New regional mapping of Precambrian rocks north of Fury and Hecla Strait, northwestern Baffin Island, Nunavut


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The Fury and Hecla Geoscience Project (FHGP) is being led by the Canada-Nunavut Geoscience Office in collaboration with researchers and students from Laurentian University, McGill University and Université du Québec à Montréal. The multiyear project involves mapping and sampling of Archean, Proterozoic and Paleozoic rocks, and Quaternary surficial deposits and features. The study area comprises all or parts of nine 1:250,000 scale National Topographic System (NTS) map areas north and south of Fury and Hecla Strait on Baffin Island and Melville Peninsula, respectively (NTS 37C, F, 47C–H and 48A).


Abstract

This paper presents new field observations collected during five weeks of Precambrian bedrock mapping in summer 2018 in the area north of Fury and Hecla Strait on northwestern Baffin Island, Nunavut, and preliminary correlations with rock units in neighbouring areas. Basement rocks, all presumed to be Archean in age, include tonalite–granodiorite orthogneiss that hosts mafic–ultramafic intrusions; supracrustal panels comprising metamorphosed quartzite, biotite psammite, biotite–muscovite±sillimanite±garnet semipelitic–pelitic, iron formation, mafic volcanic rocks and ultramafic bodies; K-feldspar megacrystic monzogranite–quartz monzonite; massive syenogranite–quartz syenite; and pegmatitic felsic dykes. A non-conformity surface separates the Archean basement components from the overlying Mesoproterozoic Fury and Hecla Group sedimentary rocks. Field observations confirm the basin’s previously defined stratigraphy and add new data to further constrain the depositional architecture and development of the basin. Neoproterozoic mafic igneous rocks cut the basin and basement rock units, and provide an uppermost age limit for the chronostratigraphic development of the Fury and Hecla Group.

Four tectonothermal events have imposed deformational and metamorphic structures, fabrics and mineral growth, which are restricted to the Archean basement rocks. Brittle deformation associated with Mes- to Neoproterozoic extensional and igneous events is evident across the study area. The area’s mineralization potential is still to be assessed through whole-rock and assay geochemistry, but may include iron-formation–hosted Au and/or Mo, and magmatic Ni-Cu-PGE±Cr associated with mafic–ultramafic rocks. Additionally, new U, Th and diamond-bearing kimberlite occurrences could be identified through analytical processing of new geophysical-survey data.

Samples were collected to support thematic research projects to determine the timing of emplacement, protoliths and tectonothermal histories of Archean basement rocks; the architecture and timing of deposition of the lithostratigraphic components of the Fury and Hecla Basin; and the geochemical signatures and timing of mafic igneous events that cut the basement and basin rocks.

Résumé

Le présent rapport fait état de nouvelles observations recueillies sur le terrain à l’été 2018, au cours de cinq semaines de travaux de cartographie du socle rocheux précambrien dans une région située au nord du détroit de Fury et Hecla, au nord-ouest de l’île de Baffin, au Nunavut; il présente en outre les premières corrélations établies entre les roches de la région et celles des régions environnantes. Les roches du socle, prouvemment archéennes, se composent d’orthogneiss de nature

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tonalitique à granodioritique, renfermant des intrusions de composition mafique à ultramafique; de panneaux de roche supracrustale constitués de quartzite métamorphisée, de psammité à biotite, de semipélite et pélite à biotite-muscovite+sillimanite+garnet, de formation ferrifère, de roches volcaniques mafiques et d’amas ultramafiques; de monzogranite et de monzonite quartzite à phénocristaux de feldspath potassique; de syénogranite et de syénite quartzite massives; et de dykes pegmatitiques de composition felsique. Une discordance sépare les éléments du socle archéen des roches sédimentaires sus-jacentes du Groupe de Fury and Hecla d’âge mésoprotérozoïque. Les observations de terrain confirment la stratigraphie du bassin auparavant établie et viennent ajouter de nouveaux éléments d’information qui permettront de mieux circonscrire la répartition sédimentaire et l’évolution du bassin. Des roches ignées de composition mafique et d’âge néoprotérozoïque recoupent les unités lithologiques du bassin et du socle rocheux et permettent d’établir une limite d’âge supérieure à la mise en place du Groupe de Fury and Hecla.

Quatre épisodes tectonothermiques ont régi l’évolution des structures métamorphiques et celles liées à la déformation, de la formation des fabriques et de la croissance des minéraux, dont le résultat ne se retrouve que dans les roches du socle archéen. Des signes de déformation cassante associés à des processus ignés et d’extension s’étant produits au cours d’une période s’étendant du Mésoprotérozoïque au Néoprotérozoïque se manifestent dans toute la région à l’étude. Le potentiel en minéralisation de la région reste à définir au moyen d’analyses sur roche totale et d’essais géochimiques; il peut s’agir d’or et/ou de molybdène encaissés dans des formations ferrifères, ou même de minéraux magmatiques (Ni-Cu-éléments du groupe du platine+Cr) associés à des roches de composition mafique à ultramafique. En outre, de nouveaux indices d’uranium, de thorium et de kimberlites diamantifères pourraient être découverts à l’aide de l’analyse de nouvelles données provenant de levés géophysiques.

Les échantillons recueillis serviront à appuyer la recherche entreprise dans le cadre de projets ayant pour objet d’étudier l’évolution de la mise en place, des protolites et des processus tectonothermiques associés aux roches archéennes du socle rocheux; l’architecture et l’histoire de la sédimentation des composantes lithostratigraphiques du bassin de Fury and Hecla; et enfin les signatures géochimiques et l’évolution des processus ignés de nature mafique ayant recoupé les roches du bassin et du socle.

**Introduction**

The land north and south of Fury and Hecla Strait comprises presumed Archean to Paleoproterozoic orthogneiss and paragneiss, a Mesoproterozoic to Neoproterozoic sedimentary basin and subvolcanic intrusions, Paleozoic carbonate rocks and a variety of Quaternary glacial deposits and landforms. Only parts of this area have been previously mapped geologically through field-based work (e.g., Blackadar, 1964; Chandler, 1988; Ciesielski, 1992), whereas some areas have been explored with low-resolution airborne geophysics (e.g., Holman et al., 2001) and still other areas have never been geologically investigated. Furthermore, a large part of the area does not have airborne geophysical data despite the presence of known mineral resources and showings in neighbouring regions, including iron-ore deposits (Jackson, 1966; Young et al., 2004), diamond-bearing kimberlite bodies (Chartier and Januszczak, 2008), and U and Th anomalies (Fisher and Kwiecien, 1981; Chandler, 1988). The Canada-Nunavut Geoscience Office, in partnership with researchers and students from Laurentian University, McGill University and Université du Québec à Montréal, has developed the Fury and Hecla Geoscience Project (FHGP) to generate new geoscience information for this area, thereby filling some of these geoscience knowledge gaps.

The FHGP is a multiyear initiative that aims to collect modern geophysical data; conduct bedrock- and surficial-geology mapping and sampling; constrain rock-crystallization ages, metamorphic events and sedimentary deposition with geochronology; and assess the natural composition and economic potential of rock and till samples with geochemistry. With this information, a comprehensive geological history of the region surrounding Fury and Hecla Strait can be constructed, including the timing and duration of episodes of crust formation, tectonometamorphic events and basin development. Similarly, relationships with neighbouring crustal blocks to the south (Melville Peninsula) and east (central Baffin Island) may be investigated to help understand paleogeographic reconstructions and the potential for economic-mineral deposits and showings. The study area includes all or parts of nine 1:250 000 National Topographic System (NTS) map areas that are located north and south of Fury and Hecla Strait on northwestern Baffin Island and northern Melville Peninsula, respectively (NTS 37C, F, 47C–H and 48A; Figure 1).

In 2017, the FHGP began with a regional airborne-geophysical survey over parts of NTS 37C and F, and 47D–F. The survey was flown with north-trending traverse lines and orthogonal control lines at 400 m and 2400 m line spacings, respectively, and passively collected naturally occur-
ring magnetic and radiometric signals from a nominal terrane clearance of 125 m above ground level. The resulting datasets (Steenkamp, 2018a–h) were used to target key areas of interest for the 2018 bedrock- and surficial-geology mapping campaign, and identify important sampling sites for thematic research projects being carried out by university partners (Figure 2). This paper presents some of the scientific questions that form the basis of the FHGP mapping campaign of Precambrian bedrock and highlight the major rock types and features identified during 2018 fieldwork. It also discusses the implications of these findings, some economic considerations, and plans for future field- and laboratory-based work that will add value to the project.

Regional and local geological setting

Basement rocks south, north and east of Fury and Hecla Strait lie within the ca. 3.0–2.5 Ga Committee Bay fold belt (Jackson and Berman, 2000; Corrigan et al., 2013), which is part of the northern Rae domain in the western Churchill Province (Hoffman, 1988). In general, these rocks represent Archean continental crust and supracrustal belts that record enigmatic tectonometamorphic events prior to 2.7 Ga, and the MacQuoid orogeny at ca. 2.55–2.50 Ga (Jackson and Berman, 2000; Bethune and Scammel, 2003a; Sanborn-Barrie et al., 2003; Berman et al., 2010). The western margin of the Committee Bay fold belt preserves a ca. 2.35 Ga metamorphic fabric that is ascribed to the Arrowsmith orogeny (Berman et al., 2013, 2015; Pehrsson et al., 2013). The greater Rae domain is bordered to the west by the 2.0–1.9 Ga Taltson-Thelon orogen (Hoffman, 1989) and to the east by the ca. 1.9–1.8 Ga Trans-Hudson orogen, to which its dominant northeast-striking structural fabric is attributed (Hoffman, 1988; St-Onge et al., 2007, 2009).

South of the strait, Archean amphibolite- to granulite-grade orthogneiss, migmatite and granitic intrusions predominate
The rocks along the shorelines of Fury and Hecla Strait and Admiralty Inlet, and up to ~100 km inland from the southern shores of Baffin Island, were first investigated in 1955–1957 (Blackadar, 1958; 1963; 1964). During later mapping along the northern shores of the strait (Ciesielski and Maley, 1980), Archean rocks from latitude 83°50’W eastward to Nyeboe Fiord (latitude 86°30’W) were divided into eastern and western blocks based on their constituent rock types (Ciesielski, 1992). The eastern block comprises tonalitic orthogneiss, with local inclusions of amphibolite and interlayered ultramafic and metasedimentary rocks, and is intruded by a large pluton of pink granite with local porphyritic textures and inclusions of amphibolite and tonalitic gneiss. The western block also contains tonalitic orthogneiss, with minor metasedimentary, amphibolite and ultramafic lenses. Metasedimentary rocks, interpreted as correlative with the Prince Albert Group, are exposed east of Nyeboe Fiord in the western block and comprise sandstone and quartz arenite, meta-ultrabasite, amphibolite and iron formation. Finally, the western block includes weakly deformed to undeformed granite intrusions that are deemed correlative with the pink granite in the eastern block (Ciesielski, 1992).

The metamorphic and plutonic basement rocks described above are nonconformably overlain by approximately 6500 m of terrestrial to marine sedimentary and minor (sub)volcanic rocks of the Mesoproterozoic to Neoproterozoic Fury and Hecla Group (Chandler et al., 1980, Chandler 1988). Chandler et al. (1980) divided the group into six members (from base to top):

1) Nyeboe Formation: immature basal conglomerate, red quartz arenite, red shale, quartz-pebble conglomerate, stromatolitic dolomite and up to three basalt flows (aerial and subaerial)

2) Sikosak Bay Formation: crossbedded and wave-rippled white and pink quartz arenite

3) Hansen Formation: chloritic, amygdaloidal, subaerial basalt flows

4) Agu Bay Formation: lower dolomite member containing reefal stromatolitic dolomite, middle black shale member containing siltstone and shale with discrete quartz arenite and calcarenite beds, and upper redbed member containing coarsening-upward red shale–sandstone

5) Whyte Inlet Formation: crossbedded, pink quartz arenite

6) Auttridge Formation: lower Mikkelsen Member comprising a fining-upward sequence of grey quartz arenite, siltstone and black shale, and upper Cape Appel Member with syneresis-cracked black shale and thin beds of rippled quartz arenite

7) Dybbol sill: 40–80 m thick, coarse-grained gabbro that caps the Fury and Hecla Group stratigraphy

Northeast of the study area, tonalitic gneiss dated at 2851 +20/–17 Ma (Jackson et al., 1990) and granodioritic gneiss with a preliminary age of ca. 2900 Ma (Young et al., 2007) predominate. Extensive belts of greenschist-facies mafic metavolcanic rocks with lesser siliciclastic rocks, banded iron formation, and felsic to intermediate volcanic and ultramafic rocks make up the Mary River Group (Johns and Young, 2006). A dacite within the Mary River Group, dated at 2718 +5/–3 Ma (Jackson et al., 1990), constrains the timing of volcanic eruptions and deposition of associated sedimentary rocks within this part of the metavolcanic belt. Weakly deformed to undeformed monzogranite–granodiorite, feldspar-megacrystic monzogranite–granodiorite and coarse-grained to pegmatitic syenogranite intrude the older tonalite–granodiorite gneiss and Mary River Group rocks (Skipton et al., 2017). Crystallization ages for these plutonic phases are limited (e.g., 2709 +4/–3 Ma crystallization age of a quartz syenite intrusion 50 km north of the Mary River Group dacite; Jackson et al., 1990), leaving questions regarding their petrogenesis and relative relationships to other plutonic bodies in the Rae domain unanswered.

The Archean rocks exposed on northern Baffin Island exhibit evidence of increasing metamorphic grade toward the southeast, reaching granulite-facies conditions, as preserved in the ~70 km wide, east-northeast-striking Dexterity granulite belt in the Eqe Bay area (Jackson and Berman, 2000). The Isortoq Fault, a major southeast-dipping structure with evidence of early northwest-directed thrusting, juxtaposes relatively lower grade metaplutonic rocks over the Dexterity granulite belt via later extensional movement along the same surface (Jackson, 2000; Bethune and Scammell, 2003b). Metamorphism and deformation along the Isortoq Fault, related to the Trans-Hudson orogen, began with thrusting at ca. 1.85 Ga and culminated with peak metamorphism at ca. 1.83–1.82 Ga, as recorded in the hangingwall and footwall rocks, respectively (Bethune and Scammell, 2003b).
This sequence has been correlated with the lower part of the Bylot Supergroup, located 200 km to the north. Like those rocks, the Fury and Hecla Group strata are interpreted to represent a transition from a terrestrial to a mainly shallow-marine environment with an eastward-migrating ocean margin where deeper water sedimentation is preserved only in the westernmost part of the basin (Chandler, 1988; Long and Turner, 2012).

Whereas the stratigraphy of the Fury and Hecla Group is largely well constrained, sedimentological details that would allow for interpretation of basin development and architecture are limited. Furthermore, the timing of sedimentary deposition has been only loosely constrained with K-Ar whole-rock ages, a method that is now superseded by modern, higher resolution geochronology methods. Chandler and Stevens (1981) determined K-Ar crystallization ages for basalts of the Nyeboe Formation at 1121 ±33 Ma, 1117 ±40 Ma and 1089 ±32 Ma; the Dybbol sill that caps the Autridge Formation at 716 ±166 Ma and 746 ±87 Ma; and two gabbro dykes that cut the stratigraphy at 631 ±43 Ma and 643 ±47 Ma. There are currently no detrital zircon or other geochronology studies available for the Fury and Hecla Group, so the depositional ages of individual units can be based only on ages determined for correlative units elsewhere in the Bylot Supergroup.

As noted in the previous paragraph, gabbroic and diabase dykes and sills intrude all previously mentioned rock units, including the Dybbol sill. These bodies are interpreted as products of the ca. 723 Ma Franklin igneous events (Heaman et al., 1992) and intrude along pre-existing, southeast-trending structural lineaments. However, the Fury and Hecla Group basalts and the Franklin intrusions would benefit from a new geochronological investigation using modern methods. Furthermore, there is currently no geochemical or isotopic information for the volcanic units in the Fury and Hecla Basin or for the dykes and sills. Such information could improve the understanding of mantle-plume-generated hotspots and Neoproterozoic tectonic events surrounding the breakup of Laurentia (Heaman et al., 1992).

**Field observations**

The 2018 field season was based from a temporary camp on the Gifford River from June 13 through August 15. Bedrock mapping involved setting out up to four teams on daily traverses and targeted stops using a Bell 206 helicopter. In the field, rock relationships, structural fabrics, and mineral modes and textures were digitally recorded in handheld field tablets by direct observation of outcrops, and digital photographs and hand samples were collected for subsequent laboratory analyses and map-unit interpretations. Described below are the characteristics of the principal rock units, ordered from oldest to youngest based on field relationships; potential correlative rock units from neigh-

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**Figure 3:** Simplified regional geology of the mapped portion of the 2018 Fury and Hecla Geoscience Project study area, northwestern Baffin Island, Nunavut.
bouring areas; and a synthesis of deformational and metamorphic features in the study area (Figure 3).

**Archean(–Paleoproterozoic) basement rocks**

**Tonalite–granodiorite orthogneiss**

Much of the central, western and northern parts of the mapped area comprises strongly foliated, medium-grained tonalite–granodiorite orthogneiss (Figure 3). The gneissic fabric is typically defined by leucocratic and mesocratic layers (Figure 4a), which contain plagioclase+quartz+K-feldspar with minor biotite, and biotite+quartz+plagioclase with local amphibole or chlorite, respectively. A mineral foliation, oriented parallel to the gneissosity, is defined by the alignment of biotite and locally by amphibole. The leucocratic material commonly contains coarse-grained feldspar crystals and envelops abundant mafic pods and lenses, which are generally finer grained (Figure 4b). The gneissic fabric is commonly tightly folded, and the folds are axial planar to the dominant gneissic and mineral foliations, as observed in hand-sample to outcrop scales.

Rafts and discontinuous layers (0.5–25 m thick) of mafic–ultramafic rocks are common in the tonalite–granodiorite orthogneiss. These bodies are transposed parallel to the orthogneiss fabric, and locally contain internal compositional layering and/or mineral foliations that are similarly parallel. Compositionally, these rocks vary between hornblende gabbro and pyroxenite, and have a range of grain sizes and textures. Present in several locations is medium-grained gabbro containing coarse plagioclase aggregates that locally define a layering fabric (Figure 4c) and give the rock a bumpy ‘popcorn’ texture on weathered surfaces. In general, these rocks have a slightly higher concentration of magnetite compared to the tonalite–granodiorite orthogneiss, thus generating small magnetic anomalies in the geophysical-survey data.


**Mafic–ultramafic intrusions**

Several 50–250 m wide, laterally continuous to folded, layered mafic–ultramafic intrusions (Figure 3) discovered in the northern and eastern parts of the mapped area are hosted within the tonalite–granodiorite orthogneiss described above. These rocks contain abundant magnetite and can therefore be easily identified as strong magnetic anomalies in the geophysical-survey data. Direct observation of these rocks is limited due to extensive till cover in most locations, and boulder-dominated subcrops in many other locations (Figure 4d). However, the magnetic-anomaly data illustrate that the intrusions are deformed along with the host tonalite–granodiorite orthogneiss, with the largest body being isoclinally folded about a north-striking axial plane (Steenkamp, 2018e, g).

The larger bodies preserve internal primary compositional layering, with rock types of anorthosite to websterite alternating every 5–25 m. Bovingdon et al. (2018) detail the characteristics of mafic–ultramafic rocks found at three sites, as well as their contact relationships to the basement orthogneiss, some structural elements and economic potential. It is not clear whether these larger mafic–ultramafic rock bodies are petrogenetically related to the smaller discontinuous enclaves, pods and lenses of mafic and ultramafic rocks in the tonalite–granodiorite orthogneiss. The layered mafic–ultramafic bodies are likely correlative with those described by Skipton et al. (2017) southwest of Pond Inlet.

**Metamorphosed supracrustal rocks**

The majority of metamorphosed supracrustal rocks are in the western part of the study area (central part of NTS 47F), although 1–10 m long enclaves and pods of similar supracrustal components are locally present in the tonalite–granodiorite orthogneiss and foliated monzogranite (described below) throughout the study area. West of Nyeeboe Fiord is an area with several 25–500 m thick panels of metamorphosed supracrustal rocks comprising pyroxene-bearing metabasite; biotite psammite; quartzite with muscovite and rare garnet; minor biotite-muscovite+sillimanite+garnet semipelite–pelite; and isolated—albeit large—boudinaged ultramafic rocks. Gossanous (rusty)—weathered biotite psammite containing sulphides (primarily pyrite) is associated with metabasite and intermediate–felsic volcanic rocks (Figure 4e). Semipelite–pelite and interlayered quartzite beds and laminae preserve centimetre- and outcrop-scale folds, as well as C′ shear bands that dissect the biotite±muscovite foliation and compositional layering (Figure 4f). The ultramafic rocks range in composition.
Potassium-feldspar–megacrystic monzogranite intrudes the tonalite–granodiorite orthogneiss in the area around Gifford Fiord (Figure 3). Potassium-feldspar crystals up to 6 cm wide were locally observed but typically average 1.5–2.5 cm wide and form up to 15% of the rock. The matrix contains medium- to coarse-grained plagioclase, quartz, biotite and fine-grained disseminated magnetite. The K-feldspar crystals are commonly in alignment with biotite in the matrix and define a weak foliation.

Quartz monzonite underlies the southeasternmost part of the study area (Figures 3, 5a). Its intrusive contact with the tonalite–granodiorite orthogneiss can be traced southward onto Kapuiviit (formerly Jens Munk Island). Potassium-feldspar is only locally porphyritic (up to 4 cm wide), although abundant (>35% of the rock). Biotite and disseminated magnetite are the common mafic phases, and biotite is aligned to define a weak foliation. Deformation is locally more intense in the easternmost visited outcrops, where the matrix-mineral grain size is reduced and K-feldspar phenocrysts are rotated, stretched and wrapped by biotite.

It is unclear if these two types of K-feldspar–phyric rocks are petrogenetically related; however, their field relationships and deformation textures suggest they record similar tectonometamorphic events and are therefore likely related in terms of emplacement. The mineral content and textures observed in these rocks are similar to the 2726–2714 Ma K-feldspar–magmatic granite of Scammell and Bethune (1995) in the Eqe Bay area, and the 2709 ±4/-3 Ma (Jackson et al., 1990) feldspar-magmatic monzogranite–granodiorite of Skipton et al. (2017) south of Pond Inlet. Although not directly observed in this study area, those intrusions are described as containing enclaves of older tonalite–granodiorite orthogneiss and supracrustal rocks.

**Massive syenogranite–quartz syenite**

Small bodies of homogeneous, medium-grained and massive syenogranite–quartz syenite cut the tonalite–granodiorite orthogneiss (Figure 3), likely as foliation-parallel sills. In the eastern part of the study area, syenogranite–quartz syenite commonly caps the outcrops on top of plateaus. Fine- to medium-grained biotite and magnetite form up to 1% of the rock (Figure 5b) and cause a slight magnetic anomaly relative to the magnetite-poor tonalite–granodiorite orthogneiss. A possible correlative rock unit in the Eqe Bay area is an undeformed, pink, biotite granite with similar field relationships that has a crystallization age of 2702 ±3 Ma (Bethune and Scammell, 2003a).

**Pegmatitic felsic dykes**

All previously described basement-rock units across the study area are cut by randomly oriented, pegmatitic felsic dykes that vary in width from 10 cm to 4 m. These dykes commonly comprise K-feldspar with white-quartz cores. 

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**Figure 5:** Representative photographs of rock types in the 2018 Fury and Hecla Geoscience Project study area, northwestern Baffin Island, Nunavut: a) K-feldspar megacrysts in biotite quartz monzonite; b) fine-grained, homogeneous and massive syenogranite with rare biotite grains and disseminated magnetite (not visible); c) vesicular basalt pillows with aphanitic, red-weathering margins (left) from the centre of the basin, and quartz-cobble conglomerate (right) from the eastern part of the basin in the lower Nyebue Formation stratigraphy (hammers for scale are approximately 40 cm long); d) orange-weathering dolomitic stromatolites (foreground in the river bed), overlain by black (mid-ground cliff exposure) and red shale (background cliff exposure, left) of the Agu Bay Formation (river is 8 m wide in foreground); e) plane beds with planar laminae (geologist for scale) in the Whyte Inlet Formation locally interrupted by thin, monomictic granule beds (inset, top surface of tempestite bed; coin for scale indicated by arrow); f) abundant sandstone and minor shale beds in the Mikkesen Member of the Atridge Formation (geologist for scale); g) repeated coarsening-upward parasequences (defined by dashed white lines) of the Cape Appel Member of the Atridge Formation (river is 15 m wide in foreground); h) two parallel Franklin dykes cut through Whyte Inlet Formation sandstone in the westernmost part of the Fury and Hecla basin, creating topographic highs near the coastline (lake is 440 m long).
and rarely contain biotite or muscovite concentrated at the intrusive contact with the hostrock. In some places, the dykes form networks dissecting the hostrock. Some of the larger pegmatitic dykes were identified along major fault traces and are associated with local alteration of the hostrock within and immediately surrounding the fault zones. The pegmatitic felsic dykes are restricted to the basement rocks within and immediately surrounding the fault zones. The mapped extent of the basin was expanded as more Fury and Hecla Group rocks were identified west of Nyeebo Fiord and a small outlier of basal Nyeebo Formation was discovered east of Gifford Fiord at Siuraajuk. Whereas the stratigraphy of the Mesoproterozoic Fury and Hecla Group rocks is well constrained (Chandler et al., 1980; Chandler 1988; Long and Turner, 2012), new field observations were collected to better interpret the basin’s depositional architecture. Samples were collected for detrital zircon and Re-Os geochronology, as well as for micropaleontology, petrography and paleomagnetic reconstruction. In general, the contacts between formations are gradational, and only recognizable where they are well exposed (i.e., river cuts or fault-scarp walls).

Many notable features were identified in the basin rocks. Eolianites are present near the base of the Nyeebo Formation and are overlain by a thick conglomerate wedge in the eastern part of the basin (Figure 5c). The deposition of this conglomerate appears broadly contemporaneous with extrusion of the 1121–1089 Ma (Chandler and Stevens, 1981) pillow and flow basalts in the western part of the basin (Figure 5c). The Sikosak Bay Formation, although generally poorly exposed, preserves ubiquitous mature, crossbedded quartz arenite and symmetric wave ripples, indicative of shallow-marine deposition. The Hansen Formation comprises massive to columnar-jointed, fine-grained to porphyritic basalt and is found between the Nyeebo and Sikosak Bay formations in the western part of the basin, and within the Sikosak Bay Formation in the central part of the basin. Geochemistry and petrography will confirm whether the Hansen Formation represents a subaerial basaltic flow (Chandler et al., 1980) or perhaps a shallowly emplaced sill that obliquely cuts the basin stratigraphy, as contact relationships are not clearly exposed and field observations are limited.

The Agu Bay Formation is characterized by shallow-marine carbonate rocks locally containing dolomitic stromatolite reefs that are overlain by black and red shales (Figure 5d), possibly representing the progressive drowning of a lagoonal environment. Similar to the Sikosak Bay Formation, the Whyte Inlet Formation is dominated by extremely mature quartz arenite with plane beds, large-scale crossbeds and symmetric wave ripples typical of a shallow-marine environment; however, it also preserves numerous monomictic granule beds (Figure 5e), interpreted as tempestites deposited during storm events. The Mikkelsen Member of the Autridge Formation contains abundant sandstone with minor shale at its base (Figure 5f) and transitions to more abundant shale and minor sandstone at its top. It appears to represent a marine transgression from the shallow-marine environment of the underlying Whyte Inlet Formation to the overlying deeper marine black shales of the Cape Appel Member. The Cape Appel Member of the Autridge Formation is characterized by repetitive, 15–20 m thick, coarsening-upward parasequences (Figure 5g) that suggest deposition in a wave-dominated environment.

Full field stratigraphic and sedimentological descriptions of the Nyeebo, Sikosak Bay and Whyte Inlet formations can be found in Patzke et al. (2018), while the Agu Bay and Autridge formations are discussed in Greenman et al. (2018).

Neoproterozoic intrusions

Dybbol sill and Franklin dykes

The top of the Fury and Hecla Group stratigraphy is capped by the Dybbol sill. Exposures are only preserved on the peninsula south of Autridge Bay and along the coast to the west at Cape Appel (Figure 3). The sill is 40–80 m thick and locally exhibits columnar jointing in cliff exposures. It comprises rocks with homogeneous, medium-grained grey plagioclase, minor green clinopyroxene (<3%) and rare magnetite. Chandler and Stevens (1981) broadly constrained the timing of emplacement of the Dybbol sill at ca. 746–716 Ma (with considerably large errors), although its magnetic source and relationships to other igneous and tectonic events are unknown.

Gabbroic dykes that cut the basement gneiss and plutons, as well as the Fury and Hecla Group stratigraphy and the Dybbol sill, were emplaced along southeast-striking faults and fractures in the study area. The dykes are 10–500 m wide, locally diverge and converge into/from parallel entities, and are continuous across the study area for more than 220 km. Where exposed, the dykes preserve 5–20 cm wide chilled margins with aphanitic to porphyritic textures. The dyke cores typically comprise medium-grained plagioclase laths (>75%), interstitial pyroxene, disseminated magnetite and rare sulphides. The dykes are attributed to the Franklin igneous events (Heaman et al., 1992), based on two K-Ar dates of 643 ±27 Ma and 631 ±43 Ma (Chandler and Stevens, 1981). However, higher precision dating and geochemical studies are required to better constrain their magnetic source and emplacement history, as well as understand the tectonic implications of such large igneous events. Further field observations of the mafic igneous events in the Fury and Hecla study area, including the Nyeebo Formation volcanic rocks, the Hansen Formation,
Regional metamorphism and deformation

Regional deformation and metamorphism have affected the basement gneiss and felsic plutonic rocks, and therefore pre-date the Mesoproterozoic Fury and Hecla Group and the Neoproterozoic mafic intrusive rocks, which appear to only be impacted by later, brittle-deformation events. Regional deformation and metamorphic events, as well as folding, foliation fabrics and stretching lineations described in this section, are given the labels Dn,Mn,Fn,Sn and Ln, respectively, where n represents a numbered ‘event’ or ‘stage’ in order of oldest (n = 1) to youngest (n = 4) based on direct field observations, and does not specifically correlate with other labelled events published by other authors (e.g., Bethune and Scammell, 2003b; Young et al., 2004; Skipton et al., 2017).

The earliest phase of deformation (D1) recorded in the basement rocks is characterized by mineral foliations in diorite and pyroxenite enclaves and pods that are oblique to foliation fabrics in the tonalite–granodiorite orthogneiss. The D1 fabrics are defined by aligned medium-grained hornblende, suggesting that the event was associated with amphibolite-facies metamorphism (M1). These features may correlate with evidence of the earliest phase of deformation and metamorphism recognized by Bethune and Scammell (2003b) in the Eqe Bay area, which is interpreted to predate the ca. 2770 Ma deposition of the Eqe Bay greenstone belt.

A second tectono-thermal event, D2, has overprinted any evidence of D1 in the tonalite–granodiorite orthogneiss. The D2 event is characterized mainly by its M2 metamorphic mineral assemblages: garnet, sillimanite, biotite and muscovite in pelite, semipelite and psammitic; amphibole and rare clinopyroxene in metasabase; and magnetite, quartz and rare amphibole in meta–iron formation. In the supracrustal rocks, the M2 biotite, muscovite and/or hornblende define bedding-parallel S2 mineral foliations. In the tonalite–granodiorite orthogneiss, S2 is defined by gneissic banding and aligned biotite (and locally hornblende). The mineral assemblages and the local presence of centimetre-scale melt pockets, seams and lenses (<3% rock volume) in the supracrustal rocks indicate that M2 peak metamorphism reached amphibolite-facies conditions below 650–750°C (the pressure-dependent temperature range for complete muscovite–dehydration reactions in pelitic rocks; Thompson, 1982; Spear et al., 1999).

A third deformational event (D3) is likely responsible for the transposition of S2 fabrics to define the main regional foliations (S3) across the study area, the local reorientation of the S2 fabrics about isoclinal folds (F3) and the development of stretching lineations (L3). The S3 fabrics are dominantly northeast and southwest striking, and moderately to shallowly dipping across the study area, suggesting northwest–southeast compressional forcing. The F3 folds are generally axial planar to the S3 fabrics, range from hand-sample to outcrop scale and have shallowly to moderately plunging hinges. Larger scale folds are also apparent in the aeromagnetic survey data (Figure 2; Steenkamp, 2018a–h). Stretching lineations (L3) defined by quartz rodding, elongate augen porphyroclasts and commonly oriented prismatic crystals (such as sillimanite or amphibole) all plunge shallowly to moderately toward the northeast. It is possible that the D3 structures developed through a protracted period of deformation following the D2 and M2 events. An alternative explanation may be that they relate to collision of the western Churchill Province and Superior plate during the ca. 1.9–1.8 Ga Trans-Hudson Orogen (Hoffman, 1988; St-Onge et al., 2007; Corrigan et al., 2009). This Himalayan-scale orogen caused penetrative and prolonged deformation and metamorphism far afield from the orogenic front and has largely overprinted evidence of earlier tectono-thermal events in the Rae domain. Structures generated during orogeny in the neighbouring northwestern Hudson Bay and central Baffin Island areas are generally northeast and southwest striking, similar to this study area, and evidence of associated granulite- and amphibolite-grade metamorphism is widespread (e.g., Bethune and Scammell, 2003b; Young et al., 2004; Steenkamp et al., 2015, 2016).

Brittle deformation is expressed predominantly in sets of northwest- and east-striking faults and fractures that cut the basement and the Fury and Hecla Group throughout the study area. In NTS 47E, two northwest-striking normal faults expose basement orthogneiss in <150 m tall footwall cliffs, with Paleozoic stratigraphy preserved in the down-dropped hangingwall. Glacially scoured fault lineaments expose bleached and brecciated hostrocks with precipitated quartz stockwork and local epidote as evidence of siliceous hydrothermal-fluid infiltration and alteration. The north-west-oriented fault set is parallel and likely related to the Nina Bang, Central Borden and White Bay normal faults to the north (Johns and Young, 2006), of which the latter is associated with the stratigraphy of the Mesoproterozoic Borden Basin (Jackson and Iannelli, 1981; Long and Turner, 2012). The east-striking fault set is parallel, and likely related, to dextral-transform faults identified in aeromagnetic data of the area extending from the Mary River area to the Barnes Ice Cap (Johns and Young, 2006), and subparallel to east-southeast-oriented faults on Melville Peninsula that are also inferred to have developed during the Mesoproterozoic (Schau, 1993). However, the Neoproterozoic Franklin dykes intrude the northwest-striking fault set but also locally follow the east-oriented fault set and illustrate minor left-lateral (sinistral) displacement of the former along the latter.

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Economic considerations

Past investigations into mineral resources associated with Precambrian rocks in the Fury and Hecla study area have been limited in scope owing to the low resolution and vintage of published framework-geological datasets, maps and information. Following the framework mapping of the Fury and Hecla Basin and the nearby Precambrian basement rocks conducted in 1979 (Chandler et al., 1980; Ciesielski and Maley, 1980), exploration of new U and Th anomalies was initiated but only lasted for a limited time span (Fisher and Kwiecien, 1981). The U and Th anomalies are concentrated in fault and fracture planes that dissect the nonconformity surface between felsic Archean metaplug- tonic and Mesoproterozoic basin rocks. During the 2018 field work, a handheld gamma-ray spectrometer was used to quantify radioactive U, Th and K concentrations at several sites along the nonconformity and throughout the Fury and Hecla Group lithostratigraphy (Patrzke, et al., 2018). Although no new anomalous values were recorded in the field, the new radiometric survey data outline two regions north of the basin with relatively high radioactive signatures (Steenkamp, 2018c–f) that may warrant further evaluation.

In the late 1990s and early 2000s, numerous new surficial-geology maps and till geochemical-survey datasets from across northern Baffin Island were released (e.g., Dyke and Hooper, 2000, 2001) and supported local prospecting that resulted in the discovery of two microdiamond-bearing kimberlite sheets on the east side of Erichsen Lake (NTS 47F). De Beers Canada staked a large region surrounding the discovery sites and collected till samples from the eastern half of NTS 47F, as well as areas north and east of the Fury and Hecla study area. The sampling led to the discovery of several more kimberlite targets and, by 2007, De Beers Canada had drilled 40 holes across their Baffin property, obtaining maximum kimberlite intersections of 2.05 m (McMonnies et al., 2007; Chartier and Januszczack, 2008).

Despite these uninspiring results, the 2018 field mapping of the nonconformity surface between felsic Archean metaplutonic rocks (Steenkamp, 2014) are associated with elevated Mo concentrations, whereas anomalous Au-grain counts in mud boil samples taken along the Roche Bay belt on Melville Peninsula are related to gossans with arsenopyrite occurrences (Tremblay et al., 2010; Corrigan et al., 2013). The metasedimentary panels identified east of Nyebroe Fjord (Figure 3) contain laterally continuous layers of silicate-facies meta–iron formation and metabasite rocks, <4 m thick, that have locally developed gossanous-weathering zones. The meta–iron formation, although relatively thin and too low in abundance to be considered as a major source of iron ore, may have potential for iron-formation-hosted Au. Quartz veins that cut Mary River Group iron formation exposed in the ‘Felsenmeer Flats’ of Johns and Young (2006) contain visible Au and Mo, which are interpreted to have been sourced from the iron formation.

The metasedimentary rocks found west of Nyebroe Fjord also preserve gossanous-weathered biotite psammitic associated with metabasite units. Similar rock assemblages and characteristics found on southern Baffin Island (Steenkamp, 2014) are associated with elevated Mo concentrations, whereas anomalous Au-grain counts in mud boil samples taken along the Roche Bay belt on Melville Peninsula are related to gossans with arsenopyrite occurrences. Following the framework mapping of the Fury and Hecla Basin and the nearby Precambrian basement rocks, two of the larger bodies reveals metre-scale compositional layering that varies from websterite to leucogabbro and orthosite (Bovingdon et al., 2018). With further assessment of their petrology and geochemistry, the potential for Ni-Cu-PGE or other magmatic metal occurrences will be better constrained. A 250 m by 1.5 km ultramafic body, comprising magmatically layered websterite to iherzolite with local serpentinitization, is associated with supracrustal rocks west of Nyebroe Fjord. This rock type may also be prospective for Ni-Cu-PGE and/or Cr occurrences, similar to meta-peridotite sills in the Prince Albert belt on Melville Peninsula (Corrigan et al., 2013) or gabbroic intrusions with Cu showings (malachite) in the Mary River Group that are exposed in Royal Society Fjord on northern Baffin Island (Johns and Young, 2004).

Metamorphosed supracrustal rocks found west of Nyebroe Fjord also preserve gossanous-weathered biotite psammitic associated with metabasite units. Similar rock assemblages and characteristics found on southern Baffin Island (Steenkamp, 2014) are associated with elevated Mo concentrations, whereas anomalous Au-grain counts in mud boil samples taken along the Roche Bay belt on Melville Peninsula are related to gossans with arsenopyrite occurrences. The metasedimentary panels identified east of Nyebroe Fjord (Figure 3) contain laterally continuous layers of silicate-facies meta–iron formation and metabasite rocks, <4 m thick, that have locally developed gossanous-weathering zones. The meta–iron formation, although relatively thin and too low in abundance to be considered as a major source of iron ore, may have potential for iron-formation-hosted Au. Quartz veins that cut Mary River Group iron formation exposed in the ‘Felsenmeer Flats’ of Johns and Young (2006) contain visible Au and Mo, which are interpreted to have been sourced from the iron formation.

Samples were collected for whole-rock geochemistry and assay analyses from the sites mentioned here, as well as numerous others across the study area, to evaluate their compositions, protoliths and depositional/emplacement histories, and their potential to host economic mineralization.

Conclusions and future work

Although there are no previously determined crystallization ages for basement rocks within the study area, they are likely correlative with similar Archean rock units dated to the south on Melville Peninsula, to the east in the Eqe Bay area, and to the north in the Pond Inlet to Mary River area. The presumed Archean supracrustal rocks are likened to the Mary River Group, based on their rock assemblages and relative metamorphic and deformational histories. Weakly deformed felsic intrusive phases appear to correlate with some of the Archean plutonic rocks described in the Eqe Bay and Pond Inlet to Mary River areas. This implies that
the Rae domain basement components are recognizably correlative for a distance of approximately 500 km from Admiralty Inlet eastward to the Barnes Ice Cap, and possibly beyond. To confirm this, new U-Pb geochronology, petrology and geochemistry analyses will be conducted and the results compared to published and ongoing studies from the northern Baffin Island and northern Melville Peninsula areas.

The known extent of Fury and Hecla Group rocks has been expanded to include an area west of Nyboe Fiord and an outlier on Siuraarjuk. Field observations of the sedimentary and mafic igneous rocks in the basin confirmed the sedimentology and stratigraphy defined by Chandler (1988) and Long and Turner (2012), in addition to further constraining interpretations of depositional environments. Black shale samples from the Agu Bay and Atrtridge formations were collected for Re-Os geochronology and micropaleontological study, and carbonate rocks from the base of the Agu Bay Formation were sampled for stable-isotope geochemistry to investigate oceanic carbon and oxygen concentrations during deposition. Quartz arenite samples from the Nyboe, Sikosak Bay and Whyte Inlet formations, and the Mikkelsen Member of the Atrtridge Formation, were collected for U-Pb detrital-zircon geochronology to constrain the timing and duration of sedimentary deposition, as well as the sources of sediments. The diverse lithostratigraphy of the Nyboe Formation is being analyzed in detail to better constrain depositional environments during early basin development.

Mesoproterozoic pillow and flow basalts in the Nyboe Formation indicate subaqueous and subaerial emplacement conditions, providing constraints on the depositional environment of lithostratigraphic units above and below. Neoproterozoic shallow mafic intrusions represent an uppermost age limit for the chronostatigraphic development of the Fury and Hecla Group. New, higher precision U-Pb geochronology, petrography and geochemical analyses on all Mesozoic and Neoproterozoic mafic igneous rocks are being conducted to determine the timing of their emplacement and define the systematics of their source and genesis.

Although explored to a limited extent in the past, new U and Th occurrences and diamond-bearing kimberlites could be identified by analytical processing of the new geophysical-survey data (Steenkamp, 2018a–h) collected as part of the FHGP. New areas of interest that are being assessed for their economic-metal potential include the mafic–ultramafic intrusions in the tonalite–granodiorite orthogneiss, and ultramafic bodies, meta–iron formation and gossanous-weathering siliciclastic and metabasite rocks found in the Archean supracrustal panels.

The field data collected in 2018 are being compiled and interpreted to generate new geological maps. The Fury and Hecla Geoscience Project will continue in 2019 with a new airborne geophysical survey and a second summer of field mapping and sampling. The 2019 area of focus will shift farther north to complete the mapping of Precambrian bedrock in the northern half of NTS 47E, the southern half of 47H, the southwest corner of 47G, and the central and eastern parts of 47F.

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