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Carbon isotope record for the onset of the Lomagundi carbon isotope excursion in the Great Lakes area, North America

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Abstract

Carbonate units of the Chocolay Group in the Lake Superior area, USA and the Gordon Lake Formation of the correlative upper Huronian Supergroup, Ontario, Canada were deposited after the last Paleoproterozoic glacial event and an episode of intense chemical weathering. The Huronian Supergroup contains at the base ∼2.45 Ga volcanics and is intruded by the 2.22 Ga Nipissing diabase dykes and sills while the Chocolay Group is bracketed in age between ∼2.29 and 2.20 Ga. The Lomagundi (∼2.22–2.1 Ga) carbon isotope excursion started after the Paleoproterozoic glacial epoch and before a plume breakout event at 2.22 Ga. Therefore, the Chocolay and Upper Huronian carbonates were deposited either before or during the onset of the Lomagundi event. Notably, thin carbonates of the basal Gordon Lake Formation and thick carbonate succession of the Kona Dolomite in the northeastern exposures of the Chocolay Group record $\delta^{13}C$ values as high as +9.5‰ versus V-PDB. Similar to other successions deposited during the Lomagundi event, both units contain pseudomorphs and molds after sulfates. This observation suggests that seawater sulfate contents rose dramatically in association with the onset of the Lomagundi event and the rise of atmospheric oxygen. Carbonates in the western and southern exposures of the Chocolay Group (Randville and Bad River dolomites, and Saunders Formation) previously assumed to be equivalent to the Gordon Lake Formation and Kona Dolomite have carbon isotope values close to 0‰. Based on basin analysis, we infer that these carbonate units were deposited during a negative carbon isotope excursion after the Lomagundi event started and are slightly younger than the Kona Dolomite and Gordon Lake Formation. This interpretation implies that the carbonate platform in the Great Lakes area transgressed to the west over shallow-marine and fluvial deposits. The negative carbon isotope excursion in the Lake Superior area might correspond to similar $\delta^{13}C$ values of the Mooidraai Dolomite in the Griqualand West Basin, South Africa supporting correlation between Paleoproterozoic successions of North America and South Africa and the notion of three global glaciations in the Paleoproterozoic Era. Carbonates of the Mille Lacs Group (Trout Lake, Glen Township, and Denham formations) in Minnesota have $\delta^{13}C$ values ranging from −1.2 to +2.5‰. Combined with geochronologic constraints, these data suggest that these units were deposited after the Lomagundi excursion and are related to the rifting event that led to development of the so far unrecognized ∼2.0 Ga passive margin in the Lake Superior area.

Keywords: Chemostratigraphy; Basin analysis; Paleoproterozoic Era; Chocolay Group; Huronian Supergroup; Glaciation

1. Introduction

Progress over the last decade has significantly improved our understanding of tectonic, environmental, and climatic changes in the early Paleoprotero-

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zoic Era. Assembly of the supercontinent Kenorland in the Late Archean up to ∼2.42 Ga time interval overlapped with plume breakout events between 2.48 and 2.42 Ga (Barley et al., 2005), and was closely followed by three global glaciations (Young, 2002). Associated with these three ice ages are two strongly positive carbon isotope excursions; one is arguably bracketed between the second and the last glacial events and called the Duitschland event, and the other radiometrically constrained between 2.22 and 2.06 Ga and named the Lomagundi event follows the glacial epoch. While the older excursion is confined to the Duitschland Formation of South Africa (Bekker et al., 2001) and has not yet reproduced in other basins potentially due to the lack of carbonates in a correlative stratigraphic position, the younger event is recognized in a number of basins worldwide and has proven useful for interbasinal correlation (cf. Karhu and Holland, 1996; Bekker et al., 2003). Geochemical and lithologic evidence for the rise of atmospheric oxygen level occur stratigraphically below the Lomagundi excursion, and perhaps beneath the older excursion as well (Bekker et al., 2005).

The duration and amplitude of the Lomagundi excursion is striking and finds no match in Earth history. It has been argued that this apparently long-lived event may have included several oscillatory sub-cycles (Melezhik et al., 1999). Our earlier review of available age constraints (Bekker et al., 2003a), however, supported the more conservative view of a single sustained event. The issue is complicated by the general absence of carbonates above the last Paleoproterozoic glacial diamictite. Instead, this post-glacial time interval appears to be one of global deposition of mature quartz sandstones and rare evaporites, suggesting extreme greenhouse conditions. Thin carbonates are rarely present within these mature quartz sandstones. These carbonates have highly variable δ^{13}C values ranging from 0 to +5‰ versus V-PDB (Lower Jatulian Group, Karelia and Kola Peninsula, Russia: Yudovich et al., 1990; Tikhomirova and Makarikhin, 1993; Melezhik and Fallick, 1996; Magusa and Whiterock members of the Kinga Formation, Hurwitz Group, Nunavut, Canada: Bekker et al., unpublished; Cercadinho Formation, Minas Supergroup, Brazil: Bekker et al., 2003).

To further investigate this post-glacial time interval, we present a chemostratigraphic and basin analysis of carbonates from the Gordon Lake Formation in the Upper Huronian Supergroup of Canada, which is younger than the ultimate Paleoproterozoic glacial event and intruded by the 2.22 Ga Nipissing diabase dykes and sills, as well as carbonates from broadly correlative units of the Chocolay Group in Wisconsin and Michigan and the Mille Lacs Group of Minnesota. Our objectives are (1) to use carbon isotope data as a test of lithostratigraphic correlations in the region; (2) to provide new constraints for development of Paleoproterozoic basins in the Great Lakes area; and (3) to characterize the tempo and mode of carbon isotope variations of the ocean in the aftermath of the Paleoproterozoic glacial epoch and through the Lomagundi event.

2. Regional setting and stratigraphy

Early Paleoproterozoic successions preserved along the southern margin of the Superior Craton include thick, predominantly siliciclastic packages. The Huronian Supergroup outcrops along the north shore of Lake Huron, Ontario, Canada and in a series of large outliers to the east-northeast of Lake Huron (Young, 1991; Fig. 1). The lower part of the Huronian Supergroup was deposited in a rift setting, while the upper part (starting with the Gowganda Formation; see Fig. 2) is a passive margin succession dominated by siliciclastic sediments (Zolnai et al., 1984; Young et al., 2001). The Huronian Supergroup is subdivided by unconformities into four groups, the upper three are climatically controlled cycles with glacial diamictites at the base followed by deltaic mudstones or carbonate and overlain by thick fluvial sandstones (Young et al., 2001).

The basal Huronian rests unconformably with locally preserved reduced paleosols on the Archean Superior Province (Prasad and Roscoe, 1996) and contains conglomerates with detrital pyrite and uraninite of the Livingstone Creek and Matinenda formations, suggesting low atmospheric oxygen content during their deposition. Interlayered volcanic rocks and intrusive contacts with the Murray and Creighton granites constrain the age of the basal Huronian to 2.48–2.42 Ga (Krogh et al., 1984, 1996; Smith and Heaman, 1999; Smith, 2002), while the entire Huronian Supergroup was folded and subsequently intruded by the 2217.5 ± 1.6 Ma Nipissing sills and dykes (Andrews et al., 1986). Facies change dramatically across the latitudinal Murray Tectonic Zone that separates shallow water sequences with subgreenschist to lower greenschist facies of metamorphism and open folds to the north from deeper water, thicker sequences with higher metamorphic grade and tight upright folds to the south (Card, 1978). Paleocurrent indicators in the lower Huronian sandstones, facies analysis, and isopach maps suggest a paleoslope towards the southeast (Fralick and Miall, 1989; Rousell and Long, 1998).

The upper part of the Huronian Supergroup deposited above the youngest Paleoproterozoic glacial deposit con-