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Climatic cycles recorded in glacially influenced rhythmites of the Gowganda Formation, Huronian Supergroup

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ABSTRACT

The Gowganda Formation of the 2.45–2.2 Ga Huronian Supergroup contains glacially-induced, varve-like rhythmites that potentially preserve a detailed record of climatic conditions during the Paleoproterozoic Era. Four rhythmic couplet thickness records were measured at two outcrops near Wharncliffe, Ontario for the purpose of time-series analysis. The couplets, which range from 1 to 32 mm thick, are composed of alternating layers of siltstone and claystone. Time-series analysis of the couplet thickness records using the MTM Toolkit of Mann and Lees (1996) consistently revealed periodicities in the range of 2.2–2.9 couplets per cycle, which is consistent with climatic cycles such as the quasi-biennial oscillation (QBO) and the El Niño Southern Oscillation (ENSO) observed in modern times. This periodicity suggests that the rhythmic couplets represent annual deposits (i.e. varves). Evidence for the presence of cycles at 3.0–4.9 couplets, 6.6–6.9 couplets, 8.8–9.2 couplets, 22.8 couplets, and 30.1–31.0 couplets were also observed in some couplet thickness records; however, the presence of these longer term cycles was inconsistent from site to site.

1. Introduction

Clastic rhythmites are subaqueous sediment couplets that are deposited in horizontal layers on a periodic basis (Bramlette, 1946; Reineck and Singh, 1972). The couplets composing a rhythmite generally consist of a coarse-grained layer, predominantly composed of fine sand or coarse silt, and a fine-grained layer, which is generally composed of fine silt or clay (Williams, 2000). Rhythmite development may be predominantly influenced by depositional environments and processes, which is the case for tidalites and turbidite deposits, or mainly by climatic conditions at the time of deposition, particularly if they are formed in association with deglaciation. De Geer (1912) was the first researcher to describe rhythmites that form annually as a result of deglaciation, introducing the term "varve" to describe a couplet. Early work on varves found in glacial lakes in eastern Canada noted that the summer, coarse-grained layers were substantially thicker than the winter, fine-grained deposits (Antevs, 1925). However, each layer comprising a varve is not necessarily homogenous, as shown in a later investigation of varves in Lake Barlow-Ojibway, Ontario, Canada (Agterberg and Banerjee, 1969). The authors subdivided the winter layer into a lower turbidite deposit overlain by a clay layer that rained out from suspension. More recently, varves have been defined as containing two or more laminal layers that repeat annually (Ojala et al., 2012). Ultimately, the thickness of individual varves in glacially-influenced environments is related to the annual influx of sediment to a regional basin, which is influenced by the annual rate of glacial meltwater discharge (Delaney, 2005).

Hughes et al. (2003) conducted a small-scale spectral analysis of 256 rhythmites within the upper Gowganda Formation from a location they referred to as the Wharncliffe argillite. The present study expands upon the work of Hughes et al. (2003) by examining four rhythmite sequences from two rock outcrops within the upper Gowganda Formation in order to: (1) determine whether climate forcing can be identified, and if found, (2) compare climatic periods across all four rhythmite records. We employ high resolution spectral analysis using the multitaper method of Mann and Lees (1996) to identify consistent periodicities associated with climatic forcing influenced rhythmite formation, implying that individual rhythmites may represent annual deposits.

2. Geologic setting

The Huronian Supergroup is a sedimentary-dominated succession that unconformably overlies Archean rocks of the Superior Province north of Lake Huron in Ontario, Canada (Fig. 1). The succession forms an approximately 325 km long belt that extends

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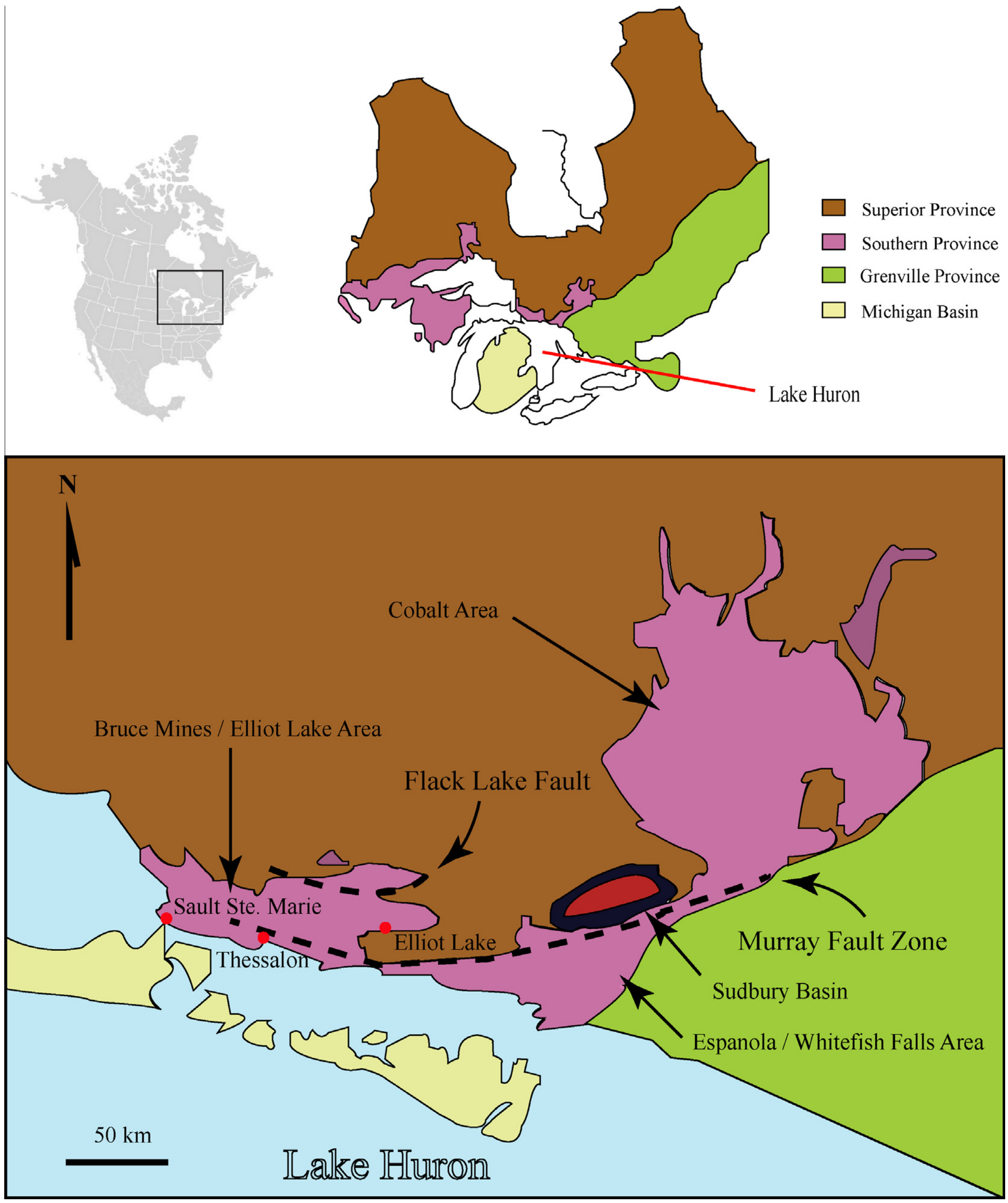

Fig. 1. Distribution of the Huronian Supergroup in Ontario, Canada. The Huronian Supergroup comprises the eastern section of the Southern Province, and is divided into three regions: the Bruce Mines/Elliot Lake area, the Espanola/Whitefish Falls area and the Cobalt area. The Flack Lake fault and the Murray fault zone (dashed lines) indicate contemporaneous down-to-basin faulting. Map modified from Freeman (1978) and Young et al. (2001).

from Noranda, Quebec in the northeast to the Sault Ste. Marie area in the west (Willingham et al., 1985). The Huronian Supergroup is up to 12 km thick at its southern boundary where it underlies Paleozoic rocks of the Michigan Basin (Young et al., 2001), and thins toward the north and west of the Southern Province. The southeastern boundary of the Huronian Supergroup is characterized by the Grenville Front, the remnants of a mountain building event that terminated at ca. 1.0 Ga (Moore and Thompson, 1980). Rocks in the Bruce Mines-Elliot Lake area have been metamorphosed to greenschist grade (Lindsey, 1969), but the prefix "meta" to describe the rock types is herein omitted for simplicity. Tectonic deformation in the area between Sault Ste. Marie and Elliot Lake ranges from low to moderate, and is characterized by upright, open folds with gently plunging hinges (Bennett, 2006). Tectonic structures are poorly developed, and the beds in the study area dip between 4 and 30 degrees. It is therefore unlikely that rhythmite thicknesses have been greatly modified.

The maximum age of the Huronian Supergroup is 2450 + 25/−10 Ma, based on U-Pb zircon analysis of the Copper Cliff Formation (Fig. 2; Krogh et al., 1984). The minimum age of the Huronian Supergroup was determined to be 2217.0 ± 6.0 Ma based on U-Pb analysis of primary baddeleyite from the Nipissing diabase dikes that intrude the succession (Corfu and Andrews, 1986). Tang and Chen (2013) suggested that the duration of the Huronian glaciation events could be constrained to 2.29–2.25 Ga, given their similarity to diamictite deposits in the Turee Creek Group, Hamersley Basin, Western Australia; Makganyene Formation, Griqualand West Basin, South Africa; Boshoek Formation and Duitschland Formation, Transvaal Basin, South Africa; Sariolian Group, Karelian Supergroup, Eastern Baltic Shield, Russia; Chocolay Group,