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Deep-water seep-related carbonate mounds in a Mesoproterozoic alkaline lake, Borden Basin (Nunavut, Canada)

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ABSTRACT

The Mesoproterozoic (1.1 Ga) Borden Basin contains extremely large, deep-water dolostone seep mounds (Ikpiarjuk Formation) whose distribution is controlled by faults. Four mounds were investigated along measured stratigraphic sections. Petrographic study revealed several depositional components, and a mixture of at least two distinct carbonate sources. Stable isotope data showed no significant methane contribution to the carbonate phases. Detritus-corrected REE+Y patterns, obtained using solution ICP-MS, depict binary mixtures between basin-water-derived precipitates and seep-fluid-derived carbonate. The purest pelagic REE+Y signal is from mound tops, suggesting that mound accumulation ceased when the seep fluid waned. The REE+Y pattern of the pelagic precipitates resembles that of modern alkaline lake water. The shale-normalised pattern of the basin water is LREE-depleted, has a positive Ce anomaly and pronounced Y-excess, but lacks the La and Gd anomalies typical of seawater. The seep-fluid-related dolomite has flat shale-normalised REE+Y patterns, no Ce anomaly, and a negative Eu anomaly. This combination of characteristics points to circum-neutral (Ca and Mg-bearing?) fluids that interacted with the underlying basement before seeping into the lake bottom through faults. The chemostratigraphic patterns of the mounds result from the relative contribution of elements from the basin water vs. seep fluids. When combined with published geochemical data for coeval black shale surrounding the mounds, the new data suggest a lacustrine setting, surrounded by catchments with a preponderance of moderately to strongly weathered alkali basalt whose runoff drove the lake to alkalinity. Seep fluid was probably evaporatively concentrated basin water that acquired new geochemical characteristics both during evaporation and through water-rock interaction in the subsurface. The new understanding of this depositional stage of the Borden Basin highlights the importance of lacustrine deposits in the Mesoproterozoic, and presents an obvious impediment to using carbonate stable isotope or trace element geochemistry to reconstruct global atmosphere-hydrosphere conditions for this time for any units that cannot be demonstrated conclusively to be of marine origin.

1. Introduction

The behaviour of the rare earth elements (REE+Y) in modern seawater is well understood and provides reliable information about water-column redox conditions (e.g., Elderfield and Greaves, 1982; Elderfield, 1988; Bau et al., 1997). In both the modern environment and the rock record, shallow-water carbonate microbialites have been established as good proxies for the REE+Y composition of seawater (e.g., Webb and Kamber, 2000; Nothdurft et al., 2004; Allwood et al., 2010) and lake water (e.g., Bolhar and Van Kranendonk, 2007; Awramik and Buchheim, 2009).

The Mesoproterozoic Milne Inlet graben (Borden Basin; ~1.1 Ga; Fig. 1) contains large, isolated, mound-shaped accumulations of dolostone related to fluid seepage along synsedimentary faults (Turner, 2004a, 2009; Hahn and Turner, 2013). The mounds (Ikpiarjuk Formation; Turner, 2009) are enclosed by black shale and were deposited in deep water, below wave-base and below the photic zone (Turner, 2004a, 2009; Hahn and Turner, 2013). The mounds contain both featureless dolomudstone, inferred, based on sedimentary context and petrography, to have precipitated in the water column and then settled to the sea-floor (pelagic dolostone), and a clotted texture that was probably produced by benthic carbonate precipitation in the presence of microbes. Precipitation of these carbonate materials is inferred to have been driven by fluid seepage at the basin floor and mixing of this fluid with basin water, based on the geographic limitation of mounds to the immediate vicinity

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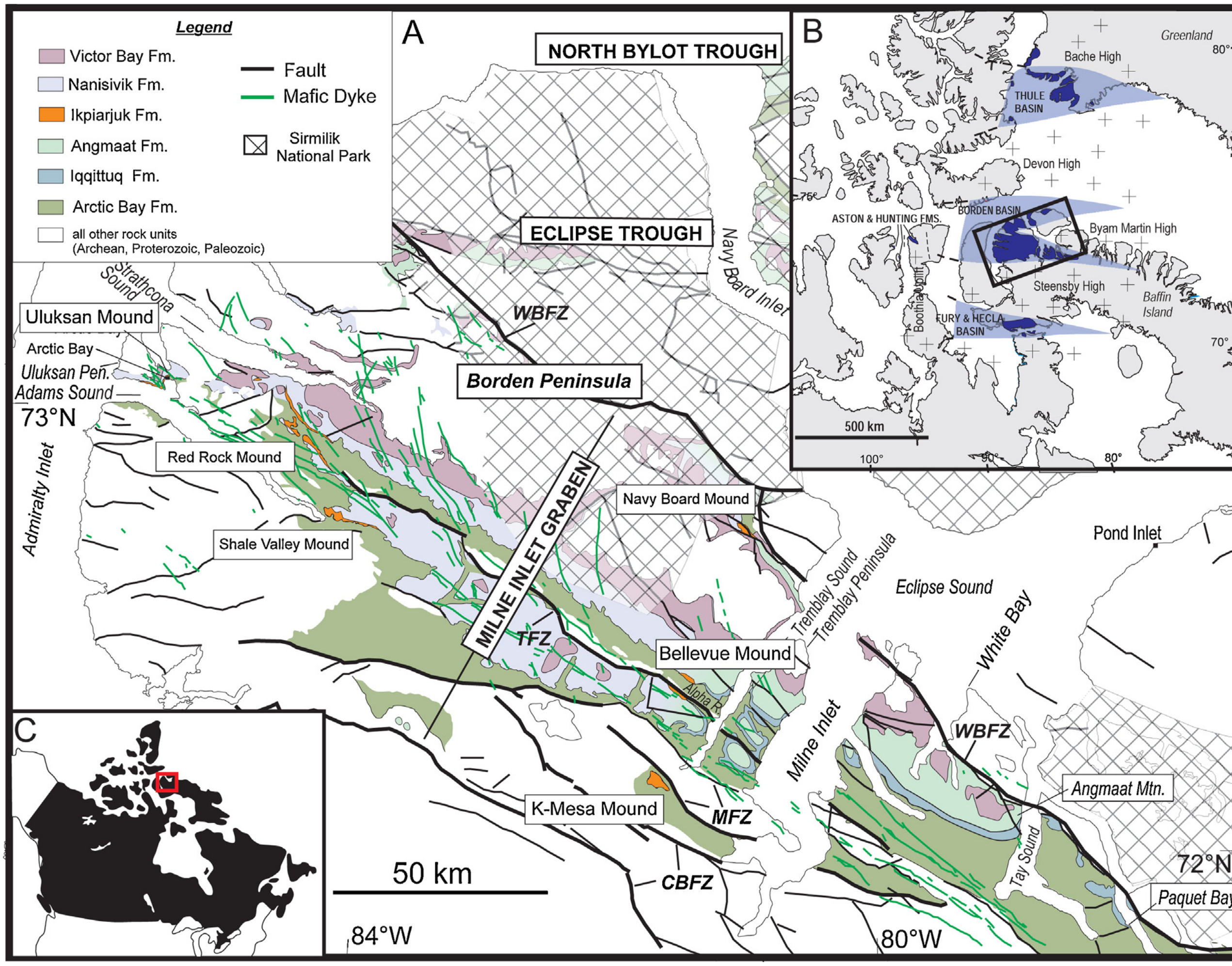

Fig. 1. (A) Geological map of the Milne Inlet Graben (MIG); only some of the Mesoproterozoic stratigraphic units are shown. Six mound exposures are known (modified from Scott and de Kemp, 1998 and Turner, 2009); larger font indicates mounds addressed by this study. CBFZ = Central Baffin fault zone; MFZ = Magda fault zone; TFZ = Tikirarjuaq fault zone; WBFZ = White Bay fault zone. (B) The Bylot Basins of the Canadian Arctic islands; Borden Basin in rectangle. Dark blue areas show the extent of present-day exposure; pale blue indicates inferred extent of the former basins (Jackson and Iannelli, 1981). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

of regional fault systems. Although the mounds come from a comparatively deep-water setting, the seep-related carbonate mound lithofacies of the Ikpiarjuk Formation satisfy the main criterion that has established shallow-water microbialites as reliable proxies for ambient water REE composition (Webb and Kamber, 2000): they are composed predominantly of precipitated carbonate, and thus provide a petrographically “instantaneous” record of the fluid(s) from which they precipitated. Different types of fluid-seep-related accumulations of carbonate material are known in the rock record. Recent studies on modern seep deposits show that REE patterns of seawater may be preserved in the carbonate precipitates resulting from the interaction of seep fluids with seawater (e.g., Himmler et al., 2010).

The Ikpiarjuk Formation mounds consist of deep-water hydrogenous carbonate rocks that provide an alternative, and possibly unique, avenue for making observations about the depositional environment of Mesoproterozoic carbonates. This study presents data collected through a combination of in situ LA-ICP-MS and high-sensitivity solution ICP-MS, in an attempt to (a) chemically distinguish pelagic and benthic carbonate facies, (b) reconstruct the geochemistry of basin water and vent fluids, and (c) constrain the redox chemistry of the Mesoproterozoic Borden Basin.

2. Geologic setting

2.1. Regional setting and stratigraphy of the Milne Inlet Graben

The Borden Basin is one of several late Mesoproterozoic intracratonic basins in Canada’s Arctic archipelago. The depositional age of most of the basin-filling strata is now known to be approximately 1.1 Ga or younger (Turner and Kamber, 2012), and the basin’s origin is probably related to tectonic stress associated with the assembly of Rodinia (Long and Turner, 2012). Strata of the Borden Basin lie unconformably on undifferentiated Paleoproterozoic and Archaean crystalline rocks of the Rae Province. The Borden Basin consists of three “troughs” (Jackson and Iannelli, 1981), the largest of which is the Milne Inlet graben (MIG; Fig. 1). The MIG is bounded by northwest-trending faults and is filled by the ~6 km-thick Bylot Supergroup (Jackson and Iannelli, 1981; Scott and de Kemp, 1998; Fig. 2). These strata are cross-cut by northwest-trending Franklin-aged dykes (~723 Ma; Heaman et al., 1992; Pehrsson and Buchan, 1999; Denyszyn et al., 2009). The basin initially formed during mild extension, when tholeiitic basalt of the Nauyat Formation (Jackson and Iannelli, 1981; Dostal et al., 1989) erupted subaqueously (Long and Turner, 2012). Marine sandstone of the Adams Sound Formation was deposited regionally above the basalt during sag-phase