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DEFORMATION, METAMORPHISM AND MAGMATIC ACTIVITY IN THE SOUTHERN TORNGAT OROGEN, LABRADOR

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ABSTRACT

In 2024, a new bedrock mapping project aimed at refining the geological understanding of the southern segment of the Torngat orogen in Labrador commenced. This study focuses on the Southeastern Churchill (SECP) and the western Nain provinces and examines the tectonic, metamorphic and magmatic evolution associated with the Paleoproterozoic Torngat orogeny. The project area is bounded by the Mistastin Batholith, Hopedale block, Harp Lake Intrusion and Flowers River Igneous Suite.

Preliminary mapping and earlier surveys indicate a complex geological framework comprising three structural domains. These domains include Archean to Paleoproterozoic rocks that preserve at least three superimposed deformation events. The lithological assemblage includes orthogneiss, paragneiss, amphibolite, granitoids, migmatites and mafic intrusions reflecting a history of high-temperature metamorphism, partial melting and magmatic activity.

Ongoing work will integrate lithogeochemical, isotopic and geochronological data to refine the tectonic boundaries, reconstruct the structural framework, and constrain the timing and nature of metamorphic and magmatic processes. These studies will advance mineral exploration strategies and contribute to a deeper understanding of the tectono-magmatic evolution of the Torngat orogen.

INTRODUCTION

As part of the Newfoundland and Labrador Government's, new Labrador-specific funding, a new 1:50 000-scale regional bedrock mapping project was initiated in north-central Labrador. Mapping focused on the tectonic units that record the Torngat orogeny, such as the Southeastern Churchill Province (SECP) and the western North Atlantic Craton (Nain Province). The mapping and related research aim to unravel the complex geological history of the region and establish a foundational dataset that supports mineral exploration for base metals, gold, and critical minerals within the orogenic belt.

The project area was, in part, previously mapped by Taylor (1972) at 1:250 000 scale and by Thomas and Morrison (1991) at 1:100 000 scale, providing general context about the lithologies, as well as the structural and metamorphic histories of the belt. However, key questions remain unresolved, including the tectonic evolution of the boundary between the SECP and the Nain Province and its role in their Paleoproterozoic amalgamation. Additionally, the timing of metamorphism and magmatic activity, and the evolution of the Torngat orogeny, is not well understood. Recent studies have examined metamorphic, geochemical and geochronological datasets in the context of the Torngat orogeny within its northern segment on the Québec side (*e.g.*, Charette, 2021; Godet, 2021). However, it remains uncertain whether the timing of orogeny can be consistently traced along the orogen's axis into its southern segment.

The project focuses on the southern parts of NTS 13M/09, 10 and 13N/12 map areas, and the northern parts of NTS 13M/05, 07 and 08 map areas. Mapping in 2024 focused within the central and eastern domains of the project area, with further work on the western domains planned for later field seasons. This report focuses on the preliminary interpretations based on the first field season of mapping.

GEOLOGICAL SETTING

The SECP (Figure 1) comprises a central Archean block (the Core Zone), which is bounded by the Paleoproterozoic New Québec Orogen to the west and the Torngat orogen to the east, separating it from the Superior and North Atlantic Archean cratons, respectively (Figure 1). In Labrador, the North Atlantic Craton (NAC) comprises the Hopedale and Saglek blocks (Bridgewater *et al.*, 1973). The Torngat orogen formed through the oblique collision of the composite microcontinent now preserved as the Core Zone (lower

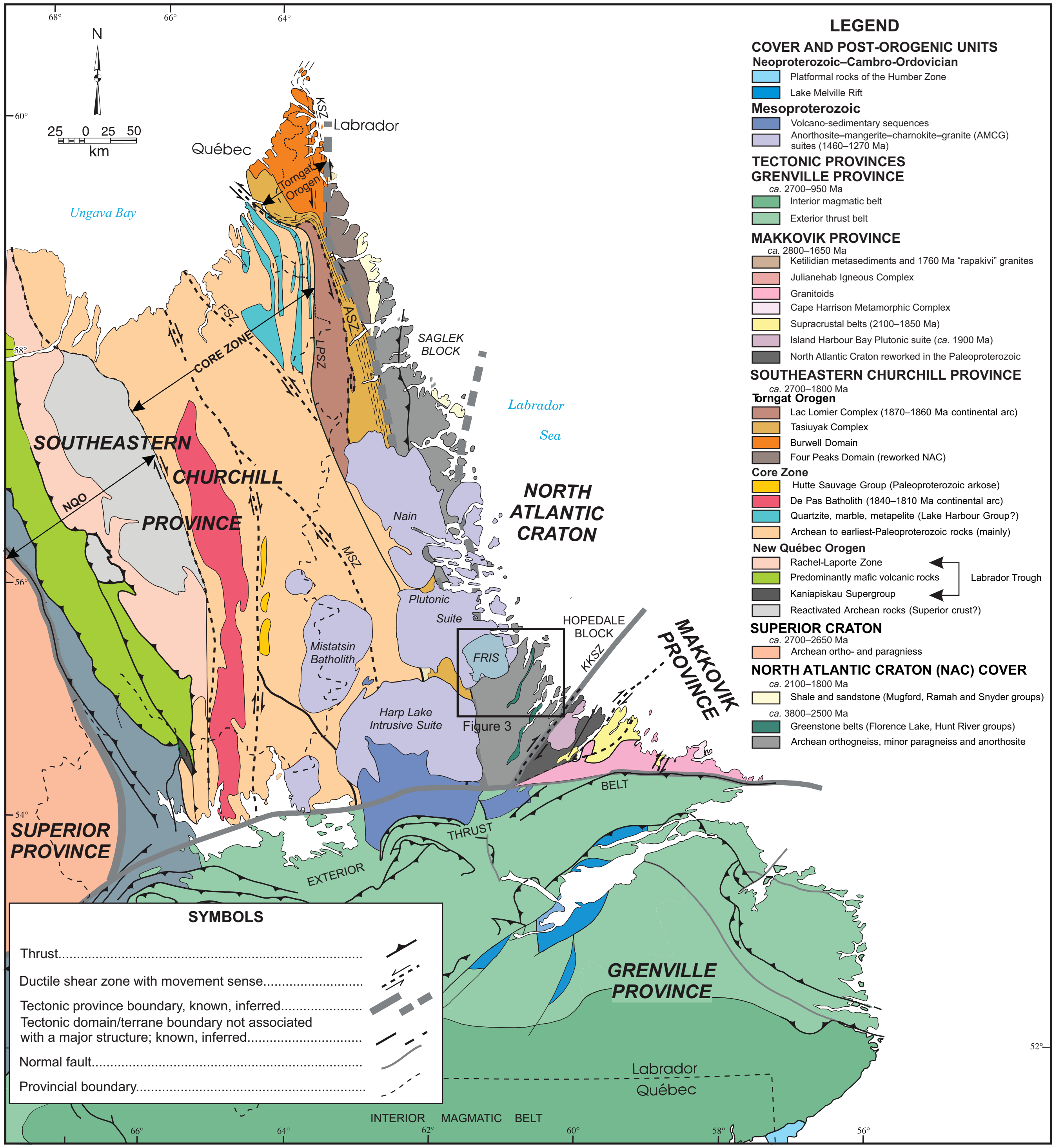

Figure 1. *Simplified geological map of eastern Québec and Labrador (modified after Hinchey* et al.*, 2024). ASZ=Abloviak shear zone; FSZ=Falcoz shear zone; MSZ=Moonbase shear zone; LPSZ=Lake Pilliamet shear zone; KSZ=Komaktorvik shear zone; NQO=North Québec Orogen; KKSZ=Kanairiktok Shear Zone; FRIS=Flowers River Igneous Suite. The location of Figure 3 is outlined.*

plate) with the North Atlantic Craton (the upper plate) (Figure 1). This orogen is characterized by a doubly-vergent structure composed of migmatized and intensely deformed rocks (Rivers *et al.*, 1996; Wardle and Van Kranendonk, 1996; Scott, 1998). In Labrador, the Torngat orogen comprises four major tectonic components, which are, from west to east: 1) the 1870–1860 Ma highly strained, granulite facies metaplutonic and orthogneiss of the Lac Lomier Complex (Figures 1 and 2; Van Kranendonk and Wardle, 1996; Campbell, 1997; Thériault and Ermanovics, 1997); 2) the 1910 and 1885 Ma calc-alkaline metaplutonic Burwell Domain (Figure 1; Scott and Machado, 1995; Scott, 1998); 3) the migmatized paragneiss and leucogranite of the Tasiuyak gneiss or Tasiuyak Complex. Here onwards, this unit is referred to as the Tasiuyak Complex, following Mathieu *et al.* (2018) (Figures 1 and 2; Mathieu *et al.*, 2018; Wardle *et al.*, 2002); and 4) the Torngat foreland, represented by the westernmost part of the NAC (Figures 1 and 2; Ryan, 1990; Van Kranendonk, 1996).

The Core Zone comprises Archean gneissic basement overlain by Archean to Paleoproterozoic supracrustal rocks. The Core Zone is composed of three distinct lithotectonic units: the George River, Mistinibi–Raude and Falcoz River blocks, which are separated by large-scale shear zones (Corrigan *et al.*, 2018). These blocks are interpreted as Archean to earliest Paleoproterozoic microcontinents and crustal fragments associated with the Manikewan Ocean. This ocean closed around 1.83–1.80 Ga during the assembly of the supercontinent Nuna (Hoffman, 1989). Compared to the highly strained high-grade rocks of the Torngat orogen, the Core Zone is characterized by less intense deformation and peak metamorphic conditions generally within the upper-amphibolite facies (Wardle *et al.*, 2002).

The Lac Lomier Complex, located along the central axis of the orogen, west of the Tasiuyak Complex (Scott, 1998), predominantly comprises an interfolded assemblage of granulitic gneisses with minor metasedimentary components highly deformed by sinistral shear related to the Abloviak and Falcoz shear zones. The complex's origin remains uncertain, with U–Pb zircon crystallization ages ranging from ~1.85 to 1.82 Ga (Bertrand *et al.*, 1993; Ermanovics and Van Kranendonk, 1998). Competing interpretations suggest it represents either the roots of a magmatic arc along the Core Zone margin (Ermanovics and Van Kranendonk, 1998) or an arc formed by eastward subduction, subsequently interfolded with the Tasiuyak Complex (Wardle *et al.*, 2002).

The Tasiuyak Complex, similarly to the Lac Lomier Complex, occurs along the length of Torngat orogen and consists of garnet biotite-bearing paragneiss and leucocratic quartzofeldspathic gneiss (Wardle, 1983). The depositional age of the paragneiss of the Tasiuyak Complex is constrained between 1940 and 1895 Ma (Scott, 1995). The rocks of the Tasiuyak Complex underwent granulite-facies metamorphism related to the Torngat orogeny between ~1.89–1.73 Ma, locally overprinted by ultra-high temperature (UHT) metamorphism during the emplacement of the ~1.3 Ga Nain Plutonic Suite (*e.g.*, Tettelaar and Indares, 2007). The regional granulite-facies metamorphism is associated with migmatization and with the formation of garnet, biotite, K-feldspar and sillimanite assemblages. Based on its juvenile isotopic character and maximum depositional ages of 1.94 Ga, Wardle and Van Kranendonk (1996) proposed that the Tasiuyak Complex formed as an accretionary prism during the eastward subduction of the Southeastern Churchill Province beneath the NAC.

THE TORNGAT OROGEN

The Torngat orogen evolved through three distinct tectonic events – termed D_1, D_2 and D_3 by Wardle *et al.* (2002) – over approximately 80 million years. While the model presented below represents the most up-to-date framework for the Torngat orogen, it is primarily based on studies conducted in the northern and central segments of the orogen in Labrador and Québec. Hence, it does not fully capture the geologic evolution of the project area, situated in the narrower southern segment of the orogen, where tectonic events are thought to be superimposed (Wardle *et al.*, 2002).

The oldest event, D_1, is characterized by U–Pb zircon and monazite and Lu–Hf and Sm–Nd garnet metamorphic ages of ~1.89–1.86 Ga (Bertrand *et al.*, 1993; Van Kranendonk, 1996; Charette *et al.*, 2021; Godet *et al.*, 2021) in the Tasiuyak Complex, where it is associated with peak granulite-facies metamorphism at pressures of 9.5 kbar and 950°C (Van Kranendonk, 1996). Similar metamorphic ages have been reported from the Torngat foreland in the western Nain Craton (Wardle *et al.*, 2002); however, the extent of Torngat orogeny-related metamorphism within the Nain Craton, particularly in the project area, remains uncertain. The straightened fabric of the Tasiuyak Complex, which predates Abloviak shear zone (Figure 1), may also result from D_1 collision-induced deformation (Rivers *et al.*, 1996).

The second event, D_2, is related to the development of the sinistral Abloviak shear zone and decompression reactions in the orogen's axial region. The Abloviak shear zone formation is constrained by zircon U–Pb TIMS dates between 1.845 and 1.820 Ga (Bertrand *et al.*, 1993) under granulite-facies conditions of 7.3–5.0 kbar and 700–600°C (Van Kranendonk, 1996). Other sinistral shear zones, such as the Falcoz and Moonbase shear zones, appear kinematically linked to the Abloviak shear zone (Figure 1).

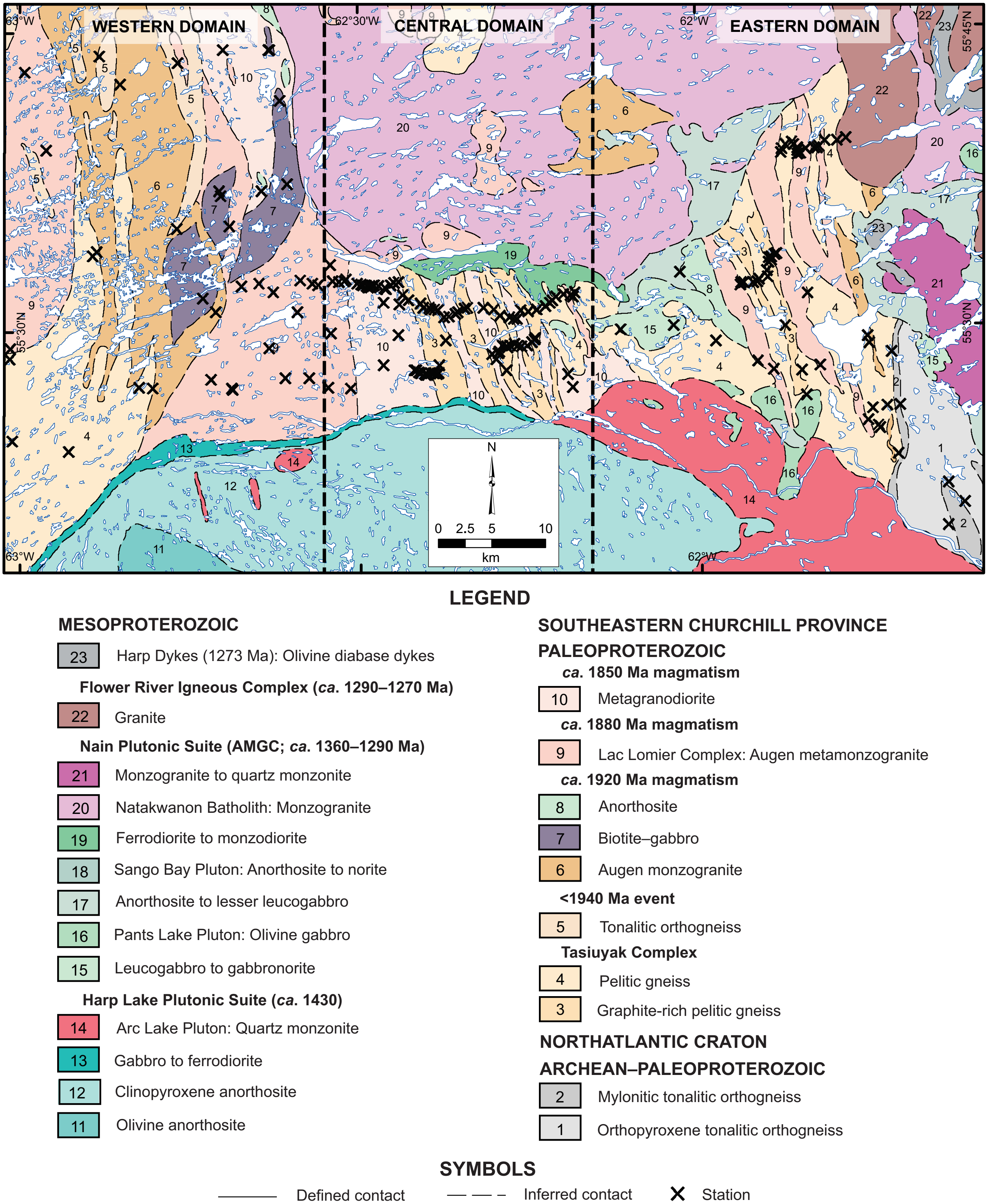

Figure 2. *Geologic map of the project area showing the three structural domains and the locations of the 2024 field season sample stations. (Additional unpublished data, A.M. Hinchey, 2025.)*

The D_3 event is localized along the eastern boundary of the Torngat orogen, and it is associated with east-verging ultramylonite zones along the Tasiuyak domain–NAC contact (Van Kranendonk, 1996), and deformation within the Komaktorvik shear zone. This event is dated by zircon U–Pb TIMS between 1.80 and 1.74 Ga (Bertrand *et al.*, 1993). Metamorphism during D_3 caused further retrogression of earlier granulite-facies assemblages. Additionally, D3 produced a series of west-side-up ultramylonite zones along the Tasiuyak Complex–NAC contact, constrained by U–Pb zircon and monazite dates at ~1.79–1.74 Ga (Van Kranendonk, 1996).

METHODS

Lithological and structural data were recorded at 195 outcrops, and 148 samples were collected for lithogeochemical and petrological analyses (*see* Figure 2 for outcrop locations and lithological details). Field data collection was conducted with the GSC field app using a Panasonic ToughPad, whereas structural measurements were taken using a Breithaupt compass with a negative 20° declination setting. Data were compiled and visualized using ArcMap and ArcGIS Pro, and structural data were analyzed and plotted using the Stereonet software v. 11.5.1 (Allmendinger *et al.*, 2012; Cardozo and Allmendinger, 2013).

RESULTS

STRUCTURES AND LITHOLOGIES

The project area has been subdivided into three structural domains (Figure 2) based on the orientation of structures (Figure 3), deformation styles and lithological differences.

Western Domain

The western domain (Figure 2, Plate 1) is continuous with similar Churchill Province rocks described by numerous studies focused on the Core Zone (*e.g.*, Hill, 1982; Thomas and Morrison, 1991; Corrigan *et al.*, 2018). Within this domain, strain is variable, with fabrics becoming progressively more mylonitic towards the eastern boundary and displaying a predominantly dextral sense of shearing. The regional structure is characterized by a series of regional-scale, upright, tight to close, periclinal F_2 folds. These F_2 folds deform earlier F_1 isoclinal recumbent folds, which are locally preserved in the hinges of the regional F_2 structures (Plate 1A) The gneissic foliation S_1 is a prominent feature in the orthogneiss and paragneiss and is locally preserved as a relict foliation within the deformed amphibolitic mafic boudins (Plate 1B). The S_2 axial-plane foliation typically dips moderately to steeply and strikes to the north, although significant variations are observed due to deflection around metaplutonic blocks, such as the 12 × 5 km gabbro intrusion described below. The western domain's predominant lithologies (Figure 2) are amphibolite-facies metaplutonic rocks derived from a variety of protoliths, including anorthosite, gabbro, monzogranite, granite, migmatite, paragneiss and subordinate mafic boudins.

Anorthosite in this domain is medium to coarse grained, consisting of euhedral to subhedral plagioclase augen, interstitial amphibole, and minor biotite. Anorthosite outcrops in the eastern part of the western domain exhibit dextral shear sense indicators (Plate 1C). A kilometre-scale gabbro body is exposed in the central part of the western domain (Figure 2). This gabbro is medium grained, foliated, and composed predominantly of biotite and hornblende.

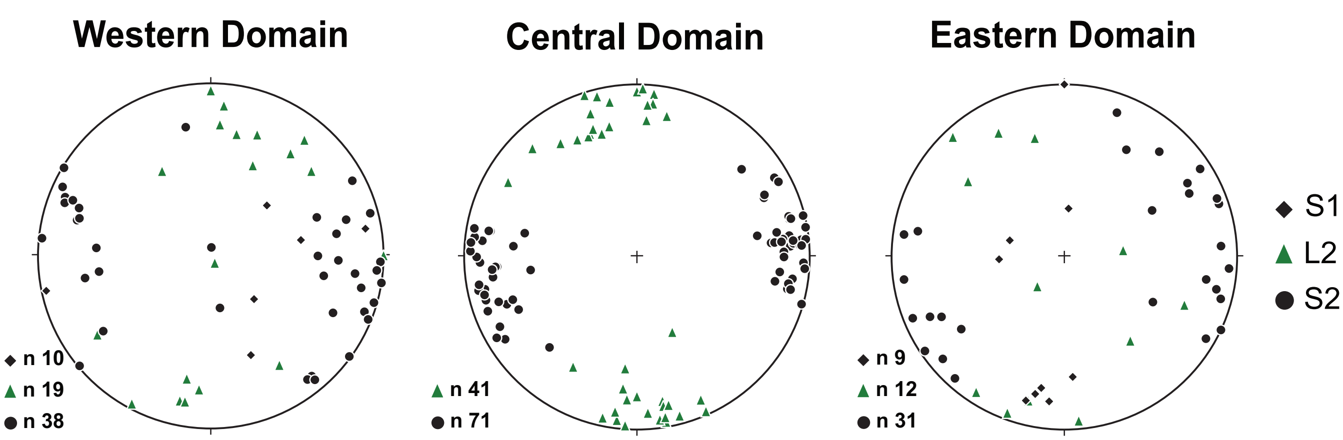

Figure 3. *Equal-area, lower-hemisphere stereonets displaying structural measurement from each structural domain. Stereographic projections were generated using Stereonet software v. 11.5.1 (Allmendinger* et al.*, 2012; Cardozo and Allmendinger, 2013).*

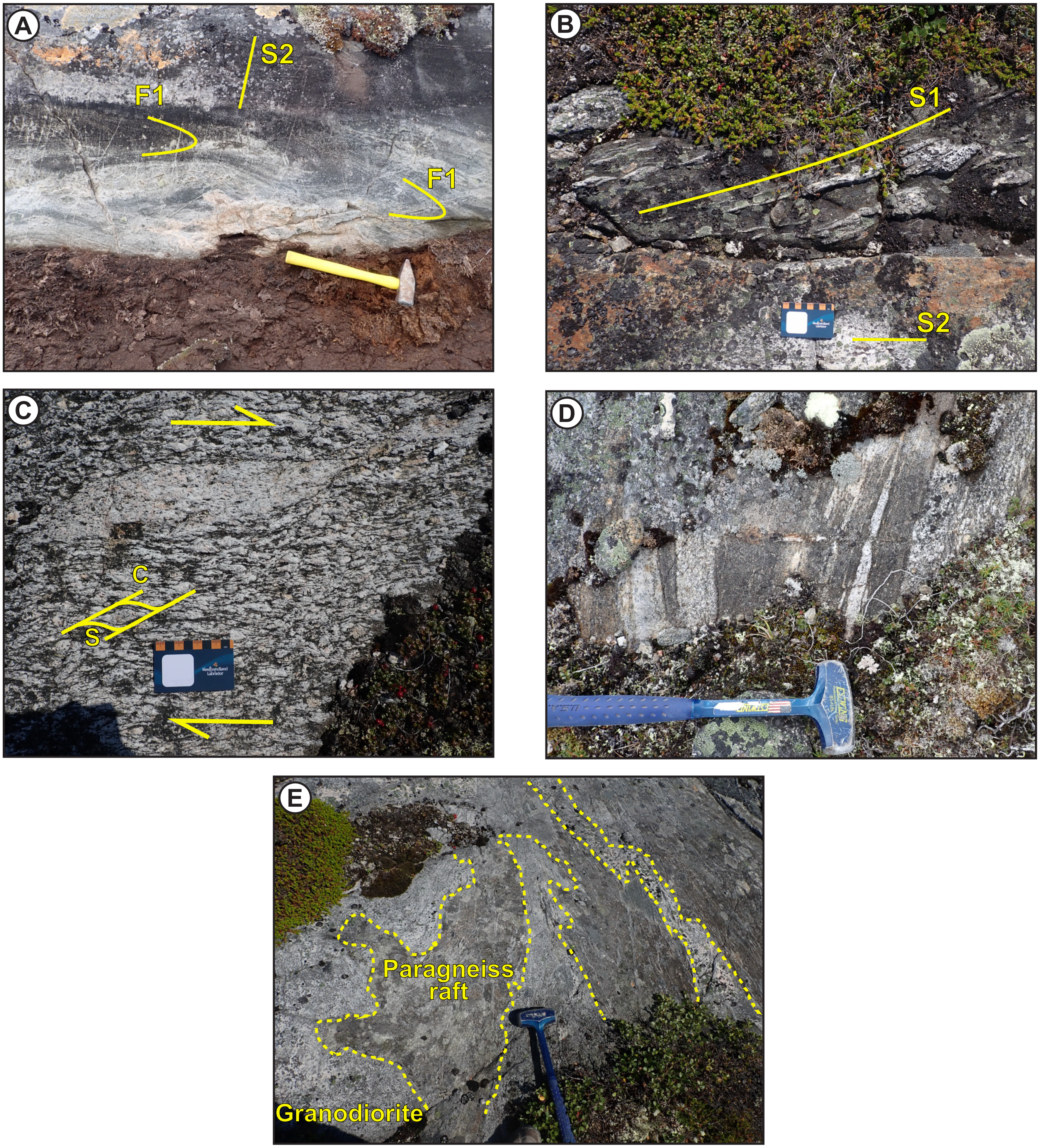

Plate 1. *Field photographs illustrating key lithologies and structures in the western domain. A) F_1 isoclinal recumbent folds preserved in the hinge of a regional-scale F_2 fold; B) Sigmoidal S_1 gneissic foliation in a deformed amphibolitic mafic boudin, indicating dextral shearing; C) Plagioclase porphyroclasts and S-C fabrics indicate dextral shear in an anorthosite; D) Paragneiss with layers enriched in hornblende and biotite, locally containing garnet, interlayered with granoblastic quartz, plagioclase and subordinate alkali feldspar; E) Paragneiss raft enclosed within deformed granodiorite.*

Monzogranite and granite are widespread throughout the western domain, occurring as medium to coarse grained, equigranular, granoblastic and undeformed to mylonitic rocks. Kilometre-scale granite intrusions have been documented in the northern sector, although these rocks more commonly represent partial melting products of orthogneiss or paragneiss. Paragneiss are characterized by centimetre-scale layers enriched in hornblende and biotite, and locally garnet, interlayered with granoblastic quartz, plagioclase, and subordinate alkali feldspar (Plate 1D). Paragneiss also occur as rafts within metamonzogranite and metagranite (Plate 1E).

Central Domain

The central domain (Figure 2) is a subvertical, north-striking D_2 mylonite zone. The mylonitic schistosity is pervasive across all lithotypes and features a strong, shallow-plunging lineation (L_2) oriented to the north or south (Figure 3). D_2 deformation is dominated by sinistral shear sense indicators, including sigmoidal porphyroblasts, S–C structures (Plate 2A), and shear bands. Locally preserved dextral kinematic indicators, currently interpreted to have formed during the D_1 deformation stage, are also observed. The earlier S_1 foliation is preserved as a gneissic fabric deformed and transposed by rootless D_2 folds (Plate 2B).

The central domain primarily comprises steeply dipping, north-trending layers (ranging from 1 cm to 200 m wide) of orthopyroxene-bearing metatonalite and metagranodiorite, amphibolite lenses and layers, metagranite, garnet-bearing leucogranite, metagabbro, and garnet–biotite pelitic gneiss. Orthopyroxene-bearing metatonalite and metagranodiorite contain pyroxene-rich lenses and layers interlayered with metagranite (Plate 2C). Amphibolite layers and lenses, composed of amphibole, plagioclase, garnet and biotite, are typically associated with the orthopyroxene-bearing metatonalite and are elongated parallel to the dominant D_2 fabric. The metagranite exhibits white- to pink-weathering and is composed of quartz, plagioclase, K-feldspar, biotite and minor amphibole (Plate 2A). Intense deformation obscures primary crosscutting relationships: however, when preserved, these relationships suggest that the metagranite intruded the orthopyroxene-bearing metatonalite and metagranodiorite. The metagabbro, primarily exposed in the western part of the central domain, has a mylonitic texture characterized by fine-grained pyroxene, plagioclase, and amphibole arranged in centimetre-scale layers. It also features boudinaged layers and lenses of pegmatitic clinopyroxene, plagioclase, quartz, and minor amphibole (Plate 2D). The garnet-bearing leucogranite, occurring mainly in the eastern part of the central domain, consists of medium-grained idioblastic garnet and fine- to medium-grained quartz and plagioclase (Plate 2E).

The garnet–biotite paragneiss exhibits a spaced S_1 foliation defined by garnet, biotite and sillimanite layers (0.5–5 cm thick) interlayered with quartzofeldspathic layers (1–20 cm thick). These layers are locally deformed by F_2 isoclinal folds (Plate 2A). The paragneiss is locally migmatitic, as indicated by the presence of foliation-parallel, elongated leucocratic lenses of quartz, plagioclase, and euhedral garnet, surrounded by melanocratic selvedges. Gossanous zones, containing biotite, white mica, graphite and pyrrhotite, occur in the paragneiss and can be up to 20 m wide. In the central domain, mafic lithologies are more common in the western side, while more evolved igneous rocks dominate towards the eastern side.

The lithological associations, deformation style, and predominant granulite-facies metamorphism in the central domain are comparable to those documented in the Lac Lomier Complex and Sukaliuk Complex (Lafrance *et al.*, 2015). Furthermore, the regional-scale shear zone in the central domain may correlate with shear zones in the northern Torngat orogen, including the Abloviak, Falcoz, Moonbase and Lake Pilliamet shear zones (Corrigan *et al.*, 2018).

Eastern Domain

The eastern domain is characterized by lower strain compared to the central domain, with strain intensity decreasing progressively eastward. A comprehensive structural definition of this domain is currently limited; however, it is generally characterized by close to tight, metre- to kilometre-scale F_2 folds having shallow to steep northwest- and southeast-plunging L_2 lineations. The axial-plane S_2 foliation dips between 2 and 29° and trends toward the northwest (Figure 3). D_2 structures are deformed and re-oriented near the Nain Plutonic Suite intrusions, suggesting that significant deformation occurred during the ~1.3 Ga magmatic event. D_2 mylonites, which are generally dextral, develop in metatexites, diatexites, and granites and are particularly common near the inferred boundary with the Nain Province (Plate 3A).

The eastern domain comprises garnet, (garnet)-bearing megacrystic granite, mafic dykes, aplites, garnet-bearing granodiorite and tonalite, garnet–biotite paragneiss, diatexite and metatexite. The garnet-bearing megacrystic granite (Plate 3B) forms intrusions of variable sizes, mostly occurring in the central part of the mapped area. It consists of plagioclase megacrysts, euhedral to subhedral garnet, and a matrix of quartz, K-feldspar, biotite and amphibole. Garnet is observed both as inclusions in K-feldspar and within the matrix. The megacrystic granite is intruded by mafic dykes and aplites (Plate 3C), with gradational contacts that suggest the aplites intruded into the granite, as evidenced by the

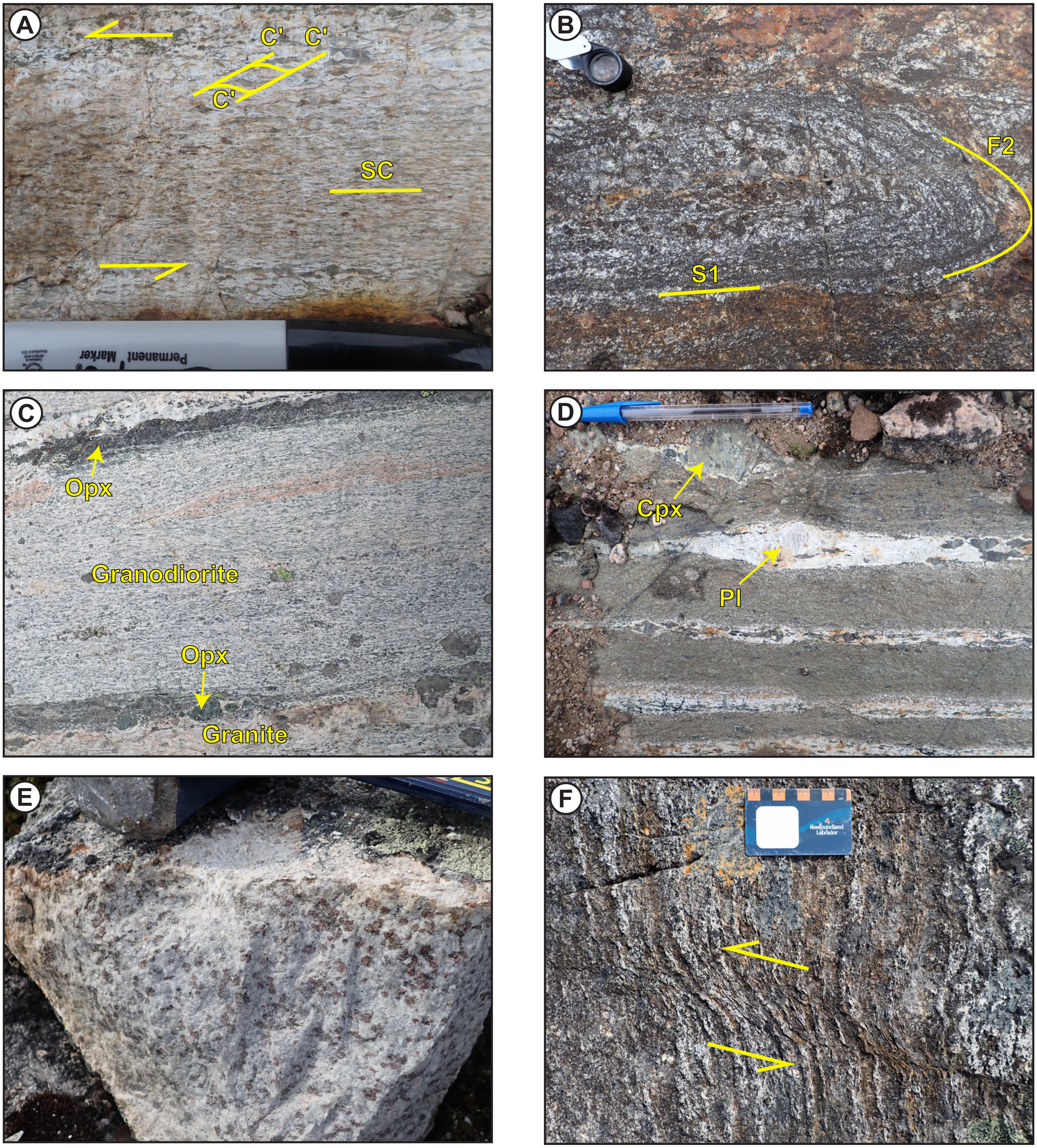

Plate 2. *Field photographs illustrating key lithologies and structures in the central domain. A) S-C fabric in mylonitic granite, indicating sinistral shearing; B) Isoclinal F_2 folds deforming S_1 spaced foliation, marked by garnet, biotite and sillimanite layers, along with quartzofeldspathic layers; C) Metagranodiorite containing pyroxene-rich lenses and layers, interlayered with metagranite (width of photograph is approximately 30 cm); D) Mylonitic metagabbro with fine-grained layers of pyroxene, plagioclase and amphibole, and boudinaged layers and lenses of pegmatitic clinopyroxene, plagioclase, quartz and minor amphibole; E) Garnet-bearing leucogranite with idioblastic garnet and fine- to medium-grained quartz and plagioclase. F) D_3 sinistral shearing localized along a brittle-ductile D_3 shear zone.*

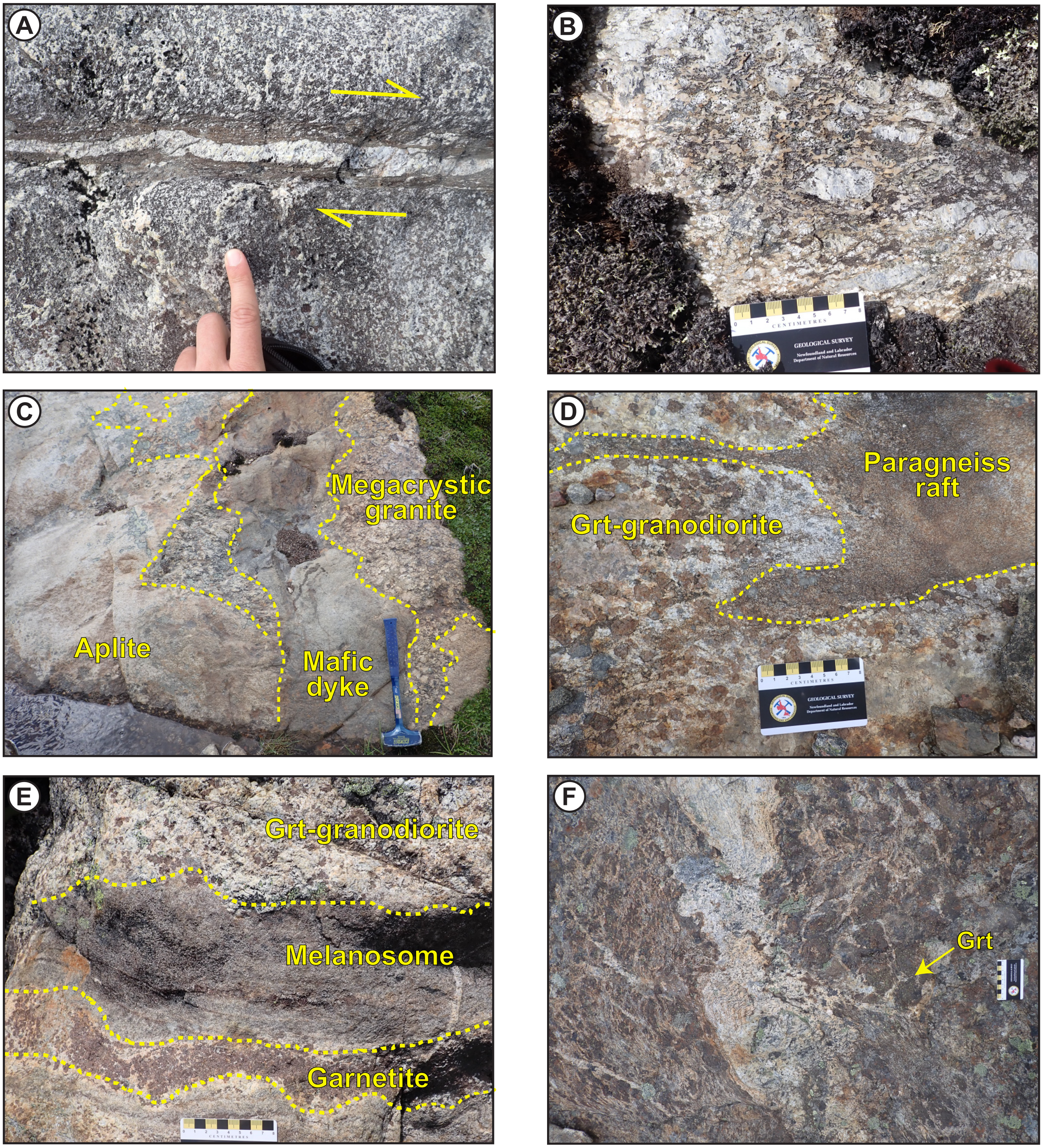

Plate 3. *Field photographs illustrating key lithologies and structures in the eastern domain. A) Dextral D_2 mylonite developed along a leucocratic vein within a metatexite; B) Garnet-bearing megacrystic granite, featuring plagioclase megacrysts, euhedral to subhedral garnet, and a matrix of quartz, K-feldspar, biotite and amphibole; C) Outcrop displaying crosscutting relationships between the garnet-bearing megacrystic granite, a mafic dyke and an aplite; D) Paragneiss raft enclosed within a garnet-bearing granodiorite; E) Banded metatexite composed of garnet-bearing granodiorite, melanosome and garnetite; F) Garnet–biotite migmatitic paragneiss featuring garnet megablasts and crosscutting leucocratic dykes.*

presence of granite megacrysts within the aplites. The megacrystic granite also intrudes the diatexites and metatexites, as indicated by mesosome and melanosome rafts preserved within it. The garnet-bearing granodiorite and tonalite are similar to those in the central domain but are coarser grained and form significantly larger intrusions. These rocks intrude the garnet–biotite paragneiss, as evidenced by paragneiss rafts within the granodiorite (Plate 3D). Layers of granodiorite and tonalite are locally concordant with mesosome and melanosome layers, suggesting they may represent partial melting products of the garnet–biotite paragneiss (Plate 3E). Intrusions of granodiorite, tonalite and megacrystic granite extend for several kilometres parallel to the north-northeast-trending regional fabric and range from 10 m to 1–2 km in width.

The garnet–biotite paragneiss exhibits compositional layering, with 1–20-cm wide, fine- to medium-grained biotite–garnet–sillimanite layers alternating with up to 1-m-wide, medium- to coarse-grained garnet-bearing tonalitic to granodioritic leucosome. Gossanous zones, up to 10 m wide, are mostly hosted in paragneiss, containing biotite, graphite, and pyrite. The garnet–biotite paragneiss is similar to those described in the central domain and has been correlated with the Tasiuyak Complex to the north (Thomas and Morrison, 1991). However, in the northeastern part of the eastern domain, it features garnet megablasts having cordierite rims, high modal proportions of fibrous to prismatic sillimanite, and a higher proportion of concordant and discordant leucosome (up to 15–20%) (Plate 3F). Partial melting of the paragneiss generates metatexites and diatexites displaying a variety migmatitic textures.

Evidence of high-temperature (HT) metamorphism and multiple generations of anatectic magmas suggests prolonged magmatism and partial melting. Observations from the eastern domain reveal a complex metamorphic and magmatic evolution, consistent with features documented in the northern Tasiuyak Complex (*e.g.*, Tettelaar and Indares, 2007; Mitchell, 2014; Charette *et al.*, 2021; Godet *et al.*, 2021). Subvertical, east–west-trending dextral and sinistral faults and shear zones crosscut D_1 and D_2 structures at high angles across the project area (Plate 2F). These features are interpreted as part of a regional-scale brittle–ductile deformation event, D_3.

ECONOMIC POTENTIAL

The economic potential has been tested by mineral exploration efforts since the 1950s, mainly focused on the Ni–Cu–Co potential in mafic magmatic and gneissic rocks located in the Pants Lake area, part of the Nain Plutonic Suite. Magmatic sulphide mineralization first identified in the Pants Lake area (Thomas and Morrison, 1991) did not attract exploration interest until 1995, following the discovery of the Voisey's Bay deposit. From 1995 to 2008, exploration was conducted on the SVB Property by operators including Donner Minerals, Teck Exploration, Commander Resources and Falconbridge Limited. Efforts encompassed stream-sediment geochemistry, prospecting, geological mapping, numerous geophysical surveys (*e.g.*, magnetics, EM, IP, gravity, UTEM), and diamond drilling with a total of 55 holes. Exploration efforts after 2014 were led by Teck Exploration, Falconbridge, Commander Resources and Fjordland Exploration Inc.

CURRENT AND FUTURE INVESTIGATIONS

The primary focus of ongoing studies in the region is to accurately locate the tectonic boundaries between the Hopedale block and the SECP. This study refines the structural and kinematic framework necessary for understanding the Torngat orogen and to support future mineral-exploration efforts in the region. Additionally, we aim to identify distinct units within the SECP to unravel the characteristics and timing of magmatic and metamorphic events, essential for interpreting the tectono-magmatic evolution of the Torngat orogeny. Characterizing the presence, structure, and extent of units within the SECP (*e.g.*, Lac Lomier Complex; Figure 1) is also crucial for establishing correlations with the better-understood northern sections of the Torngat orogen. These efforts will provide a robust basis for regional geological interpretations and facilitate comparisons across tectonic domains. A deeper understanding of the structural and metamorphic evolution of the Torngat orogen is essential for identifying major tectonic lineaments, which play a key role in determining the mineral prospectivity associated with related fault systems. Future fieldwork will concentrate on investigating the characteristics of structural and intrusive contacts in critical areas defining the main units and tectonic provinces, such as the central and eastern domains.

SUMMARY

The 2024 mapping results underscore the importance of field mapping to establish a robust structural and stratigraphic framework for understanding the Torngat orogen's architecture between the SECP and the Hopedale block (NAC). New lithogeochemical data and petrographic studies, combined with interpretations of the structural framework, will lay the groundwork for future research in the area. This project aims to develop a foundation for exploring critical minerals and base-metal mineralization.

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