Refinement of the stratigraphy of the late Mesoproterozoic Fury and Hecla Basin, Baffin Island, Nunavut, with a specific focus on the Agu Bay and Autridge formations

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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

Recent geochronological, chemostratigraphic and paleontological studies from the Mesoproterozoic Bylot Supergroup of the Borden Basin in northern Baffin and Bylot islands offer critical insights into the evolution of a late Mesoproterozoic intracratonic basin system and the origin of photosynthetic eukaryotes therein. Located in northeastern Canada and northwestern Greenland, the Borden, Fury and Hecla, Hunting–Aston, and Thule basins are collectively known as the Bylot basins. The Fury and Hecla Group comprises a relatively understudied succession of presumably late Mesoproterozoic sedimentary rocks interpreted to be broadly correlative with the Bylot Supergroup. Black shale units from the Fury and Hecla Group offer an opportunity to contribute new geochronological age constraints using rhenium-osmium geochronology and are also promising targets for microfossil analyses. This summary outlines the results of fieldwork conducted in the area in summer 2018, provides an overview of the Fury and Hecla Group stratigraphy, and highlights new observations from the Agu Bay and Autridge formations, where more detailed work is being conducted.

Correlations drawn between the individual Bylot basins have previously been founded on lithostratigraphic similarities; however, a lack of depositional age constraints make these proposed correlations difficult to corroborate. Equivalently thick successions outcrop in both the Fury and Hecla and Borden basins, but the Borden Basin contains a much greater thickness of carbonate rocks and black shale. In the absence of suitable lithological units to establish chemostratigraphic correlation, new radiometric ages and sequence stratigraphic frameworks are essential to establish temporal equivalence between these two basins and understand how they co-evolved.

Résumé

Des études récentes en géochronologie, chimiostratigraphie et paléontologie du Supergroupe de Bylot, d’âge mésoprotérozoïque, du bassin de Borden, situé dans les îles de Baffin et de Bylot, présentent un aperçu de l’évolution d’un système de bassin intracratonique datant du Mésoprotérozoïque ainsi que de l’origine des eucaryotes photosynthétiques qu’il renferme. Ce bassin comprend les bassins de Borden, de Fury et Hecla, de Hunting–Aston et de Thule, connus collectivement sous le nom de « bassins de Bylot ». Le Groupe de Fury et Hecla est représenté par une succession de roches sédimentaires (datant probablement du Mésoprotérozoïque), relativement peu étudiées et interprétées comme étant corïlatives du Supergroupe de Bylot. Les unités de schiste argileux noir et les analyses de microfossiles du Groupe de Fury et Hecla offrent une occasion de contribuer à des nouvelles datations géochronologiques en utilisant la méthode de datation radiométrique par le rhénium-osmium. Cet article présente les résultats des travaux réalisés dans la région durant...
l’été 2018, passe en revue la stratigraphie du Groupe de Fury and Hecla et fait état de nouvelles observations portant sur les formations d’Agu Bay et d’Attridge, où des travaux plus détaillés sont en cours.

Les corrélations entre les différents bassins de Bylot ont été précédemment fondées sur des similitudes lithostratigraphiques. Cependant, l’absence de contraintes géochronologiques fait qu’il est difficile de confirmer cette corrélation. D’épaisses successions d’une section stratigraphique équivalente affleurent dans les bassins de Fury and Hecla et de Borden, mais le bassin de Borden contient une épaisseur d’unités de carbonate et de schiste noir beaucoup plus importante. En l’absence d’unités lithologiques aptes à permettre l’établissement de corrélations chimiostratigraphiques, de nouveaux âges radiométriques et des données de séquence stratigraphique sont essentiels en vue de pouvoir établir une équivalence temporelle entre ces deux bassins et afin de mieux comprendre leur évolution conjointe.

**Introduction**

The Bylot basins comprise the Hunting–Aston, Thule, Fury and Hecla, and Borden basins in Nunavut (northeastern Arctic Archipelago) and northwestern Greenland (Figure 1). Deposition occurred during the late Meso- to early Neoproterozoic, meaning these strata span the amalgamation of Rodinia and early diversification of complex eukaryotes (Butterfield, 2000; Turner et al., 2016; Gibson et al., 2017; Rainbird et al., 2017). Whereas previous work on the Bylot basins has been focused primarily on the Borden Basin, the Fury and Hecla Basin, 200 km to the south, comprises approximately 6 km of relatively underexplored strata. Therefore, the Fury and Hecla Basin presents an opportunity to contribute to an improved understanding of the Bylot Supergroup, and expand on recent studies that have helped to establish and calibrate paleobiological and geochemical phenomena of the terminal Mesoproterozoic Era (Kah et al., 1999; Turner and Kamber, 2012; Knoll et al., 2013; Gibson et al., 2017).

Lithostratigraphic frameworks linking the Fury and Hecla Group and Bylot Supergroup have been proposed (Jackson and Iannelli, 1981; Chandler, 1988; Long and Turner, 2012); however, meaningful correlations are difficult to establish owing to the lack of geochronological age constraints within the Fury and Hecla Group. Black shale units from the Fury and Hecla Group offer an opportunity to contribute lower and upper age constraints on the succession using the rhenium-osmium (Re-Os) radiometric dating method. A similar approach applied to the Borden Basin revealed that most of the Bylot Supergroup was much younger (ca. 1.05 Ga; Gibson et al., 2017) than widely believed (1.2 Ga) based on loose age constraints and assumptions. Sequence stratigraphic analyses will further highlight basin evolution and, in the near absence of carbonate rocks in the Fury and Hecla Group suitable for δ¹³C and Sr²⁸⁶/Sr chemostatigraphy, will prove essential when testing correlations and geodynamic linkages with the Borden Basin.

The discovery of Bangiomorpha pubescens, the oldest taxonomically resolved eukaryote in the geological record, in both the Hunting Formation of the Hunting–Aston Basin (Butterfield, 2000) and the Angmaat Formation in the Borden Basin (Knoll et al., 2013) highlights the importance of the Bylot basins to the calibration and interpretation of early eukaryotic evolution. Precise age constraints from the Borden Basin, in conjunction with new molecular clock estimates, suggest that the primary plastid endosymbiotic event (when photosynthesis first emerged in eukaryotes) occurred ca. 1.25 Ga (Gibson et al., 2017). Eukaryovory (protists ingesting other protists) likely emerged around 1.0 Ga (Loron et al., 2018). Well-preserved microfossils interpreted as eukaryotes (Butterfield and Chandler, 1992) were described from a single specimen from the Agu Bay Formation. This single promising fossil discovery and recent important developments in middle Proterozoic paleobiology motivated a renewed effort to search for microfossils in the Fury and Hecla Group. Shaly units of the Agu Bay and Attridge formations constitute highly prospective targets for further micropaleontological studies, the importance of which will be amplified by successful radiometric dating.

Ideally, updated sedimentological and sequence stratigraphic frameworks developed for the Fury and Hecla Ba-
sin will establish patterns of sedimentary fill that can be correlated in greater detail with those of other Bylot basins. In doing so, and in conjunction with an updated geochronological framework, datasets generated from the Fury and Hecla Group will be placed in the regional tectonic context to better understand how northeastern Canada evolved through the late Mesoproterozoic to early Neoproterozoic. This paper outlines the stratigraphy of the Fury and Hecla Group and summarizes detailed work from the first of two field seasons on the Black Shale and Cape Appel members of the Agu Bay and Autridge formations, respectively.

**Previous work**

The first mapping efforts in Fury and Hecla Strait were undertaken by Blackadar (1958, 1963, 1970), who divided the succession into the Fury and Hecla, and Autridge formations. Additional fieldwork was carried out by Lemon and Blackadar (1963), Chandler et al. (1980) and Chandler (1988). Jackson and Iannelli (1981) refined the stratigraphy of the Borden Basin, suggesting that the basal strata of the Bylot basins were constrained by the ca.1270 Ma Mackenzie igneous events (LeCheminant and Heaman; 1989) and proposing correlations between the Fury and Hecla, and Borden basins. Detailed mapping of the Fury and Hecla Basin by Chandler (1988) focused primarily on the northern shore of Fury and Hecla Strait between Agu Bay and Sikosak Bay using a combination of ground traverses and helicopter surveys (Figure 2). This study culminated in the recognition and mapping of five distinct formations within the Fury and Hecla Group. Chandler (1988) interpreted the uppermost strata to be intruded by the ca.720 Ma Franklin igneous events (Heaman et al., 1992), which provides the best available upper age constraint in the succession. Results of reconnaissance fieldwork east of Sikosak Bay, along the northern shore of Fury and Hecla Strait, and on northwestern Melville Peninsula are presented in Long and Turner (2012).

**Geological setting**

Strata of the Fury and Hecla Group dip gently to the south (less than 20°) and sit nonconformably atop Paleoproterozoic granitic gneiss. The Fury and Hecla Group (Figure 3) has a total thickness ranging from 2.2 to 6 km. Most strata exposed in the Fury and Hecla Group are interpreted to represent deposition within a tidally influenced, shallow-marine environment that deepened to the west (Chandler, 1988). Sandstone and fine-grained siliciclastic rocks dominate the succession, with thin carbonate units preserved locally in members of the Nyeboe and Agu Bay formations (Figure 3). The basin contains many post depositional east-trending faults, predominantly in the northern and western areas of the basin.

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**Figure 2:** Geology of the Fury and Hecla Group along the northern Melville Peninsula, Nunavut (after Scott and de Kemp, 1998, and Long and Turner, 2012) and southwestern Baffin Island (after Chandler, 1988). Box with dashed border shows the location of Figure 5 and the asterisk, the location of Figure 7. Abbreviations: Fm, Formation; Mb, Member.
Nyeboe Formation

The Nyeboe Formation (~500 m thick) comprises conglomerate, sandstone and shale units, carbonate rocks and basalt showing significant vertical lithological heterogeneity and lateral facies variation. Basal strata commonly consist of several metres of granular, red quartz arenite, in turn overlain by several metres of medium-grained quartz arenite, with large-scale west-dipping foresets. An intraformational conglomerate wedge in the eastern portion of the basin overlies the crossbedded quartz arenite and pinches out eastward. The conglomerate contains pebble- to boulder-sized clasts of quartz arenite and presumably corresponds to the basal polymict breccia defined by Chandler (1988). The remainder of the Nyeboe Formation is predominantly composed of sandstone although poor exposure limits detailed descriptions. Near the top of the unit in the western portion of the basin, dolomite-cemented sandstone is interbedded with microbialite, which in one locality contains apparent gypsum casts. The uppermost Nyeboe Formation, in the western part of the basin, is interbedded with an altered basalt with subordinate amygdules and pillows. The Nyeboe Formation is overlain by the Hansen Formation in the west and the Sikosak Bay Formation in the east (Figure 2). A more detailed sedimentological description of the Nyeboe Formation is contained in Patzke et al. (2018).

Hansen Formation

The Hansen Formation is a laterally extensive, columnar-jointed basalt that reaches up to 30 m in thickness. Fresh surfaces are grey-green to black and a thin chilled margin is observed at the basal contact with the Sikosak Bay Formation. The Hansen Formation shares a complex stratigraphic relationship with the Sikosak Bay Formation, occurring at a stratigraphically higher level in the Sikosak Bay Formation in eastern exposures (Figure 2).

Sikosak Bay Formation

The Sikosak Bay Formation is composed of 15 to 150 m of white quartz arenite. Oscillatory-flow structures and large foreset bars are characteristic of this unit. Where observed, the contact with the overlying Agu Bay Formation is conformable.

Agu Bay Formation

The Agu Bay Formation, which reaches a total thickness of ~500 m, comprises black shale and, locally, carbonate rocks, siltstone and quartz arenite. It is subdivided into three members, which described in ascending stratigraphic order are: the Dolomite (DM), Black Shale (BSM) and Redbed (RM) members (Figures 3, 4a, b, c). The lowermost DM (Figure 4c), only observed in the centre of the basin and <10 m thick (WG-1; Figure 5), is composed of metre-scale biothermal stromatolites, oolite, oncoid, dolomite grainstone and, locally, dolomite-cemented mudstone.
The BSM (Figure 4b) directly overlies the Sikosak Bay Formation west of Whyte Inlet, whereas the RM (Figure 4a) overlies it near Sikosak Bay. The BSM is approximately 75 m thick and was divided into 13 distinct units (see Chandler, 1988, Figure 11b). It is composed of black shale, siltstone and minor coarse-grained, cross-stratified quartz arenite, comprising coarsening-upward parasequences. An ash-flow tuff 40 cm thick is exposed ~32 m from the base of the BSM (WG-2; Figure 5).

The RM is the most laterally extensive of the three and extends from Agu Bay to Sikosak Bay (Chandler, 1988). Characteristic parasequences, which extend over ~500 m, consist of red siltstone, minor shale to coarse-grained, red to white quartz arenite. Detailed descriptions of this cyclicity and accurate measurements of the total thickness is hampered by poor exposure. Aside from river cuts, outcrops commonly only preserve the coarser-grained sandstone beds capping parasequences, separated by 15–20 m lacking exposures, which likely represent the more recessive portions of the parasequences. Near the top of the RM, a basin-wide mudstone that displays desiccation cracks is observed.

**Whyte Inlet Formation**

The Whyte Inlet Formation comprises mature, pink to white, quartz arenite reaching up to 3 km in thickness. It erosively overlies Paleoproterozoic basement rocks east of Sikosak Bay and gradationally overlies the Agu Bay Formation elsewhere (Figure 2). Upper layers of the Whyte Inlet Formation contain pebbles up to 3 cm in diameter. This formation is gradationally overlain by the Mikkelsen Member of the Autridge Formation. A more detailed description of the Whyte Inlet Formation is contained in Patzke et al. (2018).

**Autridge Formation**

The Autridge Formation comprises approximately 2 km of siltstone and black shale interbedded with minor sandstone. It is subdivided into two members: the lower Mikkelsen and overlying Cape Appel members. Exposure is confined to the western portion of the basin and the formation is inferred to pinch out near Whyte Inlet (Figure 2). The Mikkelsen Member consists of up to 1500 m of grey quartz arenite, siltstone with syneresis cracks and black shale. The latter becomes more abundant upsection, where it is interbedded with cross-stratified quartz arenite showing flaser and lenticular bedding. The overlying Cape Appel Member consists of approximately 500 m of black shale (Figure 6b) and dark grey siltstone with ubiquitous syneresis cracks (Figure 6c), capped by beds of medium- to coarse-grained cross-stratified quartz arenite (Figure 6d). Parasequences are 15–25 m thick (Figures 6a, 7). The Autridge Formation is overlain by the Dybbol Sill (Chandler, 1988) of presumed Franklin age.

**Sampling**

**Agu Bay Formation**

Three partial stratigraphic sections of the Agu Bay Formation measure the Black Shale member, in the centre of the Fury and Hecla Basin (Figure 5). Six samples were collected from the Dolomite member (section WG-1; Figure 5) for stable isotope geochemistry. A suite of samples (n = 11) was collected ~36 m above the basal contact with
Figure 5: Measured stratigraphic sections of the Agu Bay Formation in the central Fury and Hecla Basin, Nunavut. Inset corresponds to the location of the map area shown on Figure 2.
Figure 6: Field photographs of facies of the Cape Appel Member of the Autridge Formation in the central Fury and Hecla Basin, Nunavut: 

- **a)** coarsening-upward parasequences (scale is approximately 15 m); 
- **b)** black shale from the base of parasequences (penny for scale); 
- **c)** siltstone, showing syneresis cracks, to fine sandstone from the middle of a parasequence (penny for scale); 
- **d)** medium- to coarse-grained sandstone from the top of a parasequence (increments of Jacob’s staff are 10 cm).
Figure 7: Measured stratigraphic sections of the Cape Appel Member of the Autridge Formation in the central Fury and Hecla Basin, Nunavut. Inset corresponds to the location of the map area shown on Figure 2.
the Sikosak Bay Formation for Re-Os geochronology and microfossil samples were collected where suitable material was present (section WG-3; Figure 5). A layer of presumed tuff 40 cm thick was sampled for U-Pb zircon geochronology from section WG-2, ~32 m from the basal contact with the Sikosak Bay Formation.

**Autridge Formation**

The Cape Appel Member of the Autridge Formation is well exposed along a river in the southwestern portion of the study area; two partial stratigraphic sections were measured during the 2018 field season (Figures 2, 7). A set of ten samples for Re-Os geochronology was collected 4 m from the base of section WG-4. Prospective samples for microfossil collection and analysis were collected from intervals where coherent siltstone material contained organic-rich flecks.

**Discussion**

Fine-grained units are generally poorly exposed in the Fury and Hecla Basin, and river cuts are generally the only location where more friable siltstone/shale packages are preserved. No syndepositional faulting was observed. The bulk of the Nyoebe Formation appears to record nearshore-marine deposition on a shallow, clastic shelf. However, the formation does contain a record of punctuated changes in depositional environment, as detailed in Patzke et al. (2018). For example, steeply-dipping foresets near the base of the Nyoebe Formation are interpreted as eolianites representing a locally developed, westward-migrating dune field. An overlying intraformational conglomerate, replete with cannibalized quartz arenite clasts, records local episodes of uplift and erosion, presumably the consequence of block faulting. Furthermore, this resedimentation event appears to be broadly contemporaneous with deposition of subaqueous pillow basalt of the Nyoebe Formation, potentially representing an important event in the evolution of the basin.

One explanation for the complex field relationships between the Hansen and Sikosak Bay formations is that the former, rather than having been emplaced by a flow (or series of flows), consists instead of a series of sills and feeder dykes that crosscut the latter at a low angle. This hypothesis is supported by the Hansen’s textural homogeneity, lack of evidence for flow or subaqueous extrusion, and absence of any change to depositional environment or lithology above and below the sill(s). Alternatively, the Hansen Formation was originally interpreted to represent a subaerial basalt interfingering with the westward-migrating sandstone facies of the Sikosak Bay Formation (Chandler, 1988). This observation is supported by the presence of columnar jointing in the Hansen Formation; however, a fully marine origin is interpreted for the Sikosak Bay Formation, which contradicts the suggested subaerial origin for the Hansen Formation. Opposing field relationships reinforce the need for a geochemical assessment, as described by F. Dufour et al. (work in progress).

The restriction of carbonate deposition to the thin and localized dolomite of the Agu Bay and Nyoebo formations suggests deposition in a lagoon or otherwise protected environment. It was deposited during transgression and is overlain by fine-grained siliciclastic rocks, indicating drowning and consequently a cessation of carbonate sedimentation. The remainder of the Agu Bay Formation comprises parasequences likely deposited close to storm-wave base. Chandler et al. (1980) observed that the Agu Bay and Whyte Inlet formations are separated by a laterally extensive surface with desiccation cracks, implying punctuated emergence of the basin.

The maturity of the Whyte Inlet Formation indicates a great deal of reworking occurred within a shallow-marine depositional environment. East of Sikosak Bay, the basal Whyte Inlet Formation includes pebble conglomerate inferred to have been deposited as fluviatile gravel bars (Long and Turner, 2012; Long, 2017), interpreted to represent the proximal equivalent of shallow-marine sediments to the west. Parasequences of the Autridge Formation with black shale, siltstone with syneretic cracks and quartz arenite showing lenticular bedding are interpreted to represent a distal equivalent to the Whyte Inlet Formation, supporting the hypothesis of an overall westward-deepening of the basin. The Mikkelsen Member was originally interpreted as a transitional member between the Whyte Inlet Formation and Cape Appel Member by Chandler (1988); this inference is supported by observations recorded this summer.

**Economic considerations**

The Borden Basin, 200 km to the north, hosts base-metal (zinc, lead, silver, copper) deposits (e.g., Patterson and Powis, 2002); however, no evidence of base-metal mineralization was observed in the Fury and Hecla study area. The Black Shale and Cape Appel members are considered shale gas reservoirs and determining their degree of thermal maturation will greatly contribute to improving understanding of their prospectivity. Future investigations of metalliferous black shale-hosted uranium will also be assessed in 2019.

**Conclusions**

Field studies on the Fury and Hecla Group north of Fury and Hecla Strait reveal several exquisitely preserved stratigraphic sections that present exposures of members of the Agu Bay and Autridge formations. Two sample sets for Re-Os analysis and another collected from a tuff bed 40 cm thick are used to establish depositional age constraints near the base and top of the succession (Figure 3). In addition to a detrital zircon provenance analysis of the Fury and Hecla
Group, a sequence stratigraphic framework will be established for the basin.

Future work will involve a micropaleontological analysis of samples from the Autridge and Agu Bay formations. Additionally, a well-resolved chronostratigraphic framework needs to be established, using black shale sample material to shed light on ocean chemistry, including redox conditions during basin development. Ultimately, these proposed datasets, constrained by new and much-needed geochemical data, will help elucidate where future work in the Baffin basins needs to take place to improve understanding of the tectonic, stratigraphic and geochemical storyline of the terminal Mesoproterozoic in northeastern Canada.

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