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Contradictory correlations of Paleoproterozoic glacial deposits: Local, regional or global controls?

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ABSTRACT

There is little agreement among recently proposed correlation schemes for Paleoproterozoic glaciogenic rocks scattered thinly around the globe. Correlations are hindered by the dearth of tight geochronological control on the ages of glacial deposits, which are notoriously difficult to date. Most attempts at global correlation are based on comparison to the Huronian Supergroup in Canada, which contains three glaciogenic formations. Although the two lower glacial units were deposited in a rift setting and have a restricted distribution even in North America, they have been used in attempts to effect international correlations. The Gowganda Formation, together with correlatives, comprises the thickest and by far the most widespread Paleoproterozoic glacial deposits in North America. Glacial deposits are also reported from South Africa, Western Australia and elsewhere, where they appear to fall within the same time period as the Huronian Supergroup (2.45–2.2 Ga) but attempts to correlate individual diamictite-bearing units to the three Huronian glaciogenic formations have proved difficult. None of the Huronian glacial formations has been precisely dated. Until such geochronological data are available it is practical and prudent to recognize that, during the early Paleoproterozoic, as in the Cryogenian, the Earth was susceptible to glaciations that could be triggered by a variety of local events including uplift, related to rifting and compressional orogeny. Within the 250 million years of the 'Huronian Glacial Event' (2.45–2.2 Ga) it is commonly assumed that ice sheet fluctuations were globally synchronous but this has not been demonstrated.

1. Introduction

There is meagre evidence of Archean glaciations but the long Proterozoic Eon is bracketed by two complex glacial episodes known as the 'Huronian-age glaciations' (Melezhik et al., 2013), or the 'Huronian Glaciation Event' (Tang and Chen, 2013) and the Cryogenian-Ediacaran glaciations. There is little evidence of frigid conditions between these great glaciations but Williams (2005), Kuipers et al. (2013) and Geboy et al. (2013) cited rare examples from the late Paleoproterozoic and late Mesoproterozoic.

Sometime during the Ediacaran period the Earth's climatic zonation appears to have gone through a radical change, for paleomagnetic results suggest that older glaciations occurred at low latitudes, whereas those of the late Ediacaran (after about 570 Ma), together with the many Phanerozoic glaciations, appear to have occurred mainly at high latitudes (Frakes, 1979; Frakes and Francis, 1988; Williams, 1975, 2008; Evans, 2003; Young, 2013a). Paleomagnetic results indicating formation of Precambrian glaciogenic deposits at low paleolatitudes sparked two competing interpretations – the snowball Earth hypothesis, drawing, among others, on early investigations by Mawson (1949) and Harland (1964), who drew attention to the wide distribution of 'late Precambrian' glaciations, but receiving world-wide attention (both positive and negative), following publication of papers by Kirschvink (1992) and Hoffman et al. (1998) – and the high obliquity theory of Williams (1975, 2008). Whereas both ideas accommodate the occurrence of ice sheets at sea level in equatorial latitudes, only the high obliquity theory provides a plausible explanation for the occurrence of fossil ice-wedge structures and varved laminites, both of which require large seasonal temperature variations (Lindsey, 1969; Williams, 1975; Hughes et al., 2003). The high obliquity theory also provides an explanation for the paucity of Proterozoic glacial deposits formed at high latitudes, in contrast to their ubiquity among Phanerozoic examples. The dearth of evidence of glaciations in high latitudes has been attributed by some to the absence of continents in circumpolar locations but it seems more than fortuitous that there was an apparently rapid change in the late Ediacaran Period to

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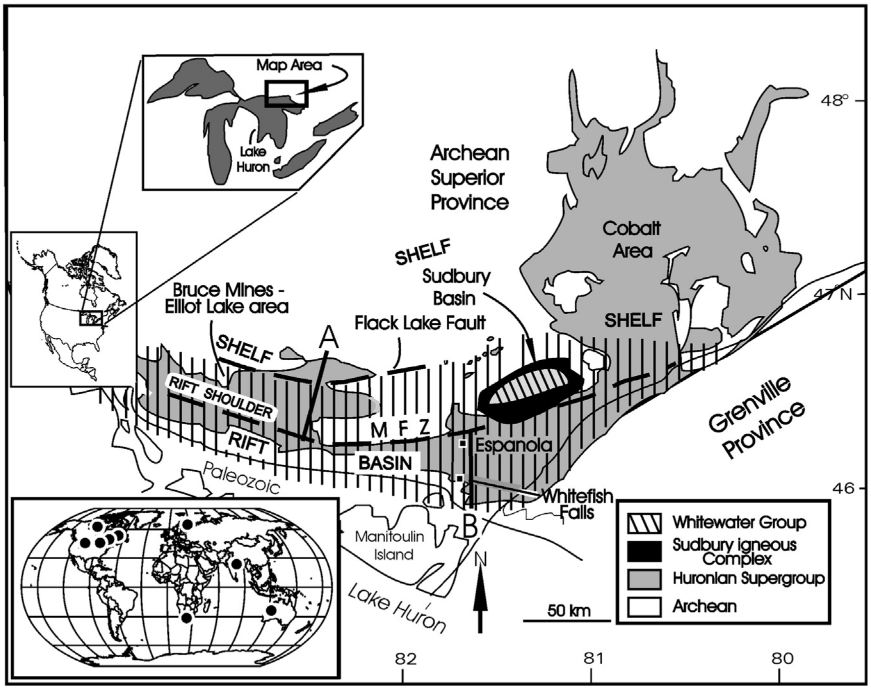

Fig. 1. Sketch map to show the location of the Huronian Supergroup on the north shore of Lake Huron. Huronian stratigraphic units below the Gowganda Formation are confined to the southern part of the Huronian outcrop belt shown by the vertical striped ornament. The area south of the Murray Fault Zone (MFZ) is considered to be the main Huronian rift basin whereas the area between the MFZ and the Flack Lake Fault represents a rift 'shoulder'. Extensive areas to the north, west and northeast, where the Gowganda and succeeding formations were deposited directly on Archean basement rocks are interpreted as a passive margin that formed and subsided after deposition of the Serpent Formation. Two heavy lines, labelled "A" and "B" show the location of the composite restored cross section shown in Fig. 2. Inset (bottom left) shows the present distribution of Paleoproterozoic glacial deposits discussed in the text.

glaciations that were exclusively developed at high latitudes. The change from 'tropical' glaciations in Early and Late Proterozoic (Cryogenian) times to circum-polar icecaps throughout the entire Phanerozoic would require the coincidence of significant climatic amelioration (preventing descent of glaciers into low latitudes) and generation of continental configurations that permitted glaciers to develop at high latitudes throughout the last 500 Ma of Earth history.

In recent years there have been several attempts to establish correlations among scattered exposures of Paleoproterozoic glacial deposits from around the world (Bekker et al., 2001; Kopp et al., 2005; Young, 2013b; Tang and Chen, 2013; Hoffman, 2013; Rasmussena et al., 2013). The highly varied results of these attempts (see Section 8) indicate that many problems remain.

The main purposes of this article are to direct attention to the tectonic setting of the Huronian Supergroup (Fig. 1), which is commonly used as the 'type area' for comparison to Paleoproterozoic glaciogenic deposits in other parts of the world, and to underline important differences between the extensive Gowganda Formation and two lower glaciogenic formations, which are considered to be local deposits, developed in a rift setting. In the light of this information, and reports from South Africa and Western Australia suggesting that Paleoproterozoic glacial formations in these areas were deposited during a period of collisional orogeny, it is suggested that the planet, for reasons as yet poorly understood, was rendered susceptible to glaciation between about 2.45 Ga and 2.2 Ga, within which time period local events such as uplift of rift shoulders (Huronian Basin) and collisional orogenies (S. Africa and W. Australia) triggered the growth of glaciers, so that Paleoproterozoic glacial deposits may have been generated at different times in different places within the long-lived 'Huronian Glacial Event'.

2. Age and nature of the Huronian glacial formations

Among Paleoproterozoic glacial deposits those in the Huronian Supergroup are probably the best known. The glacial origin of the Huronian Gowganda Formation was recognized by Coleman (1907) and these rocks have been the focus of many subsequent geological investigations (Lindsey, 1969, 1971; Mustard and Donaldson, 1987; Rainbird and Donaldson, 1988; Junnila and Young, 1985; Miall, 1985; Young and Nesbitt, 1985, 1989; Young, 2013c and references therein). Evidence was presented by Young and Chandler (1968) in support of a glacial origin for two earlier diamictite-bearing Huronian formations (Bruce and Ramsay Lake), a proposal that has been followed in most subsequent papers on the Huronian Supergroup.

Because three glacial formations of the Huronian Supergroup (the Ramsay Lake, Bruce and Gowganda formations) are commonly used as a template against which other Paleoproterozoic glacial deposits are compared, it is important to recognize significant differences in their character, distribution and tectonic setting. All three are younger than the Copper Cliff Rhyolite which has yielded a date of 2450 ± 25 Ma (ID-TIMS) (Krogh et al., 1984) and more recently a U-Pb zircon age of 2452.5 ± 6.2 Ma was reported by Ketchum et al. (2013). The Huronian Supergroup is intruded by the dominantly mafic Nipissing intrusions, which have been dated at 2217 ± 9 Ma (ID-TIMS on baddeleyite and rutile fractions) (Corfu and Andrews, 1986). The precise ages of the individual diamictites are not known but a date of ~2.31 Ga for the Gordon Lake Formation (see Fig. 2) was recently reported by Rasmussena et al. (2013). In a geochronological investigation of the Paleoproterozoic Marquette Range Supergroup in the northern peninsula of Michigan. Vallini et al. (2006) presented evidence that they interpreted to mean that the Enchantment Lake Formation – a putative correlative to the Gowganda Formation in Ontario (Young, 1973) – was deposited at about 2.317 ± 6 Ma, the age of euhedral zircon grains obtained from