToughPad running the GSC field app. Structural data were collected using a Freiberger compass set to a declination of -20.5°. Data compilation and visualization were performed in QGIS and ArcGIS Pro, structural data were plotted in the Stereonet application (Allmendinger *et al.*, 2012; Cardozo and Allmendinger, 2013).

STRUCTURE

Rocks in the belt dip subvertically (S_0 between 75–90°) and strike north-northeast (Figure 2). An easterly younging direction has been determined in one location in the southwestern Adlatok sub-belt (ASB), based on basalt pillow geometries and feeder dyke relationships. However, more younging indicators across the belt will need to be combined with interpretations of the folding pattern for a meaningful

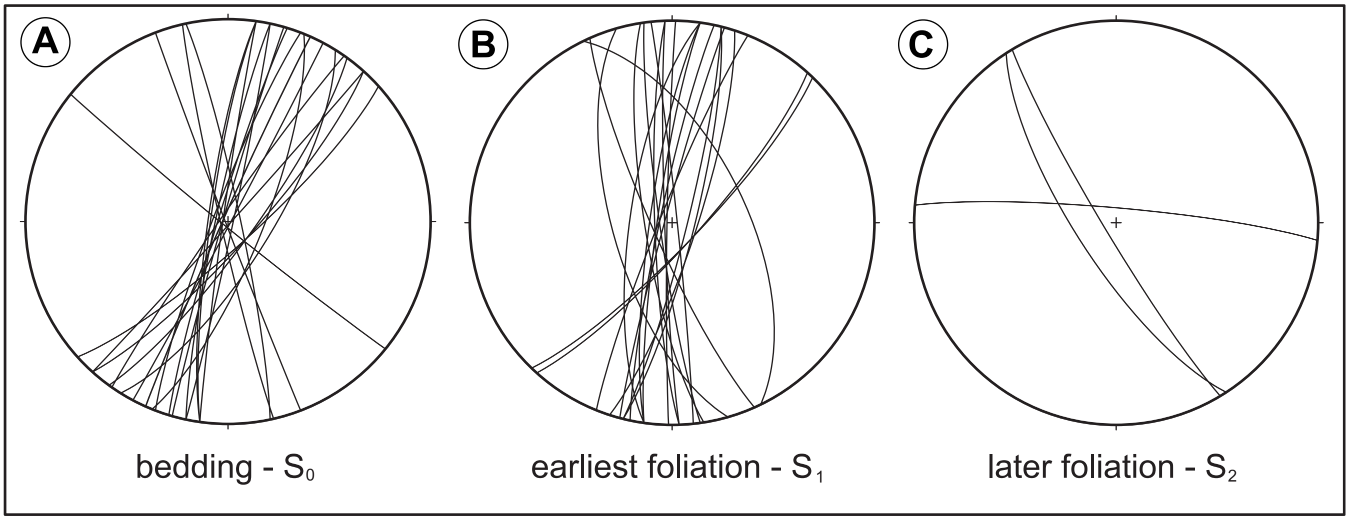

Figure 2. *Equal area projection stereonet plots of structures in the FLGB. A) Bedding (S_0) is steeply dipping and strikes north-northeast with variations due to folding; B) The earliest foliation is a penetrative cleavage (S_1) and subparallel to bedding, but systematically striking closer to north-south; C) A modification of the earlier cleavage is locally developed as later, variably dipping and east-west to northwest-southeast-striking foliation (S_2).*

determination of younging across the belt. The earliest cleavage (S_1) is subparallel to bedding and penetrative throughout the northern part of the belt (Plate 1). A later deformation event modified the S_1 cleavage and locally produced a less-penetrative S_2 cleavage. The dominant folding geometry of all lithologies in the Adlatok sub-belt is isoclinal with fold axial planes striking north to north-northeast. The dips of the fold axes and mineral lineations are mostly steep but variable and rarely quite shallow, potentially indicating the presence of doubly plunging isoclinal folds (*cf.* Ermanovics, 1993; James *et al.*, 1996). Crustal shortening, estimated from field observations is lithology-dependent and ranges from relatively undeformed to strongly shortened in east-west direction up to a ratio of approximately 1:10.

At least two phases of deformation have been identified by field observations. The older is possibly linked to a metamorphic–deformational event coeval with the intrusion of the Kanairiktok Plutonic Suite (*ca.* 2830 Ma, James *et al.*, 1996) and the younger phase, to a later regional event (Fiordian, *ca.* 2750 Ma; Ermanovics, 1993). However, the intrusions of the Kanairiktok Plutonic Suite may be syn- to posttectonic and part of the 'Fiordian event', potentially indicating an unrecognized deformation event between 3000 and 2830 Ma (James *et al.*, 2002). Up to two additional phases of deformation have been reported locally (McLean and Butler, 1993) and may be related to a 2578–2543 Ma tectono-magmatic event (*cf.* Hopedale–Saglek collision, Wasteneys *et al.*, 1996; James *et al.*, 2002).

LITHOLOGIES AND STRATIGRAPHY

The lithologies in the FLGB are volcanic and their sedimentary products, typical for Archean greenstone belts (*e.g.*, Ayer *et al.*, 2002; Plate 2). All units of the greenstone belt stratigraphy are moderately to strongly deformed and metamorphosed. The following are interpretations of volcanic protoliths with descriptions of the preserved features and mineralogy where determined in the field, in no implied chronological order. The descriptions are not intended as a complete account of all rock types in the area, and several other and mostly younger rock types are present; however, this is representative of those encountered during fieldwork in 2022.

1) Mafic to intermediate volcanic rocks are the most abundant in the ASB. Massive flows are mostly aphyric, fine grained, and dark-weathering. Where minerals could be determined in the field, chlorite and amphibole are the most abundant phases; plagioclase, minor epidote, muscovite, biotite, calcite, and magnetite are locally present. Other volcanic facies observed include plagioclase-phyric flows, pillow basalts, lobate flows, and amygdular and brecciated flows. Individual flows are <50 cm to >2 m thick and continuous between outcrops but not on the sub-belt scale. Small, mafic feeder dykes in the southwestern part of the ASB are 10–20 cm wide and experienced the same deformation events as their wallrocks. Basalt flows can be quartz altered and contain magnetite, and corridors of magnetite-bearing flows can be traced over 100s of metres. Corridors of magnetite-bearing basalt flows correlate moderately with

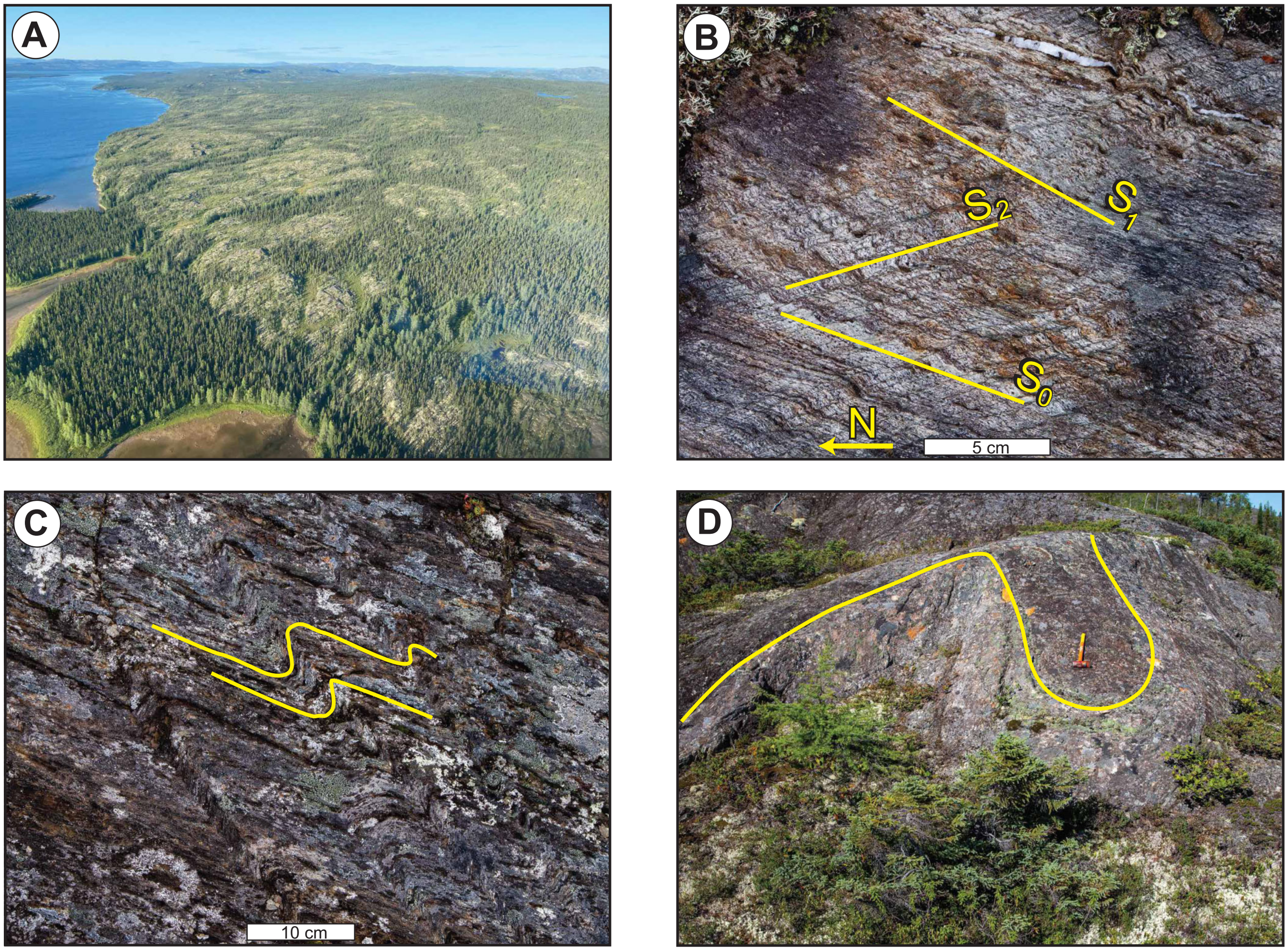

Plate 1. *Field photographs and structural features. A) Aerial photograph looking south across the ASB; B) The three dominant structural features in the FLGB developed in fine tuffaceous rocks.* S_0 *and* S_1 *are subparallel, whereas* S_2 *is an overprinting crenulation cleavage at a steeper angle to bedding; C) A set of S-folds developed in fine clastic sediments; D) Outcrop-scale Z-fold indicating the belt-scale folding pattern of dominantly isoclinal folds. Fold axes are dipping between 55–60°* *here but vary between almost flat lying to subvertical across the belt, reflecting a complex folding history.*

electromagnetic anomalies. One instance of pyrite-filled vesicles and disseminated pyrite in a basalt flow is present in the southern part of the ASB, close to its southern border.

2) Felsic volcanic and intrusive rocks comprise rhyolites and quartz-porphyritic intrusions. Rhyolites are fine grained, quartz altered, and moderately foliated with cream-weathering colours. Sericite alteration is common and often expressed by beige-yellow-weathering surface and stronger foliation. The size of individual felsic bodies can range from <10 to >50 m but cannot be traced between outcrops, indicating laterally discontinuous geometries. Quartz-porphyries contain 0.5–1.0-cm-euhedral quartz crystals in a fine-grained matrix and have sharp, intrusive contacts that cut surrounding lithologies at variable angles. Quartz-crystal tuffs and quartz-porphyries comprise similar material (*i.e.*, quartz crystals in a fine grained and altered matrix). Smaller outcrops of either rock type may not allow for an unambiguous identification as either lithology when contact relationships or other indicative characteristics like layering cannot be observed. Sericite-altered felsic volcanic units are often also Fe-carbonate-bearing and can contain trace sulphides.

3) Ultramafic rocks preserved as schistose lenses of 10–30 cm thickness have strike lengths of 5–50 m, and are preserved as coherent, magnesite- and talc-rich rocks with rust brown to black, recessively weathering surfaces. Minor chlorite and serpentine can be present. Weathered surfaces are often knobby and can be finely layered where magnesite and carbonates form pseudomorphs after the original igneous minerals. Some horizons are magnetic with euhe-

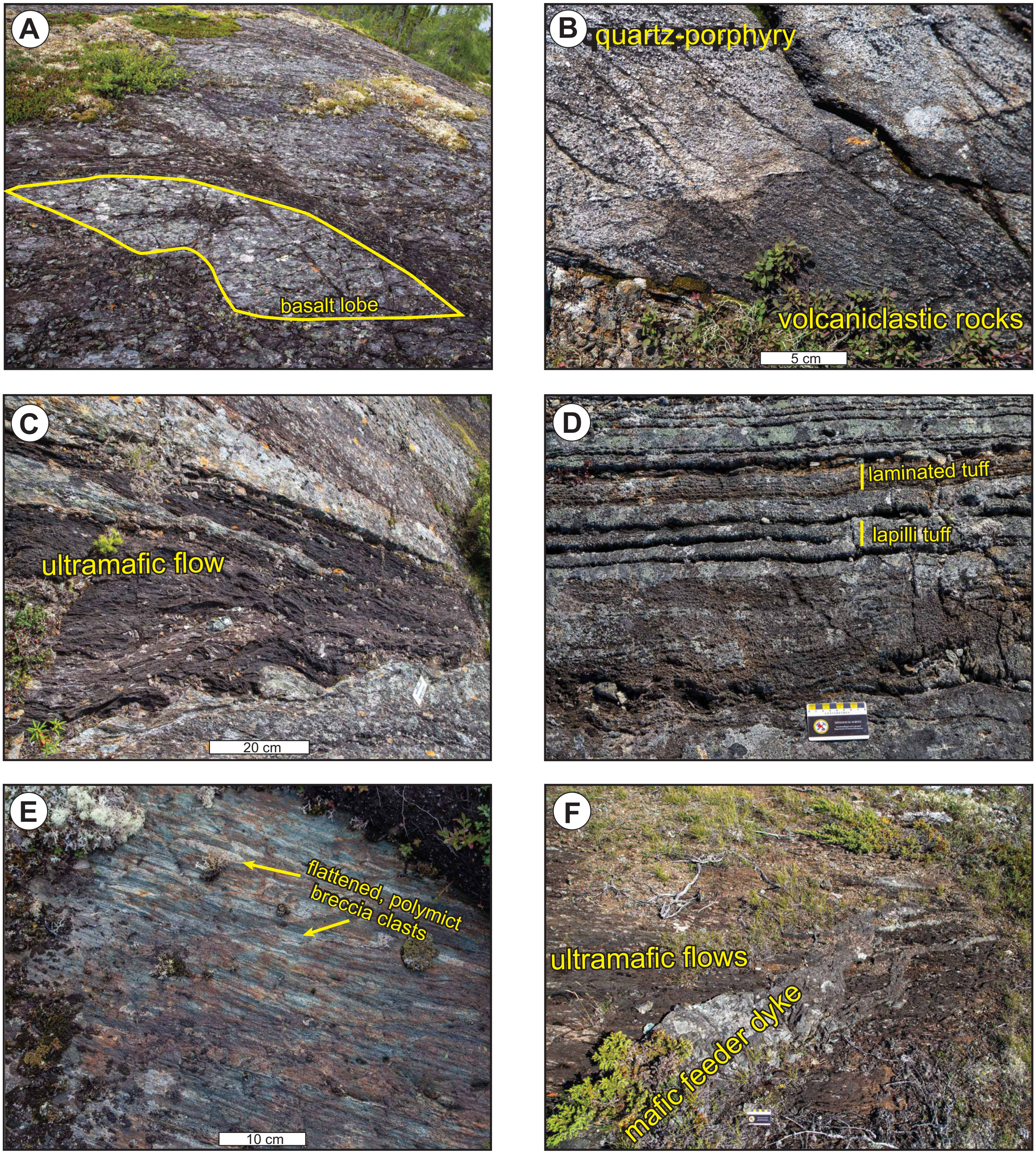

Plate 2. *Representative lithologies. A) Basalt flow with lobes; B) Quartz porphyry intruding volcaniclastic rocks; C) Ultramafic flow in a succession of mafic flows; D) Interbedded tuff facies; E) Volcanic breccia. Note the rust staining from sulphide weathering; F) Mafic dyke intruding ultramafic flows and feeding mafic flows just out of frame.*

dral magnetite crystals up to 0.5 cm. Several generations of quartz veins are preserved in ultramafic rocks, including early quartz veins that record all the same deformation events as the ultramafic host rocks, to late, undeformed skeletal quartz veins cutting the entire thickness of the host rocks. Ultramafic rocks occur as layer-parallel sets interbedded with mafic flows and sediments, and packages of ultramafic horizons can be traced over kilometres. Ermanovics (1993) and James *et al.* (1996) report a higher abundance of ultramafic rocks in the vicinity of felsic units and feldsparphyric mafic flows, but ultramafic rocks have also been found interbedded with aphyric mafic flows. The original mode of emplacement of the ultramafic rocks was likely as volcanic flows based on the absence of intrusive contacts (sills) and changing geometries on the top of the flows (flat) compared to the bottoms of flows, where pre-existing topographies of the substrate are preserved. Contact relationships with wallrocks are bedding-parallel with no recorded crosscutting of existing rocks, rendering dykes an unlikely precursor. Some of the ultramafic units may have originated as sills, but this remains unlikely in the absence of any feeder dykes, chilled margins or shallow intrusive contacts.

4) Sedimentary rocks in the FLGB reflect a great variety of origins and potential depositional environments. The most common types of sedimentary rocks are:

4a) Pelites – These rocks consist of fine-grained, thinly bedded to laminated, 3–5-cm-thick layers of mafic to intermediate-derived clastic sedimentary material. Units comprising dozens of beds can be over 1-m thick, deposited between volcanic rocks of variable affinities. Smaller sets of beds occur in mafic volcanic sequences, and the sedimentary rocks, forming chevron folds and small, high frequency S_2 folds, may have facilitated much of the deformation. The emplacement mechanism of pelites in the Adlatok sub-belt was probably similar to that of fine-grained clastic sediments in other Archean greenstone belts, produced by slow background sedimentation and distal ash deposits producing lighter weathering, intermediate laminae (Condie, 1981; Nadeau and Reynolds, 1981).

4b) Volcaniclastic rocks – These include lapilli-tuff and quartz-crystal tuff. Quartz-crystal tuff contains up to >1 cm euhedral quartz in a fine matrix. Individual beds are 20–50 cm thick and not internally organized or sorted. The composition is very similar to the quartz porphyritic intrusions and may be a sedimentary product of the same material. A distinction between quartz-bearing volcanic and sedimentary rocks can be difficult in smaller outcrops where contact relationships cannot be established. Quartz-bearing tuffs are important marker horizons with implications for the timing of felsic volcanism in the stratigraphic column, and the proximity to volcanic centres. Other volcaniclastic rocks include tuffs of various grain sizes and intermediate to felsic composition.

4c) Polymictic volcanic breccia – this rock type is a minor component of the volcanic stratigraphy by volume, but may be an important marker horizon due to its distinctive characteristics. The breccia is matrix-supported and comprises strongly deformed clasts of up to 3 x 30 cm. The clasts are mostly quartz porhyritic rhyolite with minor basalt and rare ultramafic clasts. The original geometry of the deposited clasts is uncertain due to the strong deformation, but preserved edges indicate that at least some of the fragments are subangular. The matrix is fine grained and chlorite-rich. Individual beds are more than 1 m thick and poorly sorted by clast size. The breccia is intercalated with quartz-crystal tuff beds of 10–20 cm thickness.

4d) Chert – Cherts and quartz-altered pelites are common but volumetrically minor. They occur as units comprising dozens of 5–10-cm-thick beds of variable composition and quartz content. Individual chert layers in mafic volcanic flows are preserved as pure, microcrystalline quartz and may have been deposited as inter-flow or inter-pillow cherts. Minor pyrite can be present in clay-rich beds.

5) Mafic intrusive rocks include basaltic feeder dykes, gabbros and diabase. Feeder dykes are small, <20-cm-wide shallow subvolcanic bodies that record all generations of deformation. Several gabbroic intrusions are not or only very poorly foliated and therefore possibly syn- to posttectonic. Smaller, 10–30 m lenticular diabase sills are likely part of the volcanic succession and may represent subvolcanic intrusions.

ECONOMIC POTENTIAL

The economic potential of the FLGB has been tested by mineral exploration efforts since the 1950s, with efforts focusing mostly on orogenic gold hosted in carbonate-altered felsic and ultramafic rocks, and Ni–Cu–PGE potential in mafic–ultramafic intrusions. This includes work undertaken by BRINEX between the 1950s–70s (*e.g.*, Beavan, 1953; Wilson, 1959; Piloski *et al.*, 1960; Sutton, 1971), BP Minerals in the 1980s (Stewart *et al.*, 1983), Falconbridge in the 1990s (*e.g.*, McLean, 1992), Altius in the 2010s (Morgan and Lachance, 2016), and Labrador Gold Inc. The most significant findings of the exploration efforts are the discovery of the Baikie Ni–Cu showing and the Thurber Dog Au showing. Several other indications have been reported (*cf.* Plate 3), including chalcopyrite on the northern shore of the ASB, and pyrite along the shore of Ugjuktok Bay in the east (Brace, 1990 and references therein; Ermanovics, 1993).

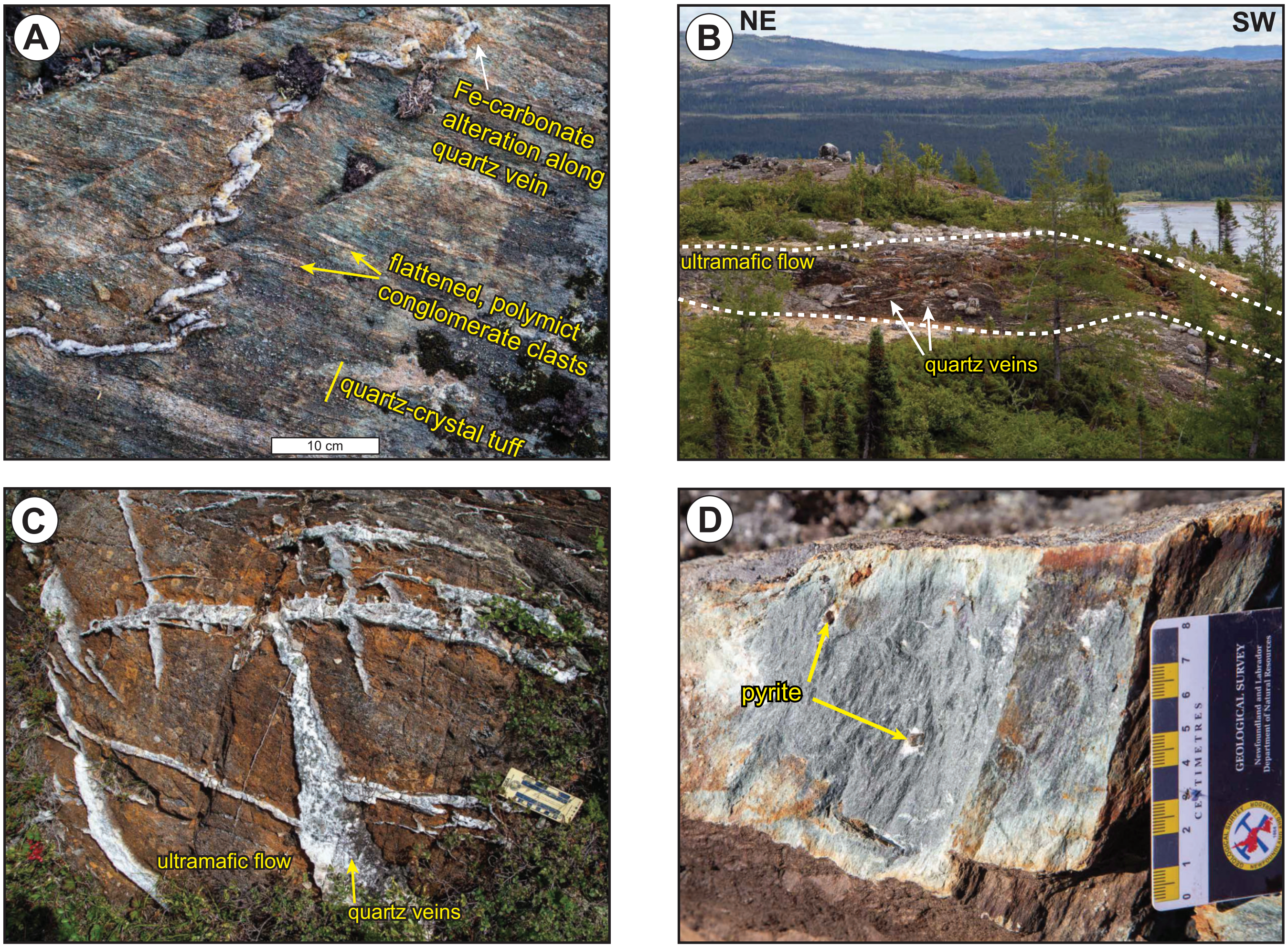

Plate 3. *Examples of prospective features. A) Volcaniclastic rocks cut by a quartz vein that introduces Fe-carbonate; B) Field aspect of early quartz veining in an ultramafic flow. The quartz veins are deformed and record all deformational events experienced by the host rocks; C) Late quartz veins. Skeletal structure is not deformed, indicating a posttectonic origin of quartz veins; D) Pyrite in amygdular basalt. Early void filling events precipitating pyrite may indicate syn-volcanic hydrothermal activity.*

CURRENT AND FUTURE INVESTIGATIONS

The major focus of ongoing and future investigations in the FLGB will be on the structure and stratigraphy of the FLGB. This will provide an improved geological and tectonostratigraphic framework that may help future exploration efforts in the area, and a foundation for understanding the wider Hopedale Block. This work will also concentrate on outliers separated from the main greenstone belt, their volcanic and structural origin, and relationship to the FLGB and Hunt River volcanic belt. Further, occurrences of the Maggo gneiss and Weekes amphibolite will be studied to identify their origin and relationship to the supracrustal rocks in the FLGB and HRVB.

The contact relationships between the FLGB and the Kanairiktok Plutonic Suite, as well as the Maggo gneiss, will also be evaluated critically to reconstruct an emplacement and deformation history. The difference between undeformed to deformed and foliated granites of the Kanairiktok Plutonic Suite and high-grade (up to migmatitic) Maggo gneisses will be investigated and supported by geochronological analyses. The proper identification of rocks in contact with the supracrustal assemblages in the Hopedale Block is a critical part of the reconstruction of the geological history, particularly because the difference in metamorphic grade necessitates a significant structural offset along any true contact between amphibolite-facies supracrustal rocks with migmatitic gneisses, whereas contacts with granites do not indicate any structural offset. The timing of the structural development of the FLGB and the wider

Hopedale Block is important for the identification of ancient fault systematics and the localization of mineral prospectivity linked to such deep fault systems. The nature of structural and intrusive contacts will be investigated in key areas, such as the southwestern part of the Adlatok sub-belt, and the Baikie showing.

SUMMARY

The results of the mapping in 2022 highlight the importance to establishing a structural and stratigraphic framework for the greenstone belt architecture in the Hopedale Block as indicated by previous provincial and federal government geologists (*cf.* Ermanovics, 1993; James *et al.*, 1996). Pending geochemical analyses and petrography, along with preliminary interpretations of doubly plunging isoclinal folding and easterly younging directions will provide the foundation for future work in the area. Confirmed and new indications, including pyrite in basalt vesicles in the southern part of the ASB, and sulphides in sericitized felsic volcaniclastic rocks in the underexplored northwestern part, highlight the density and variability of showings and indications of mineralization. As part of the GSNL–GEM GeoNorth initiative, this project will focus on providing a framework for exploration for critical minerals, as well as precious- and base-metal mineralization.

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