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REVISITING MESOPROTEROZOIC MAGMATISM IN LABRADOR: EVALUATING AMCG AND PERALKALINE MAGMATISM

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ABSTRACT

Research this past summer (2022) marked the continuation of a collaborative program between the Geological Survey of Canada, Geological Survey of Newfoundland and Labrador, and the Nunatsiavut Government. The program is aimed at upgrading the geoscientific knowledge of, and stimulating mineral exploration in, the Saglek to Makkovik region of Labrador. This project is supported by the GEM-GeoNorth program at Natural Resources Canada and the Geological Survey of Newfoundland and Labrador. Some objectives of the GEM-GeoNorth program are to assist in completing regional-scale geological mapping across Canada's north and to enhance the geological knowledge of key areas of the Canadian Shield. The GEM-GeoNorth project addresses the latter objective by targeting specific areas in the Nain and Makkovik provinces.

In the Hopedale study area, voluminous AMCG (anorthosite–mangerite–charnockite–granite) plutonic suites intrude across the boundary of the Archean North Atlantic Craton (Hopedale Block) and Archean to Paleoproterozoic Churchill Province. The Sango Bay pluton, the Flowers Bay pluton and the Merrifield Bay pluton are all part of the larger AMCG Nain Plutonic Suite in the study area, and are the focus of detailed mapping coupled with sampling for petrographic analysis, lithogeochemical, isotopic and geochronological studies. In addition to the aforementioned plutons, detailed mapping and sampling were carried out on the Flowers River Igneous Suite (FRIS), which comprises a younger, peralkaline suite. One aim of the latter investigations is to ascertain whether the geophysical highs surrounding the Flowers River Igneous Suite reflect lithological variations within the FRIS and/or Nain Plutonic Suite. From an economic perspective, the AMCG plutonic rocks have potential to host critical minerals such as Ni–Cu–PGE's mineralization because the Voisey's Bay Ni–Cu–Co magmatic sulphide deposit to the north is hosted by an early troctolite component of the Nain Plutonic Suite. In addition to base metal–precious metals in the AMCG intrusions, significant rare earth–critical minerals may be present in the peralkaline rocks of the FRIS.

INTRODUCTION

Selected areas in the Nain and Makkovik provinces are targets of a joint project of the Geological Survey of Canada, Geological Survey of Newfoundland and Labrador, and the Nunatsiavut Government. The study region is geologically complex, located at the junction of five tectonic domains/orogens (Figure 1). These include the 3.3–2.8 Ga Hopedale Block, the 4.0–3.2 Ga Saglek Block, the 2.8–2.3 Ga Core Zone, 1.9–1.8 Torngat Orogen and the 1.88–1.74 Ga Makkovik Province (Wardle *et al.*, 2002; James *et al.*, 2002; Ketchum *et al.*, 2002; Corrigan *et al.*, 2018; Hinchey *et al.*, 2020; Godet *et al.*, 2021). Part of the current project includes the acquisition of new aeromagnetic and radiometric data for part of the Makkovik Province, the results of which are expected to be published in the summer of 2023.

The Hopedale Block is intruded by voluminous anorthosite–mangerite–charnockite–granite (AMCG) bodies that form part of the aerial extensive Nain Plutonic Suite (NPS; Figure 1). The NPS hosts the world-class Voisey's Bay Ni–Cu–Co deposit and is thus extremely prospective to host additional Ni–Cu–Co mineralization (Figure 2). This study was initiated to update the geological framework of three intrusions of the NPS, namely, the Sango Bay pluton, the Flowers Bay pluton and the Merrifield Bay pluton. Another NPS intrusion to the west of the studied plutons is the Pants Lake intrusion, described in more detail in Kerr (2012 and references therein). Regional 1:100 000-scale reconnaissance mapping was carried out in the region (Hill, 1982a–c). This project was initiated in the summer of 2022 and entails detailed mapping coupled with sampling for petrographic analysis, as well as, lithogeochemical, isotopic and geochronological studies. Detailed mapping and sampling were also carried out on the Flowers River Igneous Suite (FRIS), which comprises younger peralkaline rocks (Figure 3). The FRIS study will explore whether the lobe-shaped geophysical highs (*see* Figure 4) surround-

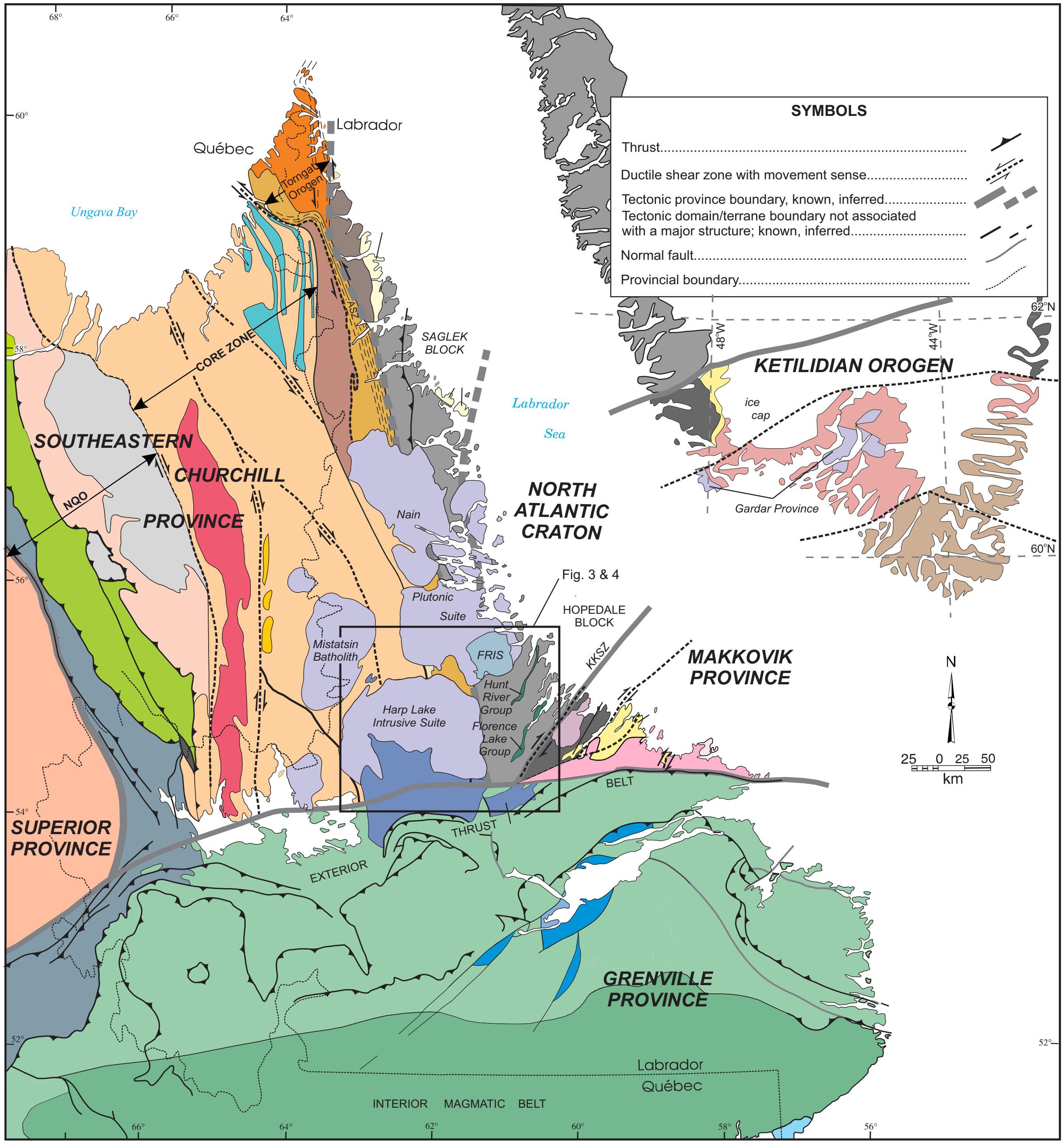

Figure 1. *Simplified geological map of eastern Québec, Labrador and southern Greenland showing the landmasses before the complete Mesozoic opening of the Atlantic Ocean. (Data compiled from Wardle* et al.*, 1997; St-Onge* et al.*, 2009; Corrigan* et al.*, 2018; Bagas* et al.*, 2020; Godet* et al.*, 2021; Hinchey, 2021). KKSZ=Kanairiktok Shear Zone; FRIS=Flowers River Igneous Suite. NQO=New Québec Orogen; ASZ = Abloviak Shear Zone. The location of Figures 3 and 4 are shown.*

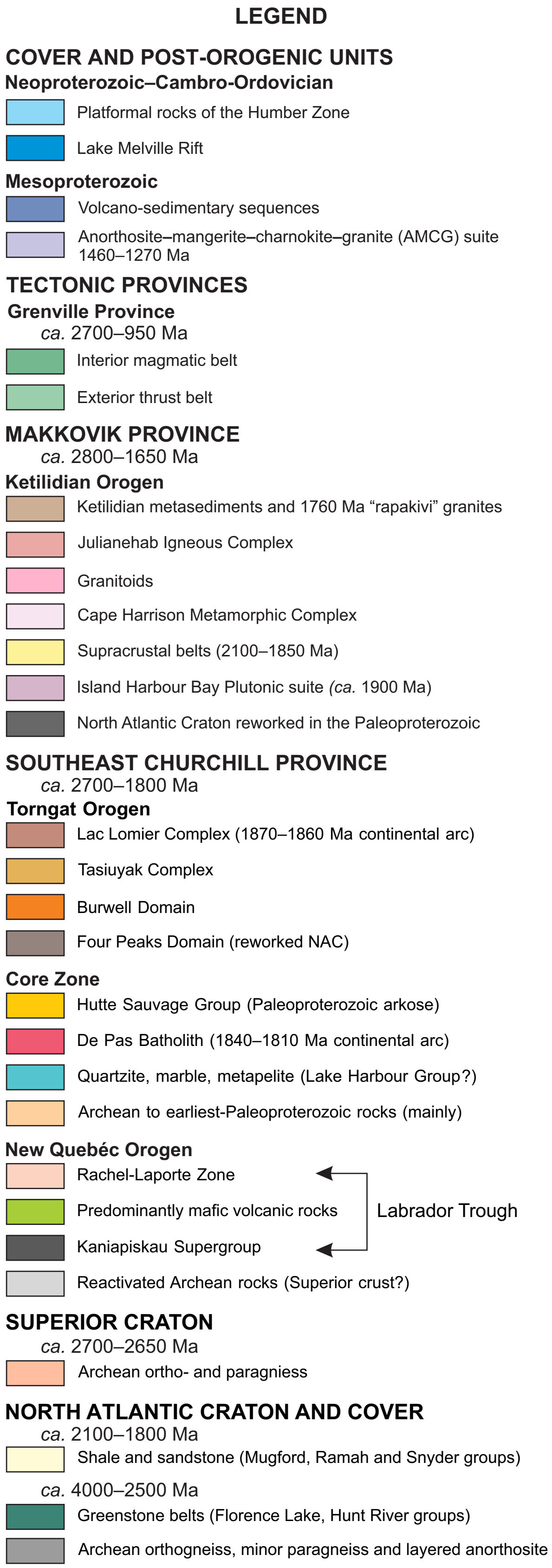

Figure 1. *Legend.*

ing the suite reflect lithological differences in the NPS or the FRIS.

REGIONAL GEOLOGY

The Hopedale and Saglek blocks from the Nain Province are part of the North Atlantic Craton (NAC), which extends through Greenland to northwest Scotland (Bridgewater *et al.*, 1973). These two Archean crustal fragments are inferred to have been juxtaposed in the Late Archean (Connelly and Ryan, 1996; Wasteneys *et al.*, 1996) along a nebulous, north-northeast-trending high-strain zone. The North Atlantic Craton is separated from the Core Zone by the *ca.* 1.89–1.85 Ga Torngat Orogen, a zone of intense transpression and high-grade metamorphism affecting the Tasiuyak Gneiss, the Lac Lomier Complex, and the eastern edge of the Core Zone (Figure 1; Wardle *et al.*, 2002; Godet *et al.*, 2021). To the south, the Core Zone and North Atlantic Craton are bounded by the Makkovik Province, a zone of Paleoproterozoic crustal reactivation and terrane accretion (Ketchum *et al.*, 2002; Hinchey *et al.*, 2020; Hinchey, 2021).

The Hopedale Block comprises variably deformed and metamorphosed Archean (3100–3000 Ma) orthogneiss (Maggo gneiss) and lesser, younger supracrustal belts (*i.e.*, Florence Lake Belt, Hunt River Belt and Weekes Amphibolite). These supracrustal rocks were intruded by tonalite and granodiorite of the *ca.* 2858–2838 Ma Kanairiktok Plutonic Suite (Loveridge *et al.*, 1987; Ermanovics, 1993; Wasteneys *et al.*, 1996). During the Mesoproterozoic, voluminous AMCG magmas intruded the region (Emslie, 1978), including the NPS and Harp Lake Intrusive Suite (Figure 1). The products of slightly younger, peralkaline volcanism and plutonism are preserved in the *ca.* 1272 Ma FRIS (Hill, 1991; Ducharme, 2018; Rayner, 2022). Abundant mafic dykes intruded the region between 2238 ± 6 and 2216 ± 2 Ma (*i.e.*, Kikkertavak dykes) and *ca.* 1273 ± 1 Ma (*i.e.*, Harp dykes) (Cadman *et al.*, 1993; Sahin and Hamilton, 2019).

The NPS comprises numerous plutons that formed between *ca.* 1360 to *ca.* 1290 Ma (Ryan, 2000) covering an area of approximately 18 500 km^2. The NPS straddles the boundary of the North Atlantic Craton with the Southeastern Churchill Province/Core Zone plus its two bounding orogens that amalgamated between *ca.* 1.89 to 1.85 Ma (Figure, 1; Wardle *et al.*, 2002; Charette *et al.*, 2021; Godet *et al.*, 2021). The dominant rock types are anorthosite and pyroxene- and olivine-bearing granitic plutons with rare peridotite to leucogranite (Ryan, 2000). The most abundant rock types are anorthosite (including leuconorite and leucotroctolite), granite (including monzonite, quartz monzonite and syenite; many contain fayalite, orthopyroxene and clinopyroxene),

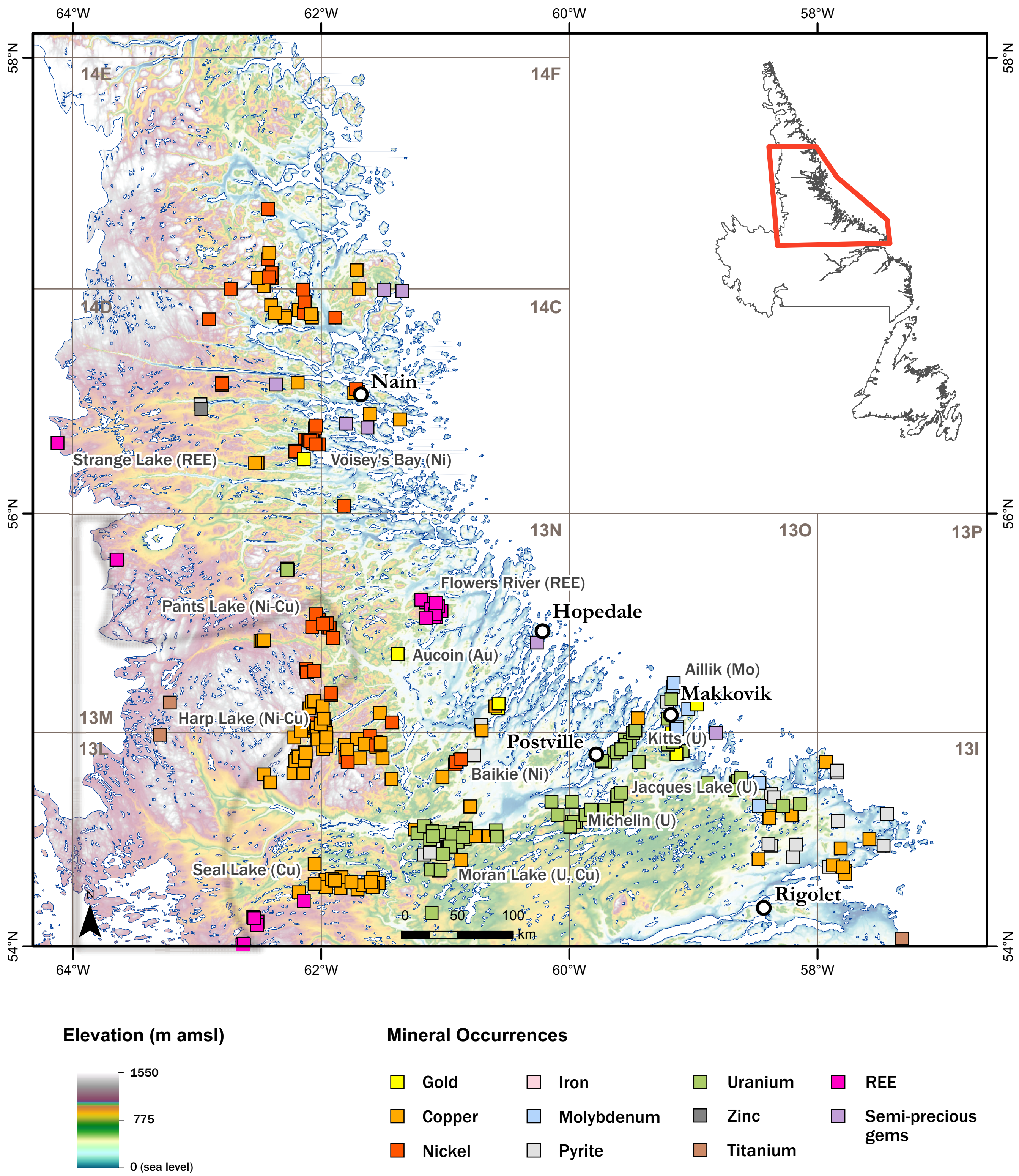

Figure 2. *Digital elevation map illustrating the significant mineral occurrences in the study area (figure drafted by S. Jenkins). Mineral occurences are from the Geological Survey's Mineral Occurrence Database System. Amsl=average mean sea level.*

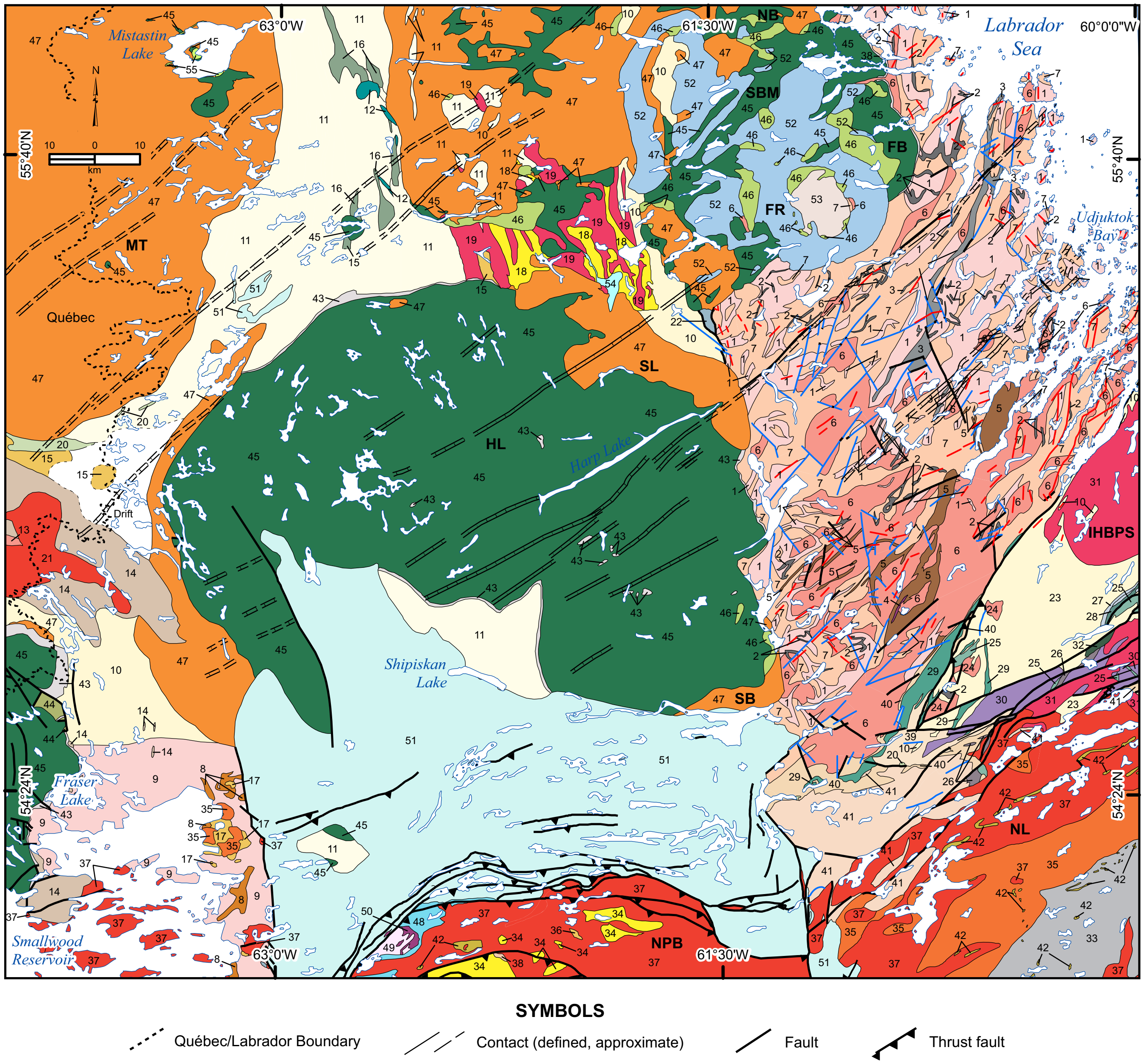

Figure 3. *Geological map of north-central Labrador (simplified after Wardle, 1993). N=Notakwanon batholith; MT=Mistastin Lake Batholith; SL=Snegamook Lake Pluton; SB=Sango Bay pluton; FB=Flowers Bay pluton; HL=Harp Lake Intrusive Suite (gabbroid rocks); MI=Michikamau Intrusion (gabbroid rocks); HLF=Heggart Lake Formation; TLB=Trans-Labrador Batholith; DLMS=Disappointment Lake Metamorphic Suite, Sl=Snegamook Lake Pluton; PL= Pants Lake intrusion; IHBPS=Island Harbour Bay Plutonic Suite; NL=Nipish Lake Intrusive Suite.*

ferrodiorite and troctolite. Rare peridotite occurs as m-scale inclusions or as ultramafic cumulates in layered basic intrusions (Hill, 1982c); whereas, leucogranite occurs as cm- to m-scale dykes (Ryan *et al.*, 2017).

The southern NPS is the focus of this study and has received less attention than the northern parts, which have had more systematic research (*see* Emslie and Stirling, 1993; Emslie *et al.*, 1994; Ryan, 2000; Voordouw, 2001; James and Byrne, 2005; Myers *et al.*, 2008). Much of the known geochronology for the NPS is from the northern NPS. Zircon antecrysts having U–Pb ages *ca.* 1370 Ma occur in the *ca.* 1340 Ma Pearly Gates anorthosite intrusion of the NPS (Tettelaar, 2004) and anorthositic plutons were emplaced periodically until at least *ca.* 1295 Ma (Hamilton, 1994). The U–Pb zircon TIMS (thermal ionization mass

LEGEND

TERTIARY

54 Mistastin Lake Formation (Mistastin Lake impact crater)

STRUCTURAL PROVINCES

MIDDLE PROTEROZOIC

Flowers River Igneous Suite (FRIS)

53 Peralkaline volcanic rocks

52 Peralkaline granite

51 **Seal Lake Group**

Harp Dykes 1274 ± 2 Ma

50 **Red Wine Alkaline Suite**

Letitia Lake Group 1337 +10/-8 Ma

49 Peralkaline volcanic rock

48 Peralkaline syenite

AMGC Suites

Granitoid Intrusions

47 **Nain Plutonic Suite; granitoid rocks**

46 Ferrodiorite, monzodiorite–diorite, gabbro

Gabbroid Intrusions

45 Anorthosite

44 Troctolite

43 Gabbroic rocks

42 Michael Gabbro and equivalent rocks

GRENVILLE PROVINCE AND ADJACENT AREAS

LOWER PROTEROZOIC

Bruce River Group

41 Sylvia Lake Formation

40 Brown Lake Formation

39 Heggard Lake Formation

38 Porphyritic andesite of Red Wine River area

Trans-Labrador Batholith and Equivalents

37 Granitoid rocks

36 Quartz diorite plutons

35 Crooked River granite

Metamorphic rocks

34 Wapustan River Gneiss\DLMS

33 Granodioritic–dioritic orthogneiss

MAKKOVIK PROVINCE

LOWER PROTEROZOIC

Kokkorvik dykes

32 Diorite

31 Granitoids 1890–1800 Ma

Early Granitoid Plutons

30 Granitoid to granodiorite

Moran Lake Group and Deformed Equivalents

29 Joe Pond Formation

Post Hill Group (*ca.* <2013 Ma)

28 Amphibolite and mafic metavolcanic rocks

27 Metasedimentary schist and phyllite

Unassigned supracrustal rocks

26 Schistose or phyllitic metasedimentary rocks

25 Schistose metavolcanic rocks (includes HLE)

ARCHEAN

Structurally reworked equivalents of Nain Province rocks

24 Granitoid metaplutonic rocks

23 Granitoid gneisses; minor amphibolite

EASTERN CHURCHILL PROVINCE

LOWER PROTEROZOIC

22 **Ingrid Group**

21 Foliated granitic intrusions

20 Gabbroic–metagabbroic intrusions

19 Foliated to gneissic plutons

18 **Tasiuyak Gneiss**

LOWER PROTEROZOIC AND/OR ARCHEAN

17 Polyphase plutonic suite in Smallwood Reservoir area

16 Mafic gneisses

15 Metasedimentary gneiss

14 **Petscapiskau Group; mafic metavolcanic rocks**

13 Meta-arkose, conglomerate, and minor quartzite

12 Meta-anorthosite

11 Quartzofeldspathic gneiss and migmatite

ARCHEAN

10 Tonalitic-grandioritic, amphibiolite- to granulite-facies gneisses

9 Foliated to gneissic tonalite, minor volcaniclastic rocks

8 Metabasalt (locally pillowed)

NAIN PROVINCE

LOWER PROTEROZOIC

Kikkertavik Dykes *ca.* 2200 Ma

ARCHEAN

7 Migmatite gneiss, in part from KIS and Maggo Gneiss

6 Kanairiktok Intrusive Suite (KIS) 2858 +4/-3 Ma

Florence Lake Group

5 Mafic-volcanic and volcaniclastic rocks

4 Serpentinized peridotite sills

3 **Hunt River Group; metagabbro to metaleucogabbro**

2 **Weekes Amphibolite**

1 **Maggo Gneiss**

Figure 3. *Legend.*

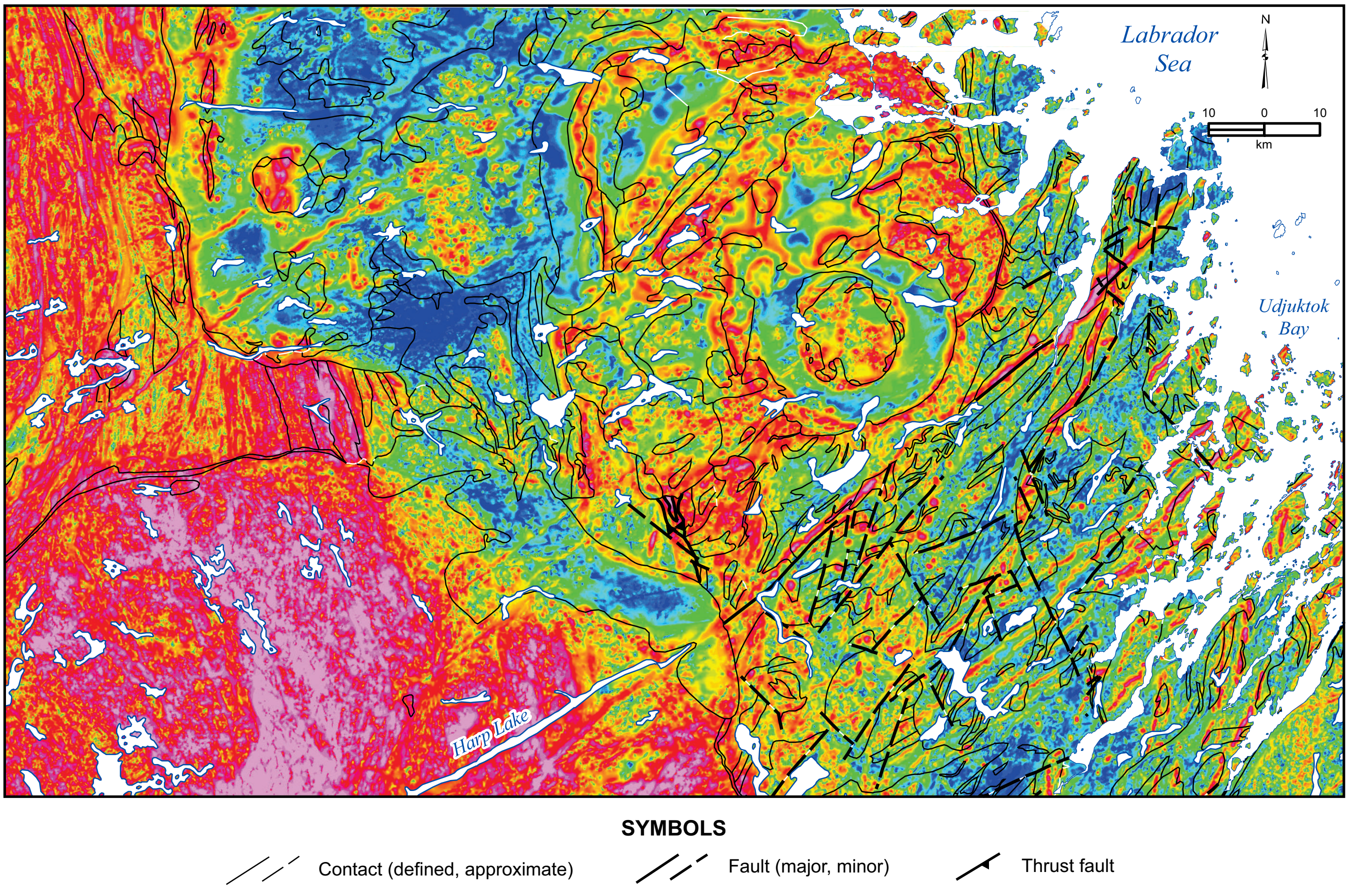

Figure 4. *First vertical derivative of the aeromagnetic survey draped over 10° magnetic tilt in the grey scale for the Hopedale region. Geological linework was modified after Wardle (1993). Aeromagnetic data from (Coyle 2019a–d), processing completed by C. Pike.*

spectrometry) zircon ages from granitic rocks of the NPS record silicic magmatism extending from 1363 ± 3 Ma (Tessiarsuyungoakh intrusion; Tettelaar, 2004) to *ca.* 1292 ± 2 Ma (south of Kogaluk River; Ryan *et al.*, 1991). Minor volumes of ferrodioritic to gabbronoritic rocks are most widely documented post-1330 Ma and occur until *ca.* 1298 Ma (Ryan *et al.*, 2017). Troctolitic intrusions comprise a) the Voisey's Bay intrusion that has U–Pb zircon TIMS age of 1333 ± 1 Ma and hosts the world-class Ni– Cu–Co deposit (Amelin *et al.*, 1999; Evans-Lamswood *et al.*, 2000) and b) the Kiglapait layered intrusion, which has a U–Pb zircon TIMS age of 1306 ± 2 or 1307 ± 1 Ma (Yu and Morse, 1993; Hamilton, 1997). East of the study area, an olivine gabbro from a drillhole sample from the Pants Lake north intrusive suite yielded a combined (zircon and baddeleyite), intercept, U–Pb TIMS date of 1322 ± 2 Ma; and a sample of gabbro from a drillhole from the Pants Lake south intrusive suite yielded a baddeleyite, intercept, U–Pb TIMS date of 1338 ± 2 Ma (Smith, 2006; Kerr, 2012). The NPS is a record of compositionally diverse magma pulses spanning tens of millions of years.

CRITICAL MINERAL POTENTIAL

North-central Labrador is known to contain numerous mineral occurrences (Figure 2). However, apart from the Voisey's Bay Ni–Cu–Co mine, northern Labrador does not have any other operating mines and its geological framework and evolution in relation to mineral potential are aspects in need of further studies. Despite the abundance of lithologically similar and coeval intrusions to the host rocks of the Voisey's Bay deposit, there has yet to be a discovery of other deposits (Figure 3). This warrants further investigation and generation of new baseline geological mapping and data to further enable the exploration community to apply modern exploration techniques.

The Mesoproterozoic, peralkaline, FRIS intrudes the Hopedale Block and has known critical minerals occurrences (REE, Y, Nb and Zr mineralization). The FRIS shares many similarities with the Strange Lake intrusion, which has been studied and explored in more detail and has a proven economic REE deposit (Miller, 1990; Salvi and Williams-

Jones, 1990, 2006). Similar Mesoproterozoic intrusions in the Gardar Province in southwest Greenland (Figure 1) are also known to be associated with economic quantities of rare-metal mineralization (Goodenough *et al.*, 2016; Hutchison *et al.*, 2021).

In addition, the Hopedale Block contains two greenstone belts (Florence Lake and Hunt River) having possible economic potential for gold and base metals (Figures 1 and 3). The Florence Lake greenstone belt, a 65-km-long by 1–5 km-wide supracrustal assemblage trending northeast in the southeastern part of the Hopedale Block, consists mainly of mafic and ultramafic metavolcanic rocks with lesser felsic metavolcanic and metasedimentary rocks (Ermanovics, 1993; James *et al.*, 2002). The belt is typical of greenstone belts around the world but in comparison to many such supracrustal sequences elsewhere (*e.g.*, Ontario and Québec), has not been adequately evaluated systematically. A project focussing on the greenstone belt mineral potential was initiated as part of the current Geological Survey of Canada, Geological Survey of Newfoundland and Labrador, and the Nunatsiavut Government joint program (Diekrup et al., *this volume*)

NAIN PLUTONIC SUITE

Regional bedrock mapping in the late 1970s produced the most recent geological maps of the study area (Hill, 1982a, b). Much of the subsequent research in the region was carried out focussing on the REE-mineral potential of the FRIS (*see* Miller, 1994 and references therein). There has been limited systematic lithogeochemical, isotopic, or geochronological research on the areally extensive NPS outside of this study area. The southern part of the NPS is volumetrically dominated by gabbroid and granitoid rocks with lesser intermediate compositions. Much of what is reported here combines the early work of Hill and Miller with field observations from the 2017 to 2022 field seasons. The descriptions below focus on the Sango Bay, Merrifield Bay, Flowers Bay plutons and minor parts of the Notakwanon Batholith. Details of the Pants Lake southern and northern intrusions that occur to the west of the study region are found in Kerr (2012 and references therein).

ROCK TYPES

Gabbroic Plutons

Gabbroic intrusions are interpreted as the oldest members of the southern part of NPS. Previous regional mapping (Hill, 1982c) recognized fifteen separate gabbroic intrusions; however, it was postulated that they were likely remnants of once larger bodies that were dissected by younger granitoid plutons. Despite this interpretation, contacts are rarely observed in the field. Hill (1982a, b) divided the gabbroic rocks into three lithologic zones, the Outer Border Zone, the Inner Border Zone and the Cumulate Zone, although these divisions do not reflect the recently acquired geophysical data for the region (Coyle, 2019a–d). For this report and future maps, we will divide and describe the units based on rock types.

Anorthosite

Anorthosite is the most volumetrically significant rock type, making up roughly 90% of exposures in the region. The Flowers Bay (FB) and Merrifield Bay (MB) plutons are examples of intrusions in which anorthositic rocks constitute a significant component (Figure 3). The anorthosites are cumulates and typical of layered intrusions, in which the compositional layers range from solely plagioclase to solely mafic minerals. The rocks are white-weathering and grey-fresh. Minerals comprise plagioclase, olivine, augite, orthopyroxene, Fe-Ti oxides and apatite. Plagioclase is exclusively cumulate, whereas, most of the other minerals are intercumulate. The feldspar crystals, both as individuals and aggregates, display significant variation in size – from sub-cm to tens-of-cm scale – and locally the tabular grains define an igneous lamination and lineation (Plate 1A).

Leucogabbro

Leucogabbro is less abundant than the anorthosite; however, plagioclase volume remains around 80% (Plate 1B). Clinopyroxene is generally intercumulate. Minor oxides, apatite, and orthopyroxene are also present. Grain size varies from 5 mm to 18 cm, the latter being the most abundant. Gently inclined, rhythmic igneous layering occurs at the outcrop scale, and plagioclase displays adcumulate-like textures.

Olivine Gabbro

Olivine gabbro, medium to very coarse grained, consists of plagioclase, olivine, augite and Fe-Ti oxides; however, locally (outcrop scale) can vary to gabbronorite and monzogabbro. This unit is pegmatitic to medium grained (Plate 1C). Local compositional variants within this rock unit include gabbronorite and monzogabbro. Some of the gabbroic rocks are plagioclase-phyric, having phenocrysts that range from 1–15 cm. Relative to the olivine and plagioclase, most other minerals are interstitial and typically oikocrystic. Igneous layering is typically steeply dipping.

Leuconorite

Leuconorite comprises plagioclase, orthopyroxene and abundant magnetite; minor olivine occurs locally. It is typ-

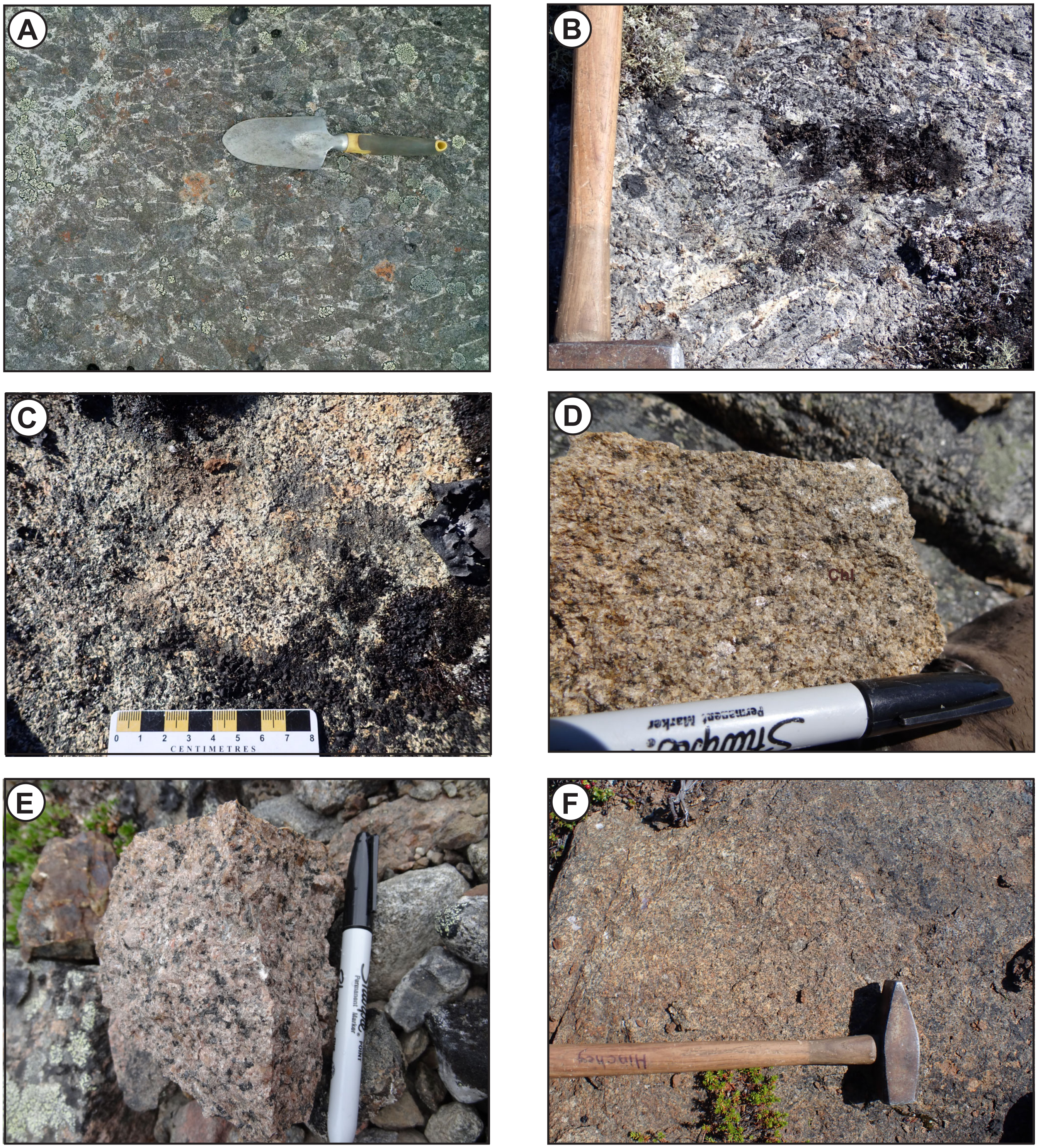

Plate 1. *Outcrop photographs NPS rock types in the study area rock. A) Very coarse-grained olivine gabbro from the Flowers Bay pluton (17AH027). Dark-grey laths are plagioclase. A 20-cm-long trowel for scale; B) Eight to ten-cm plagioclase laths in the anorthosite of the Flowers Bay pluton (22AH039). Dark mineral is pyroxene. The hammer handle length is 31 cm; C) Medium-grained, homogeneous leuconorite of the Sango Bay pluton (22AH033). The light mineral is plagioclase and the dark mineral is pyroxene. D) Medium-grained mangerite of the Notakwanon intrusion (18AH035). Marker is 13 cm long; E) Medium- to coarse-grained hornblende monzogranite to syenogranite (17AH018). Marker is 13 cm long; F) Medium-grained quartz syenite (west of the Flowers Bay pluton; 22AH037). Hammer handle is 30 cm long.*

ically homogeneous, medium to fine grained and weathers pale-brown. The Sango Bay leuconorite is finer grained than the leuconorite that is associated with the Flowers Bay pluton. Leuconorite adjacent to granites of the FRIS is intruded by dykes and veins emanating from the latter, younger intrusions.

Gabbronorite

Gabbronorite comprises plagioclase, orthopyroxene, clinopyroxene and magnetite. It is typically homogeneous, fine grained and weathers orange-brown. The feldspars locally occur as phenocrysts that are 1 to 2 cm long. Anorthositic rocks proximal to the gabbronoritic intrusions are intruded by dykes from these younger mafic plutons.

Intermediate Plutons

Mangerite/Monzonite

The monzonite (mangerite) subdivision includes rocks ranging from monzonite to quartz monzonite, having as their main minerals plagioclase, potassium feldspar, quartz, clinopyroxene and magnetite; orthopyroxene, biotite, hornblende and olivine are locally present. These rocks are typically medium to coarse grained, equigranular, and brown on weathered surfaces but grey-green on fresh surfaces (Plate 1D). Locally, plagioclase and potassium feldspar occurs are phenocrysts that are up to 2 cm long. Quartz content varies in outcrop but is generally less than 10%. Exposed contacts against older orthogneiss demonstrate that the monzonite (mangerite) intrusions have chilled margins.

Syenite

Syenite comprises potassium feldspar, plagioclase, quartz, orthopyroxene, magnetite and some rocks contain olivine. It is typically medium to coarse grained, light-pink on fresh surfaces and a salmon pink on weathered surfaces. Locally, potassium feldspar occurs as phenocrysts up to 2 cm long. Syenite occurs as distinct plutons and as thin gradational zones marginal to larger intrusions.

Granitoid Plutons

Granite

This rock unit ranges from granite to granodiorite in composition. Mafic minerals include clinopyroxene, olivine, hornblende and local biotite (Plate 1E). The rocks are typically, massive and extensively weathered to rusty-orange, and they are generally medium grained but coarse-grained variants, as distinct layers, are locally present. Feldspar laths have interstitial quartz and mafic minerals.

Quartz Syenite

This unit ranges in composition from quartz syenite to quartz monzonite. Mafic minerals include hornblende, clinopyroxene, orthopyroxene, biotite, olivine and magnetite (Plate 1F). The rocks exhibit an extensive rusty-orange veneer and are typically medium grained and massive, having plagioclase phenocrysts up to 1 cm long.

FLOWERS RIVER IGNEOUS SUITE

Regional bedrock mapping in the early 1990’s focussed on the REE-mineral potential of the FRIS (*see* Miller, 1994 and references therein). The FRIS comprises numerous, discrete, peralkaline granites that surround a variably exposed sequence of felsic volcanic rocks (Nuiklavik volcanic rocks; Figure 3). The FRIS is interpreted as a composite series of high-level felsic stocks, bounded by an outward-dipping caldera, emplaced during and/or following a period of uplift and erosion. The uplift raised the plutons 6–14 km to their present level of exposure within 30–100 Ma of their time of crystallization (Hill, 1991). A M.Sc. research project was completed in 2018 and explored the timing and petrogenesis of the suite at a regional scale (Ducharme, 2018). The study to be undertaken by the authors aims to evaluate the lithogeochemical variations in the FRIS and determine whether these variations correspond to magnetic highs and lows in the recently acquired, regional geophysical survey (Figure 4; Coyle, 2019a–d).

FLOWERS RIVER GRANITE PLUTONS

A ring of peralkaline granite plutons surrounds exposures of the Nuiklavik volcanic rocks (Figures 3 and 4). The plutons have homogenous interiors, are typically hypersolvus, medium- to coarse-grained, equigranular rocks (Plate 2A). They are amphibole (riebeckite–arfvedsonite)–pyroxene (aegirine to sodium-rich ferrohedenbergite)-bearing and having minor olivine and aenigmatite (Na-rich, iron titanium silicate; Hill, 1991). The granites were, on the basis of grain size, divided into medium- to coarse-grained granites and microgranites (Miller, 1993). The coarse-grained granites occur in the internal parts of the plutons. Microgranite occurs structurally above the coarser grained granites and intrudes the lower section of volcanic rocks and likely represents chilled variants of the medium-coarse-grained plutons (Hill, 1991).

NUIKLAVIK VOLCANIC ROCKS

The Nuiklavik volcanic rocks are seemingly confined within several overlapping collapsed calderas. Hill (1991) recognized five varieties of volcanic rocks: i) massive to well-banded rhyolite flows, ii) massive quartz–perthite por-

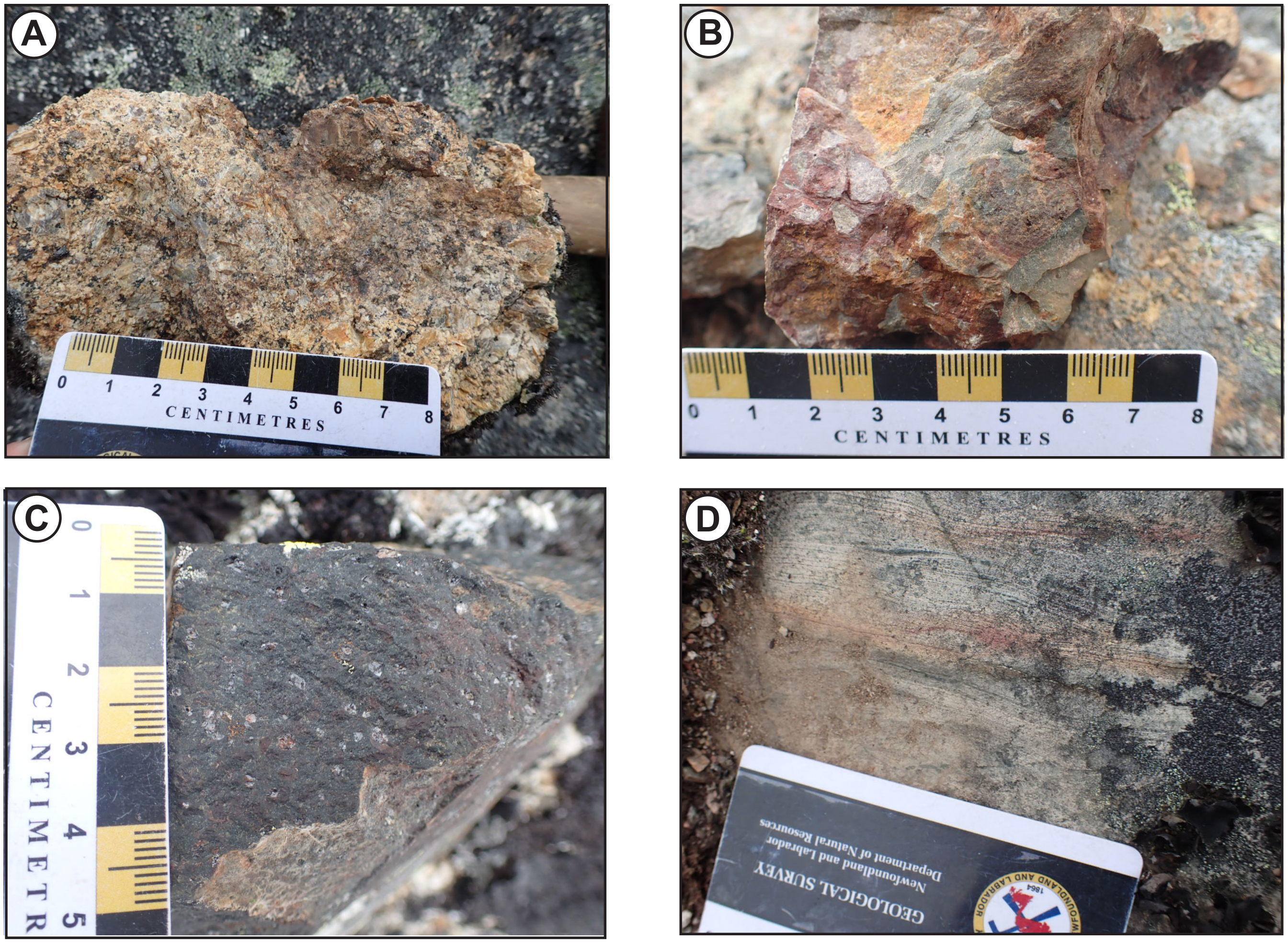

Plate 2. *Outcrop photographs of the FRIS with a graduated card for scale (in centimetres). A) Medium-grained, amphibole–pyroxene-bearing hypersolvus granite of the Flower River Plutonic Suite (22AH060); B) Brecciated rhyolite with lithic fragments, highly angular clasts possible volcanic pipe of the Nuiklavik volcanic rocks (22AH024); C) Quartz–potassium feldspar-phyric rhyolite, (22AH025); D) Strongly banded crystal tuff with minor quartz fragments, weakly magnetic (22AH026).*

phyry, iii) welded lapilli tuff, iv) air-fall agglomerate with bombs up to 1 m long, and v) various tuffisite and flow breccias (Plate 2B). Miller (1993) subdivided the volcanic sequence into: a basal tuff, an amphibole-bearing porphyry; crystal-poor and quartz-phyric felsic tuff; and upper felsic tuff. Ducharme *et al.* (2021) disregarded lithological subdivisions proposed by earlier researchers and suggested, on the basis of LAM-ICP-MS (laser ablation multi-collector inductively coupled mass spectrometry) zircon dates to define the rocks in terms of three chronological episodes of volcanism. Field observations from 2017 to 2022 noted the extensive till cover over much of the region underlain by the volcanic rocks making the seperation of lithological units based solely on geochronology problematic. In addition, the age domains proposed by Ducharme *et al.* (2021) fail to take into account the effect of topography and late-brittle faulting that control the map pattern distribution of age domains. Whereas geochronology plays an integral part in unravelling the tectonic history of a region, such studies are best framed within the known stratigraphy of a volcanic complex. The present writers, therefore, prefer to retain the stratigraphic proposed in the detailed mapping of White (1980), Hill (1982b) and Miller (1993). As part of the current project, detailed petrography and lithogeochemistry of the Nuiklavik volcanic rocks will be aimed at evaluating the stratigraphy, geochronology and aeromagnetic signature.

The volcanic rocks are subaerial and mostly rhyolitic (Plate 2C). They were deposited, in part, on a basement of NPS rocks. Despite the pristine general appearance of the rocks, they are recrystallized to a mosaic of quartz, feldspar and minor mafic minerals. Amphibole-bearing quartz–feldspar porphyries and felsic tuffs (Plate 2D) are interpreted as the oldest exposed volcanic units (Miller, 1992).

Quartz–feldspar porphyry is volumetrically the largest exposure of the Nuiklavik rocks and is associated with lesser aphyric to porphyritic rhyolite. Flow banding in the rhyolite, where exposed, strikes northwest and dips gently to the northeast. Lithic tuft occurs above the aforementioned porphyry–rhyolite sequence, but till cover hampers a definitive understanding of the actual stratigraphy of these volcanic rocks. Miller (1994) suggested there are at least seven, complete to partially eroded, nested calderas that are filled with ash-flow tuff and are encircled by rhyolitic hypabyssal ring dykes. The calderas and their volcanic fill are floored by subvolcanic granites (Flowers River granitic plutons) and, as noted above, older plutonic rocks of the NPS.

AGE CONSTRAINTS

There are few U–Pb ages for the NPS in the study area, but several samples were collected in the summer of 2022 to further refine the ages of various plutonic phases (*see* above for details on geochronology for the northern NPS). Hamilton (1997) reported a U–Pb zircon TIMS date of 1294.5 ± 1 Ma leucotroctolite from southernmost Sango Bay; however, the sampling location is not known. In addition, Ducharme *et al.* (2021) sampled parts of the NPS, which they renamed the Three Bay Pluton (combining Sango, Merrifield and Flowers Bay plutons) and their analyzed rocks yielded ages from 1289 ± 2 to 1300 ± 14 Ma. Unfortunately, it is not known how these plutons fit into the mapped lithological units (*i.e.*, Sango, Merrifield and Flowers Bay plutons). For example, their sample T0001 yields an age of 1293 ± 3 Ma and is described as a fayalite granite but plots, on Hill's geological map (Hill, 1982b), within the anorthosite of the Sango Bay Pluton. The report by Ducharme *et al.* (2021) lacks concrete information (outcrop descriptions, photographs) from which the present writers can offer alternative interpretations of the age data and the region's magmatic history.

There are greater geochronological data on the FRIS than the NPS. A peralkaline granite from the FRIS yielded a U–Pb zircon TIMS age of 1271 ± 15 Ma (Hill, 1991), whereas, a quartz–feldspar porphyry from the Nuiklavik volcanic rocks yielded a U–Pb zircon SHRIMP (sensitive high resolution ion microprobe) age of 1273 ± 13 (Rayner, 2022). Krogh (1993) reported a U–Pb zircon TIMS date of 1289 ± 2 Ma for a Nuiklavik rhyolite, and M.A. Hamilton (personal communication, 2023) derived a U–Pb zircon TIMS date of 1287 ± 2 Ma for a FRIS peralkaline granite. Recent LAM-ICP-MS zircon age data for Nuiklavik volcanic rocks define three distinct groups: concordia ages of 1290 ± 5, 1282 ± 4 and 1271 ± 6 Ma (Ducharme *et al.*, 2021). The range in ages suggests that magmatism was ongoing for ~20 m.y.

CURRENT AND FUTURE INVESTIGATIONS

The research to be undertaken during the 2023 year GSC–GSNL–NG program aims to address several knowledge gaps in our current understanding of the evolution of the southern NPS and FRIS, and consequently the evolution of the Labrador crust during the Mesoproterozoic. In that regard, the writers have sampled both the NPS and FRIS for systematic analytical studies. These studies will be centred around several key aspects of the rocks. For example, petrographic, lithogeochemical, isotopic and geochronological analyses will be undertaken to address deficiencies in current knowledge, and to create a foundation upon which to construct the magmatic history of the region. In addition, the Hopedale Block project area and appropriate rocks within it will be evaluated for elements (*e.g.*, base metals, rare earths) that might have potential for evaluation by exploration companies and contribute to the present and future industrial needs for 'critical minerals'.

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