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Euxinia linked to the Cambrian Drumian carbon isotope excursion (DICE) in Australia: Geochemical and chemostratigraphic evidence

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ABSTRACT

The Cambrian Drumian carbon isotope excursion (DICE) event is a negative carbon isotope ($\delta^{13}C$) excursion. It is associated with the first appearance datum (FAD) of the agnostoid arthropod *Ptychagnostus atavus*, whose first appearance in the Global boundary Stratotype Section and Point (GSSP) defines the base of the Cambrian Series 3 Drumian Stage. Although this isotopic event has been clearly identified in the Great Basin, USA, it has not been consistently reported in other areas of the world. Here, we report a study integrating isotopic and geochemical data from middle Cambrian (Series 3) sections from the northeastern Georgina Basin, Australia, to investigate the occurrence of the DICE event in Australia and the paleoenvironmental conditions associated with this event. The similarity between the isotopic excursions observed in the Georgina Basin (−2‰ to −3.2‰ $\delta^{13}C$ excursion) and that observed in the Great Basin (−2‰ to −3.6‰ $\delta^{13}C$ excursion) highlighted the presence of the DICE in Australia and emphasized the potential use of this event for refining global isotopic correlations. The multi-proxy correlation used in this study also showed a pulse of euxinia in association with the DICE, suggesting strongly euxinic conditions near the base of the Drumian Stage.

1. Introduction

The Cambrian represents a crucial period in Earth history and life evolution. The Cambrian Explosion, described as a rapid shift from dominantly microbial forms to a predominance of taxonomically diverse multicellular organisms, is regarded as a major evolutionary event (i.e. Maruyama et al., 2014). This event, however, has been described as a complex succession of cycles of extinction and radiations (Knoll and Walter, 1992). Although numerous factors such as ocean oxygenation and variation in seawater chemistry (Maruyama et al., 2014), intrinsic triggers related to the enhancement in diversity of large gene regulatory networks (Peterson et al., 2009) or ecological causes (e.g. zooplankton and phytoplankton diversification (Butterfield, 2009)) have been suggested for the cause of this event, the exact triggers of the Cambrian Explosion remain enigmatic (Zhang et al., 2014). The middle Cambrian represents a key interval in which the metazoan reef systems, which developed during the early Cambrian, collapsed worldwide (Boucot, 1990). Although a rise in atmospheric oxygen during the Cambrian was previously linked to the Cambrian Explosion (Canfield et al., 2007), reports of widespread anoxia at different stages of the Cambrian suggest that the ecological challenges associated with widespread anoxia could have had a crucial impact on metazoan evolution (e.g. Hough et al., 2006; Gill et al., 2011).

The understanding of this complex radiation event is further challenged by the lack of global correlation of carbon isotopic excursions in the middle Cambrian. Although carbon isotope chemostratigraphy spanning the middle Cambrian has been conducted in numerous stratigraphic successions (e.g. Ahlberg et al., 2009; Babcock et al., 2004; Brasier and Sukhov, 1998; Lindsay et al., 2005; Zhu et al., 2006), the data are not always consistent, resulting in a questionable use of chemostratigraphy for correlation of the middle Cambrian in some areas. In compliance with the guidelines of the International Commission on Stratigraphy (ICS), subdivisions are based on the boundary-stratotype principle, with the base of each chronostratigraphic unit being marked by a Global Stratotype Section and Point (GSSP). The GSSP of the Cambrian Series 3 Drumian Stage (ca. 506.5–503.0 Ma) is defined by the first appearance datum (FAD) of the cosmopolitan agnostoid arthropod *Ptychagnostus atavus* (Babcock et al., 2004, 2007; Zhu et al., 2006). The FAD of *P. atavus* has also been associated with a negative isotopic excursion occurring at the base of the Drumian Stage (Drumian carbon isotope excursion (DICE)) (Babcock et al., 2004, 2007; Zhu et al., 2006; Lehnert et al., 2013). The DICE event was observed in the Great Basin, USA (Howley and Jiang, 2010). However, this excursion has not been consistently identified in other sections from other continents (Fan et al., 2011; Howley and Jiang, 2010). These discrepancies likely derive from the low resolution of isotopic data or from the biostratigraphic control on existing chemostratigraphic profiles (Howley and Jiang, 2010). In addition, although numerous studies on Cambrian chemostratigraphy have been conducted, very few

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included characterization of paleoenvironmental conditions associated with major isotopic excursions.

The northeastern Georgina Basin, in Australia, is an area where the chemostratigraphy of the Cambrian System has not been well established yet. A better age constraint and characterization of paleoenvironmental conditions through the middle Cambrian can be used to further understand the depositional environment of the middle Cambrian sections. The present study investigates bulk carbon isotopic data (carbonate and kerogen) to study the occurrence of the DICE event in Australia, to obtain a better age constraint on the investigated sections and provide a global correlation with other Cambrian sections. Biomarker and geochemical analyses were also performed to characterize the depositional environment associated with the DICE event in the Georgina Basin. This study also aims to provide greater insight into the paleoenvironmental conditions of the middle Cambrian to further understand the complex relationship between environmental conditions and metazoan evolution.

2. Geological history

2.1. Regional geology

During the middle Cambrian, Australia was located in the Southern Hemisphere tropics along the margin of Gondwana (Fig. 1). The Georgina Basin (Fig. 2) is the largest of the intracratonic Neoproterozoic-Paleozoic basins of the North Australian Craton and is dominantly bounded by Paleoproterozoic rocks of the Arunta Region to the south, Tennant Region to the west, and Mount Isa Block to the east. The Georgina Basin has a complex evolutionary history (Dunster et al., 2007) and was originally part of the Centralian Superbasin, which also included the Officer Basin, Amadeus Basin and Ngalia Basin. At ~850 Ma, the Centralian Superbasin was initiated by the crustal sagging (Walter et al., 1995). A major plate reorganization corresponding to the main phase of the Petermann Orogeny occurred by about 550 Ma (late Ediacaran), during which dextral transpression led to strike slip movement between northern and southern blocks in central Australia and subsequent deposition of shallow marine carbonates and siliciclastic sediments in the different basins. The southern Georgina Basin was characterized by non-deposition and erosion between 518 and 511 Ma. Buick et al. (2005) proposed an early to mid-Cambrian rift located between the present-day Amadeus and Georgina Basin (southern margin of the basin) and links the associated mafic magmatism to the Kalkarindji Flood Basalt Province (Glass, 2002). Over much of the area to the north and northwest, carbonate platform deposition resumed in the Georgina Basin during the middle Cambrian (Narpa and Cockroach groups; Fig. 2). In the northeastern part, variations in mineralogy and facies were associated with the new subsidence of the Mount Isa Block and the formation of a seaway, allowing the entrance of oceanic waters highly rich in nutrients.

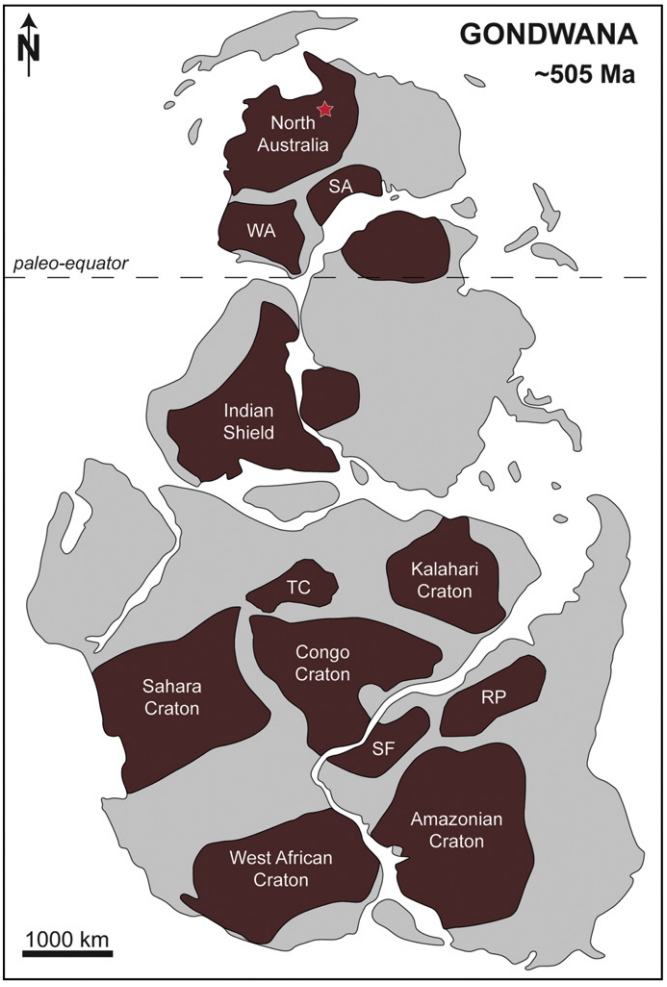

Fig. 1. Map of Gondwana showing the position of Australia during the Cambrian period (modified from Meinhold et al., 2013). Abbreviations: RP – Río de la Plata Craton, SA—South Australia, SF—São Francisco Craton, TC—Tanzania craton, WA—West Australia. The red star indicates the location of the Undilla subbasin, Georgina Basin.

A detailed stratigraphic study, based on sequence stratigraphic concepts, of middle Cambrian sections of the Georgina Basin is given by Southgate and Shergold (1991). In summary, the early Ordian (Series 2) was characterized by: a) the presence of the deepest waters in the Toko Syncline (southern basin) implying rapid subsidence of this area during the early middle Cambrian, and b) much slower subsidence in the northeast area of the basin allowing the development of a transgressive system and the deposition of extensive phosphorite horizons. The late Templetonian to early Undillan (Series 3, Stage 5 and Drumian) time interval was characterized by successive marine transgression-regression cycles which led to the deposition of extensive organic-rich shales of the Beetle Creek and Inca formations in the basin, the latter being a subject of this study.

2.2. Local geology and lithology

The central-northern Georgina Basin includes Ediacaran rocks of the Kiana Group and a thin, entirely middle Cambrian platform succession. BMR Mount Isa 1 drillhole (total depth 250 m) was drilled in the northeastern part of the Georgina Basin, in the Undilla subbasin. In this part of the basin, a depositional hiatus in the late early Cambrian coincided with the outpouring of continental flood basalt in northern Australia. Intervening volcanic and minor sedimentary rocks of the early Cambrian, Helen Springs Volcanics, are related to the Kalkarindji Province (Glass, 2002) which extends across large parts of the Northern Territory, central Western Australia and western South Australia. In the early middle Cambrian, a widespread marine transgression inundated the central-northern platform domain of the Georgina Basin. All middle and early late Cambrian rock units in the eastern Georgina Basin, including much of the Undilla subbasin, are included within the Narpa Group and horizontally-unconformable over steep dipping basement.

The BMR Mount Isa 1 drillhole contains shallow marine carbonates and shales from the Thorntonia Limestone, the Inca Formation and the Currant Bush Limestone. The Currant Bush Limestone is characterized by partially dolomitised argillaceous, quartzic and bioclastic limestone, with fine layers of shale, siltstone, and chert (Rawlings et al., 2008). A highly diverse assemblage of fossils of trilobites, brachiopods, molluscs, hyoliths, echinoderms, sponge spicules and algae was reported from this formation (i.e. Rawlings et al., 2008). In BMR Mount Isa 1, the sedimentary succession consists of thinly laminated calcareous and dolomitic siltstone and shale interbedded with limestone and dolostone (Fig. 3a). The fine laminations with the calcareous siltstones and