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Origin and hydrology of a large, intact Early Cambrian paleocave system and its role in overlying fluidisation structures, Arctic Canada

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ABSTRACT

Paleokarst is most commonly expressed as subtle stratigraphic surfaces rather than large void systems penetrating deeply into the paleo-subsurface. In contrast, a regional Precambrian-Cambrian unconformity on Victoria Island (NWT, Canada), is associated with exceptional exposure of large, intact Cambrian paleocaverns (100 m diameter; tens of m high). The paleocaves are distributed along a paleo-horizontal plane, and an associated gryke network is present in the 30–60 m of Neoproterozoic dolostone between cave rooves and the base of overlying Cambrian sandstone; both are filled by Cambrian sandstone. The formation and preservation of such karst features require aggressive dissolution along a stable paleo-water-table shortly before transgression and deposition of shallow-marine sand over the dolostone. During the transgression, the karst network acted as a conduit for flowing groundwater that was discharged through overlying, unconsolidated Cambrian shallow-marine sand, producing water-escape structures (sand volcanoes and their conduits). The conduits are preserved as cylindrical remnants of the sand volcanoes' feeder pipes. Sediment fluidisation was probably caused by variations in the hydraulic-head gradient in a meteoric lens near the Cambrian coastline under a tropical climate with abundant, probably seasonally variable rainfall that caused pulses in subsurface fluid flow. Spatial distribution of the paleocaves and sand volcanoes suggests their formation on the southeast side of a recently faulted horst of Proterozoic carbonate bedrock that formed a nearshore island during early Cambrian sea-level rise. Fluidisation structures such as those reported here have generally been difficult to interpret owing to a lack of data on the fluid hydraulics of the underlying aquifer. This is the first report linking the hydraulics of a well-characterised paleokarst to development of fluid-escape structures. Such structures are widely known from sandstones overlying the sub-Cambrian unconformity around the circumference of Laurentia.

1. Introduction

Although numerous modern cave systems in the interiors of continents and on modern carbonate islands exposed well above present-day sea-level consist of large dissolutional subsurface structures such as caves and solution-widened joint networks, ancient karst systems consisting of large caverns are not common, and generally have not remained open or intact. Although the fluid dynamics of groundwater in karst are almost exclusively understood from modern karst systems that are large enough to be visited or tested by humans (e.g., Fleury et al., 2007; Bayari et al., 2011; Baechler and Boehner, 2014; Kogovsek and Petric, 2014), direct evidence of fluid behaviour in ancient karst systems is seldom preserved. Most studies of paleokarst focus on surface structures or petrographic attributes of associated meteoric alteration (e.g., Meyers, 1988; Wright, 1988; George and Powell, 1997; Praekelt et al., 2008).

Enigmatic cylindrical sedimentary structures have been documented in the rock record since Hawley and Hart (1934) described large sandstone cylinders in the Cambrian Potsdam Formation in New York and Ontario (e.g., Gabelman, 1955; Draganits et al., 2003; van Loon and Maulik, 2011), and have even been documented on Mars (Rubin et al., 2017). These structures, referred to as sand volcanoes (or sand volcano feeder pipes if the surficial cone is absent) have, over the years, been attributed to either the upward expulsion of water and sand (e.g., Gabelman, 1955; Li et al., 1996; Massari et al., 2001) or the downward movement of sand into underlying cavities (e.g., Buck and Goldring, 2003; Sanford and Arnott, 2010). Although experimental studies on the formation of such structures have been conducted (e.g., Nichols et al., 1994; Ross et al., 2011) and modern equivalents have been documented (e.g., Li et al., 1996; Draganits and Janda, 2003) there is no consensus about the mechanism of sand volcano formation in the rock record.

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Using a combination of depositional environment, sedimentary architecture, and paleogeomorphology, this entirely field-based study (a) examines and explains an extraordinary system of very large, intact paleokarstic caverns associated with a Precambrian-Cambrian unconformity, (b) scrutinises the groundwater hydraulic system associated with nearby shallow-marine sand volcanoes, and (c) examines the implications of the karst and sand volcanoes for the paleotopography and paleoclimate of low-latitude northwestern Laurentia during Early Cambrian sea-level rise.

2. Geological background

The rocks described in this study are exposed on remote northwestern Victoria Island (Northwest Territories, Canada) and belong to the

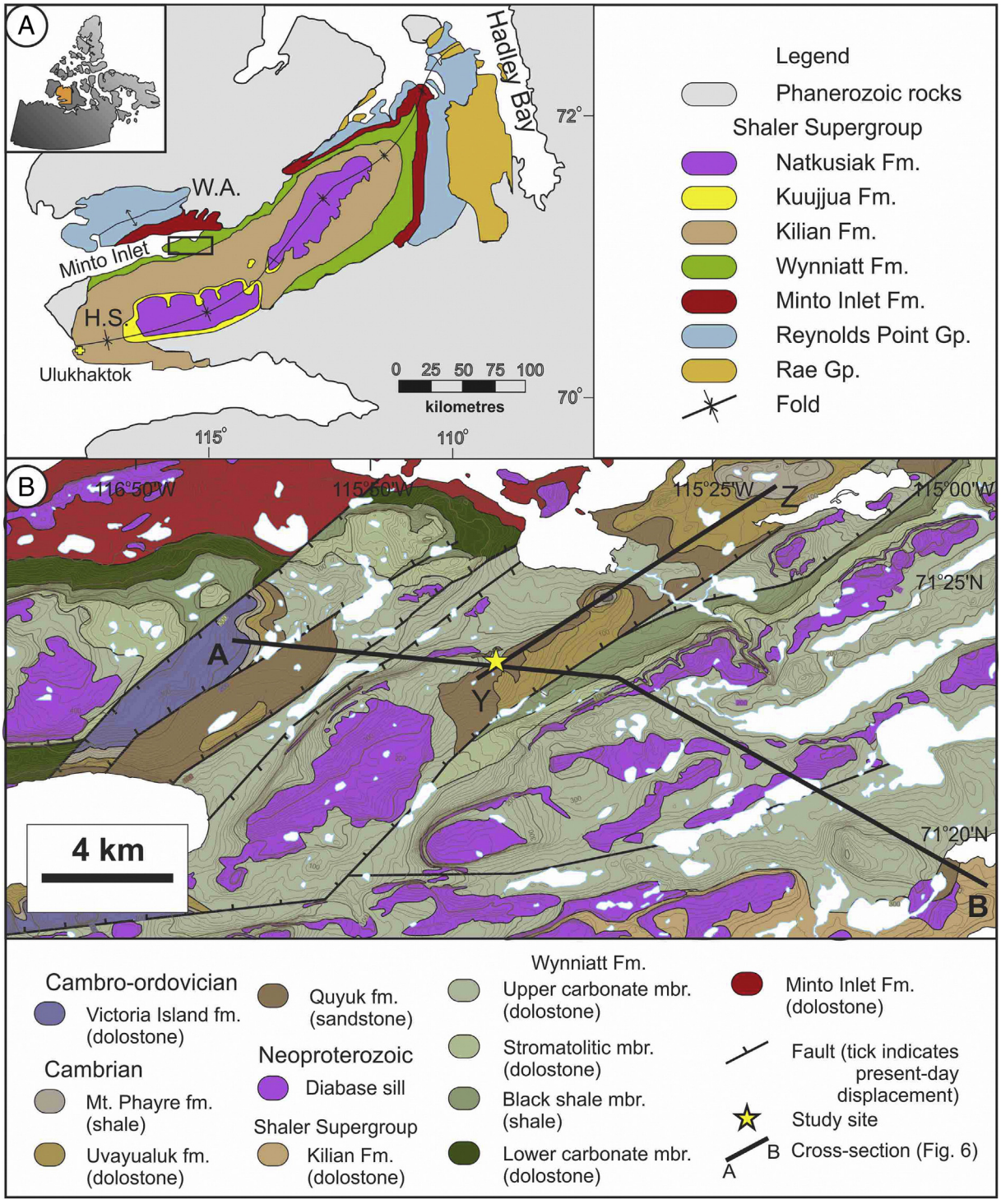

Fig. 1. (A) General bedrock geology of western Victoria Island, Northwest Territories, Canada, after Thorsteinsson and Tozer (1962), highlighting the Proterozoic Minto Inlier (coloured), Walker Bay anticline (W.A.) and Holman Island syncline (H.S.). Rectangle is enlarged in (B). (B) Detailed local geology near the head of Minto Inlet from Rainbird et al. (2013a), highlighting normal faults and study area (star); Paleozoic member names are from Dewing et al. (2015). Cross-sections A–B and X–Y are shown in Fig. 5. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)