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Tectonic controls on distribution and stratigraphy of the Cryogenian Rapitan iron formation, northwestern Canada

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ABSTRACT

Paleogeographic data indicate that the Neoproterozoic Rapitan Group accumulated in two spatially related, silled basins during the first mid-Neoproterozoic glacial episode (ca. 711 Ma), yet the controls on glaciation, reason for basin development, spatio-temporal relationships among stratigraphic units, and constraints on iron formation deposition and distribution in this region and globally at this time have not been adequately explained. The lack of a coherent understanding of the group's regional stratigraphy has been a significant barrier to deciphering the geologic history of this critically important succession. Based on new stratigraphic data, and incorporating the results of a related geochemical study, the Rapitan Group accumulated in tectonically complex sub-basins of a young rift zone. The spatial and temporal dynamics of these sub-basins controlled the grain size, volume, and distribution of detrital sediment (predominantly turbidites and diamictites) deposited during two glacially influenced episodes with ice cover. During an interglacial episode, the rotated, exposed upper surfaces of newly displaced rift blocks directed drainage away from basin margins, precluding significant clastic sediment delivery, and subaqueous margins of outboard tilted fault blocks acted as sills that isolated local bottom water, allowing the accumulation of an entirely hydrogenous succession (jaspilitic and hematitic iron formation). Two strike-parallel normal faults that strongly controlled basin-margin development are prominent thrust faults in the present-day orogen. Syndepositional activity of strike-normal transfer faults segmented the basins along their length, as reflected in pronounced along-strike variations in the presence/absence, thickness, and composition of the three stratigraphic units (Mt. Berg, Sayunei, and Shezal formations), and in the presence or absence of iron formation (locally >100 m thick; top of Sayunei Formation). Differential subsidence in actively rifting basins was essential for deposition of Rapitan-type iron formation, but glaciation, although coeval with Rapitan Group accumulation, was not a strong control. The timing of the onset of glacially influenced sediment deposition in the closely spatially related Rapitan (∼711 Ma) and Mount Harper groups (∼717 Ma) in northwestern Laurentia differs by ∼6 m.y., arguing for diachronous Sturtian glaciation, both locally and globally.

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1. Introduction

The Neoproterozoic recorded two major turning points in the evolution of Earth's surface environments: the second major rise in oxygenation of the ocean and atmosphere (the Neoproterozoic oxygenation event(s); Campbell and Squire, 2010; Och and Shields-Zhou, 2012), and the appearance of the first undisputed macroscopic metazoans (Canfield et al., 2007). These significant changes in Earth's surficial system seem to be temporally, and may be causally (Canfield et al., 2008; Peterson et al., 2008; Shields-Zhou and Och, 2011) affiliated with the "snowball Earth" glaciations, a group of possibly global glacial events that took place between 740 and 582 Ma (Kirschvink, 1992; Hoffman et al., 1998; Hoffman and Li, 2009). Despite their obvious geological significance, there remains substantial disagreement over the cause and scale of the Neoproterozoic glaciations. There are strong arguments for a "hard snowball Earth", with full global glaciation (Hoffman and Schrag, 2002; Hoffman, 2009), whereas others make a case for localised, continental-rift-related events (e.g., Young, 2002; Eyles and Januszczak, 2004; Eyles, 2008). In either case, the geological implications of these glacial events are substantial.

A peculiar aspect of the Neoproterozoic glaciations is the deposition of banded iron formation, a sediment type that had not been

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deposited in significant volumes after the latest Paleoproterozoic (Bekker et al., 2010). The Neoproterozoic resumption of iron formation deposition is a key aspect of Proterozoic redox evolution models (Poulton and Canfield, 2011). Although the Neoproterozoic glaciogenic iron formation ("Rapitan-type" iron formation; Gross, 1993) is not unique in its stratigraphic association with glacioclastic sediment (e.g., Smith et al., 2013), nor in its age (e.g., Basta et al., 2011), the overwhelming majority of glacial-associated iron formation deposits in the geological record were deposited during the Neoproterozoic. Rapitan-type iron formation is generally associated with Sturtian glacial deposits (∼720–660 Ma) (Macdonald et al., 2010), which belong to the first of three proposed Neoproterozoic glacial episodes, although some examples have not been assigned to any specific glacial episode owing to stratigraphic complications and the lack of geochronologic constraints (e.g., Freitas et al., 2011).

Iron formation is not universal in Sturtian glacial deposits (Hoffman, 2009), and it is commonly geographically limited within the glacial basins that contain it. Most Sturtian glacial deposits were deposited in young continental rifts, similar in scale to the modern Red Sea (Young, 2002), and few, if any, accumulated on passive continental margins (Eyles, 1993). This relationship may reflect (a) a preservational bias, (b) the sheer abundance of incipiently rifting margins at ca. 700 Ma (due to the dispersal of Rodinia), or (c) a causal link between rifting and both glaciation and Rapitan-type iron formation (e.g., Young, 2002). Although the dynamics of the link between rifting and Neoproterozoic glaciations remain unresolved, development of partially restricted, sediment-starved marine basins has been shown to facilitate deposition of iron formation (Baldwin et al., 2012b).

The archetypal Neoproterozoic iron formation is the Rapitan iron formation of the Mackenzie and Wernecke Mountains (Northwest Territories and Yukon, Canada). Most, if not all, of this unit was deposited after 711 Ma (Baldwin et al., 2012a) during the Sturtian glaciation, and is associated with glacioclastic turbidites and diamictites of the Rapitan Group. The Rapitan Group is preserved in an arcuate belt in the northern Canadian cordillera (Fig. 1), but its exposure is discontinuous over 370 km of strike, and defines two distinct depositional basins: the Snake River basin (SRB) and Redstone basin (RB). The iron formation unit is even more discontinuous than the Rapitan Group as a whole, and for much of its strike-length is thinner than 10 cm. Significant thicknesses (>30 m) of iron formation are limited to the SRB, at the northwestern end of the exposure belt (Yeo, 1981). This sector also encompasses most of the known textural variation. Thickness and compositional differences between the two basins have resulted in disputed stratigraphy and correlation at the formation level (e.g., Yeo, 1981; Klein and Beukes, 1993; Hoffman and Halverson, 2011).

Thickness variations in the Rapitan Group in the Mackenzie Mountains were addressed in a paleogeographic context by Eisbacher (1985), whose study emphasised implications for

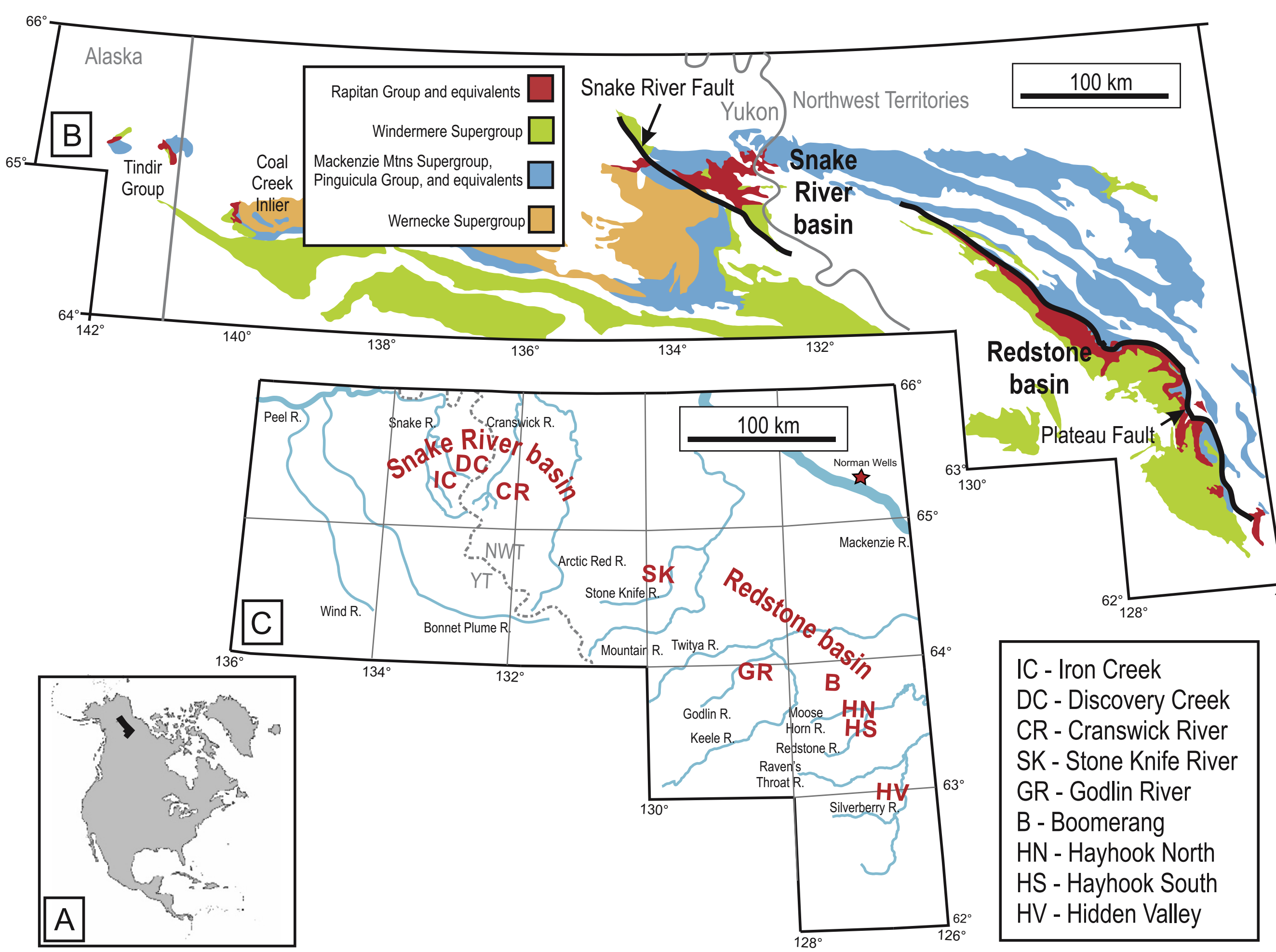

Fig. 1. (A) Location of study area in northwestern Canada. Black area is enlarged in (B). (B) Regional geology map showing the distribution of Proterozoic rocks in the northern Canadian cordillera (after Yeo, 1981; Baldwin et al., 2012b). Rapitan Group shown west of the Snake River Fault is orthoconglomerates (Eisbacher, 1981b) that resemble fanglomerates of Redstone River Formation member 2 (Jefferson and Ruelle, 1987) or Mount Berg Formation conglomerates (Yeo, 1981); the stratigraphic affinity of these exposures is uncertain. (C) Location of stratigraphic sections and locations discussed in the text.

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