Re-Os geochronology highlights widespread latest Mesoproterozoic (ca. 1090–1050 Ma) cratonic basin development on northern Laurentia

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ABSTRACT

The terminal Mesoproterozoic was a period of widespread tectonic convergence globally, culminating in the amalgamation of the Rodinia supercontinent. However, in Laurentia, long-lived orogenesis on its eastern margin was punctuated by short-lived extension that generated the Midcontinent Rift ca. 1110–1090 Ma. Whereas this cratonic rift basin is typically considered an isolated occurrence, a series of new depositional ages demonstrate that multiple cratonic basins in northern Laurentia originated around this time. We present a Re-Os isochron date of 1087.1 ± 5.9 Ma from organic-rich shales of the Agu Bay Formation of the Fury and Hecla Basin, which is one of four closely spaced cratonic basins spanning from northeastern Canada to northwestern Greenland known as the Bylot basins. This age is identical, within uncertainty, to ages from the Midcontinent Rift and the Amundsen Basin in northwestern Canada. These ages imply that the late Mesoproterozoic extensional episode in Laurentia was widespread and likely linked to a common origin. We propose that significant thermal anomalies and mantle upwelling related to supercontinent assembly centered around the Midcontinent Rift influenced the reactivation of crustal weaknesses in Arctic Laurentia beginning ca. 1090 Ma, triggering the formation of a series of cratonic basins.

INTRODUCTION

The Mesoproterozoic tectonic history of Laurentia is a narrative of long-lived crustal thickening on its southern and eastern margins, which culminated in the Shaminigan orogeny ca. 1220–1160 Ma (McLelland et al., 2013) and the Grenville orogeny ca. 1090–980 Ma (Hynes and Rivers, 2010). The Midcontinent Rift, located in the western Great Lakes area of central North America, records an episode of intraplate extension between these orogenes on Laurentia’s present eastern margin. High-precision radiometric ages demonstrate that Midcontinent rifting and associated volcanism occurred ca. 1110–1085 Ma (Swanson-Hysell et al., 2019). Intraplate magmatism at this time was not restricted to the Midcontinent Rift but rather extended from present-day western (Guitreau et al., 2016) and southwestern United States (Timmons et al., 2005; Bright et al., 2014) to eastern Canada (Fig. 1A; McLelland et al., 2010).

Recent rhenium-osmium (Re-Os) radioisotopic dating of organic-rich strata hints that previously poorly constrained successions in middle to late Proterozoic sedimentary basins in Arctic Canada record extension following the development of the Midcontinent Rift in the Amundsen Basin at 1067.3 ± 13.5 Ma (Rainbird et al., 2020) and in the Borden Basin at 1048 ± 12 Ma (Gibson et al., 2018). The Fury and Hecla Basin on northwestern Baffin Island and northern Melville Peninsula (Figs. 1A and 1B) is assumed to be cogenetic with the nearby Borden Basin (Jackson and Iannelli, 1981; Chandler, 1988); however, a lack of radioisotopic ages from the former has left this interpretation unsubstantiated. Here we present a new Re-Os date of 1087.1 ± 5.9 Ma on black shale of the Agu Bay Formation in the lower Fury and Hecla Group and interpret new geodynamic linkages between the development of the Amundsen and Bylot basins ca. 1090–1050 Ma and significant mantle upwelling at the Midcontinent Rift.

GEOLOGICAL BACKGROUND

The Bylot basins comprise the Fury and Hecla, Borden, Aston-Hunting, and Thule Basins (Fig. 1A). Fahrig et al. (1981) linked the origin of these basins with magmatism of the 1.27 Ga Mackenzie large igneous province (LIP; LeCheminant and Heaman, 1989) based on paleomagnetic data from the lower Bylot Supergroup in the Borden Basin. Jackson and Iannelli (1981) inferred that the Bylot Supergroup recorded the opening of the proto–Arctic Ocean and inferred an age of ca. 1250–1200 Ma for the succession. However, most of the Bylot Supergroup stratigraphy postdates the Mackenzie LIP by >200 m.y. based on Re-Os dates of 1048 ± 12 Ma on the Arctic Bay Formation and 1046 ± 16 Ma on the Victor Bay Formation (Gibson et al., 2018). Turner et al. (2016) further showed that Grenville-aged zircons were captured only in the upper Bylot Supergroup (Strathcona Sound Formation) and proposed that extension in the Bylot basins was associated with far-field stress from the Amazonia-Laurentia collision.

Stratigraphy of the Fury and Hecla Group

The Fury and Hecla Group is ~2.8 km thick and records deposition in an elongate, westward-deepening basin (Fig. 1). The Nyboe Formation at the base of the succession contains red-weathering, shallow-marine and terrestrial siliciclastic deposits with minor carbonate and mafic lava flows (member 2A). The contact with the overlying Sikosak Bay Formation is poorly preserved, but the latter comprises cross-bedded, tan-colored shallow-marine sandstone. The upper contact between the Sikosak Bay Formation and the Agu Bay Formation is gradational through...
interbedding of sandstone lenses, dune-form sets, and shale. The Agu Bay Formation begins with a thin and discontinuous ∼1-m-thickstromatolite biostrome, overlain by ∼70 m of gray and black shale, which transitions into ∼500 m of mostly red siltstone and sandstone organized in ∼10–15-m-thick parasequences. The overlying Whyte Inlet Formation comprises mostly shallow-marine sandstone that transitions westward into the shale- and siltstone-dominated Atrridge Formation. The Fury and Hecla Group is cross-cut by mafic dikes and sills, including sills of the Hansen Formation, and is capped by the Dybvol Sill; these intrusions are inferred to be related to the ca. 720 Ma Franklin LIP (Chan- der, 1988; Heaman et al., 1992).

RESULTS

Samples of black shale (n = 11) were collected 35 m above the base of the Agu Bay Formation on Baffin Island (see the Supplemental Material; Fig. 1C). The Re-Os isotopic composition data (n = 7) yield a model 1 age of 1087.1 ± 5.9 Ma, with an initial 187Os/188Os (Os*) of 0.65 ± 0.02 (Fig. 2; Table S2 in the Supplemental Material). This date provides the first depositional age constraint on sedimentary strata of the Fury and Hecla Group.

DISCUSSION

Tectonostratigraphy of the Lower Fury and Hecla Group and Bylot Supergroup

Our Agu Bay Formation Re-Os date confirms a latest Mesoproterozoic age for the Bylot basins (Gibson et al., 2018) and provides an anchor for testing previous lithostratigraphic correlations between the lower Bylot Supergroup and lower Fury and Hecla Group (Fig. 3; Jackson and Iannelli, 1981; Chandler, 1988; Long and Turner, 2012). Together, the sandstones and basalts of the Nyboe Formation are interpreted to correlate with similar lithofacies of the Nauyat and Adams Sound Formations of the Borden Basin (Fig. 3), as proposed by Chandler (1988) based on lithostratigraphy. Considering that basalt magmatism represented by member 2a of the Nyboe Formation is interpreted to corre- spond to the Mackenzie LIP (Chandler, 1988), the Agu Bay Formation date implies that a major unconformity must exist in the lower Fury and Hecla Group, though no stratigraphic discontinuity has previously been recognized. However, the contact between the Nyboe and Sikosak Bay Formations is the most logical horizon for an unconformity given that the former contains volcanics inferred to be part of the Mackenzie LIP and the latter shares a gradual, conformable contact with the overlying Agu Bay Formation (Fig. 3). The contact between the Nyboe and Sikosak Bay Formations is poorly preserved in the basin, and any unconformity may have been obscured by wave ravinement during renewed subsidence given the similar shallow-marine lithofacies of both units. The implication that the Nyboe Formation is nearly 200 m.y. younger than the Sikosak Bay Formation can be tested by provenance analysis.

The necessity for a long-duration unconfor- mity has also been noted for the Borden Basin given the assumed Mackenzie age for the Nauyat Formation and the ca. 1050 Ma depositional age for the Arctic Bay Formation (Turner et al., 2012). Together, the sandstones and basalts of the Sikosak Bay Formations are interpreted to correlate with similar lithofacies in the adjacent Fury and Hecla Group, though no stratigraphic discontinuity has previously been recognized. However, the contact between the Nyboe and Sikosak Bay Formations is the most logical horizon for an unconformity given that the former contains volcanics inferred to be part of the Mackenzie LIP and the latter shares a gradual, conformable contact with the overlying Agu Bay Formation (Fig. 3). The contact between the Nyboe and Sikosak Bay Formations is poorly preserved in the basin, and any unconformity may have been obscured by wave ravinement during renewed subsidence given the similar shallow-marine lithofacies of both units. The implication that the Nyboe Formation is nearly 200 m.y. older than the Sikosak Bay Formation can be tested by provenance analysis.

The necessity for a long-duration unconform- ity has also been noted for the Borden Basin given the assumed Mackenzie age for the Nauyat Formation and the ca. 1050 Ma depositional age for the Arctic Bay Formation (Turner et al., 2016; Gibson et al., 2018). Gibson et al. (2019) proposed that this unconformity be placed near the contact between the Adams Sound and Arctic Bay Formations. Irrespective of the exact placement of the unconformity, it is clear that the Arctic Bay

Figure 1. Latest Mesoproterozoic cratonic basin development on Laurentia. Ottawan orogenic belt is after Hynes and Rivers (2010). (A) Intrapatle magmatism ca. 1.1–1.08 Ga recorded by dating of volcanic rocks including Hawkeye granite (Chiarenzelli and Mclelland, 1991), Pikes Peak granite (Flowers et al., 2020), and Southwest Laurentia large igneous province (SWOLLIP; Bright et al., 2014). Red box indicates location of B. LIP—large igneous province. (B) Geology of Fury and Hecla Basin. Fault location is taken from Spratt et al. (2013). Yellow star shows sample location of Re-Os sample set 18SUB-W054. Gp.—Group; Fm.—Formation. (C) Stratigraphic section WG1901 (see C for location) of Fury and Hecla Group exposed on Melville Peninsula, after Greenman et al. (2019).
and Sikosak Bay–Agu Bay formations record renewed subsidence and sedimentation in the Bylot basins following a ~200 m.y. depositional hiatus. Importantly, while these units are lithologically similar and stratigraphically analogous, a direct chronostratigraphic correlation is negated by the Re-Os ages that indicate that the Arctic Bay Formation is at least 21 m.y. younger than the Agu Bay Formation (Fig. 3).

In the Borden Basin, reactivation of WNW-ESE normal faults that define the Milne Inlet graben provided accommodation space for deposition of as much as ~1 km of organic-rich shale of the Arctic Bay Formation into a restricted basin ca. 1050 Ma (Turner and Kamber, 2012; Turner et al., 2016; Gibson et al., 2018, 2019). A swarm of similarly trending brittle faults is observed on the northern Melville Peninsula (Fig. 1B; Spratt et al., 2013) with the same orientation as the Fury and Hecla Basin. Reactivation of fault systems is common during tectonic regime shifts (Sykes, 1978; Sibson, 1985), and given that reactivation of roughly
WNW-ESE faults in the Borden Basin is linked to the deposition of the Arctic Bay Formation (Turner and Kamber, 2012), we infer that extensional reactivation of similar oriented faults on the northern Melville Peninsula generated accommodation space for the Agu Bay Formation ca. 1090 Ma.

**Comparison with the Shaler Supergroup**

The updated age assignments for the lower Fury and Hecla Group and lower Bylot Supergroup are consistent with their lithostratigraphic resemblance to the upper Coppermine River Group–lower Shaler Supergroup in northwestern Canada (Fig. 3). The Coppermine River Group comprises Mackenzie-aged basalts overlain by a terrestrial red-weathering sandstone with interbedded subaerial basalt flows (Meek et al., 2019) that were deposited in the Hornby Bay Basin. A ∼200 m.y. unconformity separates the Coppermine River Group from the overlying Escape Rapids Formation, which begins with a transgressive systems tract mostly comprising parallel-laminated siltstone interlayered with organic-rich mudstone (Rainbird et al., 2020). The Re-Os age of 1067.3 ± 13.5 Ma from the basal Escape Rapids Formation dates the opening of the Amundsen Basin (Rainbird et al., 2020). Notably, this age is identical, within uncertainty, to the Agu Bay Formation date. A commonality among these ca. 1090–1050 Ma shale-rich successions of northern Canada is their transgressive nature marked by interbedded, shallow-marine sandstone transitioning into monotonous shale and siltstone (Rainbird et al., 2020; Greenman et al., 2019; Jackson and Iannelli, 1981). Given the lack of evidence for coeval compression, we posit that this rapid subsidence was controlled by regional extension, which in the case of the Bylot basins appears to have reactivated long-lived fault systems that had previously accommodated earlier Mesoproterozoic strata (Turner and Kamber, 2012).

**Crustal Thinning on the Margins of the ca. 1 Ga Laurentian Craton**

The Midcontinent Rift can no longer be considered an isolated late Mesoproterozoic extensional event in the shadow of the Grenville orogen. Rather, it is now evident that extension extended into Arctic Laurentia and was accommodated by zones of pre-existing crustal weaknesses ca. 1090–1050 Ma. This scenario may be analogous to crustal thinning causing renewed normal faulting on the uplifted Tibetan Plateau during the Cenozoic India-Eurasia collision (Blisniuk et al., 2001) and offers an explanation for the ∼200 m.y. unconformity if a phase of gentle uplift in Arctic Laurentia occurred sometime between ca. 1270 and 1090 Ma, feasibly attributable to the Shawinigan orogeny.

The evolution of these ca. 1.1 Ga cratonic basins on Laurentia has historically been interpreted individually. However, temporal and tectonostratigraphic similarities suggest that a more holistic interpretation is more suitable for the ca. 1090–1050 Ma successions discussed here. Given the great thickness of volcanics and sediments within the Midcontinent Rift (∼10–25 km) and total volume of associated magmatic rocks (>2 × 106 km³), it is evident that this region experienced both significant lithospheric extension and a massive thermal anomaly (Edwards and Blackburn, 2018) related to mantle upwelling (Swanson-Hysell et al., 2021). The relatively long duration and pulsing nature of magmatism in the Midcontinent Rift implies that the thermal anomaly was not the consequence of a single mantle plume, but rather may have been the result of multiple plumes, mantle return flow related to slab avalanche (Swanson-Hysell et al., 2019), thermal blanketing by the large composite continent residual from Nuna that included Laurentia (Hanson et al., 2004), or some combination of these influences. In any case, the concurrence of ca. 1.10–1.08 Ga magmatism on southwestern Laurentia, >2000 km away (Bright et al., 2014), attests to the long wavelength of this thermal anomaly. We suggest that the influence of this broad mantle plume reached the northern margin of Laurentia as well, but there manifested in the crustal thickening and thinning that gave rise to the Bylot and Amundsen basins. This asymmetric tectono-thermal response on opposite margins of Laurentia may be attributable to the additional influence of rapid (>20 cm/yr) eastward drift (in present coordinates) of Laurentia driven by slab pull beneath Amazonia (Swanson-Hysell et al., 2019).

The depositional history of the Bylot, Amundsen, and Midcontinent Rift basins overlaps temporally with the Ottawan phase of the Grenville orography (Fig. 1A; ca. 1090–1030 Ma; Hynes and Rivers, 2010; Rainbird et al., 2017), which is posited to have played a role in the development of the Bylot basins (Turner et al., 2016) and the Midcontinent Rift (Swanson-Hysell et al., 2019). It represented a stress regime switch to compression as Laurentia collided with Amazonia (Hynes and Rivers, 2010; McLelland et al., 2010). Subsequent fault inversion at the Midcontinent Rift is not interpreted to have occurred until the Rigollet phase (1005–980 Ma; Hynes and Rivers, 2010) of the Grenville orogeny (Swanson-Hysell et al., 2019). Should this return to compressional tectonics have been as widespread as was extension, it may provide a constraint on renewal of compression in the Bylot basins. Sherman et al. (2002) attributed an angular unconformity in the upper Bylot Supergroup to fault inversion in the Bylot basins ca. 1.2 Ga. However, in light of new age constraints, a much younger age, closer to 980 Ma, now represents a more logical estimate for renewed compression and may account for the appearance of Grenville-aged zircons in the upper Bylot Supergroup (Nunatsiaq Group; Turner et al., 2016).

**CONCLUSION**

A Re-Os age of 1087.1 ± 5.9 Ma from the Agu Bay Formation adds to mounting evidence for latest Mesoproterozoic cratonic basin rejuvenation in Arctic Laurentia. Stratigraphic comparisons between the Fury and Hecla, Borden, Amundsen, and Midcontinent Rift basins paired with recent ages imply a shared geodynamic driver. Late Mesoproterozoic magmatism and rift-basin development demonstrate that the margins of the craton of Laurentia experienced localized crustal thinning, presumably in response to a combination of mantle upwelling associated with significant thermal anomalies, slab-pull subduction, and rapid plate motion of the Laurentian plate subducting underneath Amazonia (Swanson-Hysell et al., 2019). We speculate that other poorly geochronologically constrained late Mesoproterozoic successions on Laurentia from the American southwest (Timmons et al., 2005) to northwestern Canada (Pinguiucula Group, Yukon) and possibly as far as Siberia (Puchkov et al., 2014) may record similar geodynamically linked basin formation or rejuvenation ca. 1090–1050 Ma.

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