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Intermittent euxinia in the high-latitude James Ross Basin during the latest Cretaceous and earliest Paleocene

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ABSTRACT

Seymour Island, in the James Ross Basin, Antarctica, contains a continuous succession of latest Cretaceous sediments deposited in a shallow marine environment at high latitude, making it an ideal place to study environmental changes prior to the K–Pg mass extinction. We measured major and trace elements and conducted petrographic analysis of two sections from the Maastrichtian–Danian López de Bertodano Formation of Seymour Island. Several lines of evidence point to intermittently anoxic to euxinic conditions during deposition, including the presence of pyrite framboids with a size distribution suggesting syngenetic formation in the water column, and enrichments in several trace elements, including molybdenum, arsenic, copper, zinc, and chromium. Molybdenum enrichments are clearly associated with enrichments in manganese and authigenic iron, suggesting "shuttling" of redox sensitive trace elements across a chemocline that fluctuated across the sediment-water interface. Comparisons with modern systems suggest relatively high-frequency redox variability, possibly over approximately annual timescales, which may be related to the annual cycle of polar sunlight and associated seasonal changes in primary productivity. Glauconitic horizons are associated with more reducing conditions, including at the K–Pg boundary, though this does not appear to be a uniquely euxinic interval; similar degrees of trace element enrichment are seen in other highly glauconitic intervals. While euxinia may have contributed to low diversity in the lowermost '*Rotularia* Units', redox conditions do not seem to have been the primary control on the transition to a mollusc dominated fauna in the latest Maastrichtian. Redox conditions show little to no response to the eruption of the Deccan Traps or Maastrichtian climatic changes. Instead, intermittent euxinia appears to have been a characteristic feature of this high-latitude environment during the Cretaceous–Paleogene transition.

1. Introduction

The Cretaceous-Paleogene (K–Pg) mass extinction was among the most severe biodiversity crises of the Phanerozoic, ending the Mesozoic Era and impacting both marine and terrestrial flora and fauna on a global scale. The Chicxulub extraterrestrial impact has been firmly linked to the K–Pg extinction worldwide (Schulte et al., 2010). However, the extinction event also occurred during a period of longer-term environmental change. Several lines of evidence suggest that the Mesozoic and early Cenozoic were characterized by a greater degree of environmental variability than is typically implied when they are described as stable 'greenhouse' environments (Clarke and Jenkyns, 1999; Miller et al., 2005; Friedrich et al., 2012). Global temperatures reached a minimum during the Maastrichtian stage (72–66 Ma; Linnert et al., 2014), alongside evidence for large and rapid sea level changes (Miller et al., 2005).

In addition, the terminal Maastrichtian also saw the eruption of the extensive Deccan Traps large igneous province (LIP) in India (Schoene et al., 2015; Renne et al., 2015). Given the prominent role that LIPs are believed to have played in driving environmental changes during other mass extinction events (Wignall, 2001; Bond and Wignall, 2014), it is reasonable to ask whether cascading environmental impacts of the Deccan Traps eruptions on a global scale could have contributed to the end-Cretaceous extinction event (Caldeira and Rampino, 1990; Kidder and Worsley, 2010; Courtillot and Fluteau, 2010; Tobin et al., 2016).

These differing explanations for the cause of the K–Pg extinction need not be mutually exclusive. A "press-pulse" model, in which mounting long-term environmental stress is punctuated by a catastrophic event, has been proposed as a general model for mass extinctions (Arens and West, 2008). Fully assessing the applicability of this

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model to the terminal Cretaceous requires a detailed understanding of potential environmental deterioration leading up the extinction horizon. Changes in temperature resulting from Cretaceous climate evolution or the Deccan Traps eruptions and associated greenhouse gases may have been especially prevalent in the environmentally sensitive high latitudes (Tobin et al., 2012; Petersen et al., 2016).

Our understanding of high-latitude environments during the Cretaceous–Paleogene 'greenhouse' remains poor, even in their "baseline" state prior to the environmental disruptions of the K–Pg mass extinction. There is no modern analogue for these settings (Chin et al., 2008), which were characterized by extensive vegetation cover and a lack of large permanent ice sheets on land, but were governed by the extreme seasonality of the polar light regime. Records from high-latitude Cretaceous environments have the potential to yield important clues about the sensitivity of polar ecosystems to warm climates in the near-future (e.g. Davies et al., 2009).

Seymour Island (SI), in the James Ross Basin, Antarctica (Fig. 1), contains the southernmost, most expanded onshore K–Pg succession in the Southern Hemisphere, and has been the subject of intense paleontological and geochemical study (e.g. Feldmann and Woodburne, 1988; Crame et al., 2004; Olivero, 2012). In this study, we aim to: 1) characterize pre-extinction "baseline" redox conditions in the James Ross Basin during the latest Cretaceous and early Paleocene using new petrographic and geochemical data; 2) determine whether changes in basinal redox chemistry can be linked to local and/or global environmental changes; and 3) assess the effects of any such redox variability on the local marine fauna, prior to and during the K–Pg mass extinction.

2. Geologic setting

2.1. Overview

Extensive outcrops of Early Cretaceous to Eocene sediments deposited in the James Ross Basin (JRB) are exposed across an archipelago of islands located off the northeastern tip of the Antarctic Peninsula (Fig. 1). Despite its relative inaccessibility, the JRB has received intermittent study since the early 20th century (e.g., Kilian and Reboul, 1909; Spath, 1953; Wilckens, 1910), as it provides the key nearshore sedimentary succession of this age in Antarctica. Deposition occurred in a rapidly subsiding back-arc basin to the east of the Antarctic Peninsula magmatic arc (Elliot, 1988; Hathway, 2000), and the Mesozoic basin-fill is typically divided into two principal lithostratigraphic groups: the 2.6 km-thick Gustav Group (Barremian-Coniacian; Riding and Crame, 2002; Crame et al., 2006), overlain by the 3 km-thick Marambio Group (Santonian-Danian; Rinaldi et al., 1978; Crame et al., 1991; Olivero, 2012).

Much of the JRB sedimentary succession, particularly in the Marambio Group, is highly fossiliferous (Feldmann and Woodburne, 1988 and references therein; Pirrie et al., 1997; Crame et al., 2004), and the fossils are generally quite well-preserved, both physically and geochemically (Ditchfield et al., 1994; Dutton et al., 2007; Tobin et al., 2012; Tobin and Ward, 2015). The excellent preservation of fossil material, and the poor consolidation of the sediments, are largely the consequences of minimal burial depth and a lack of tectonic activity in the area since deposition. There has been little tectonic movement of the

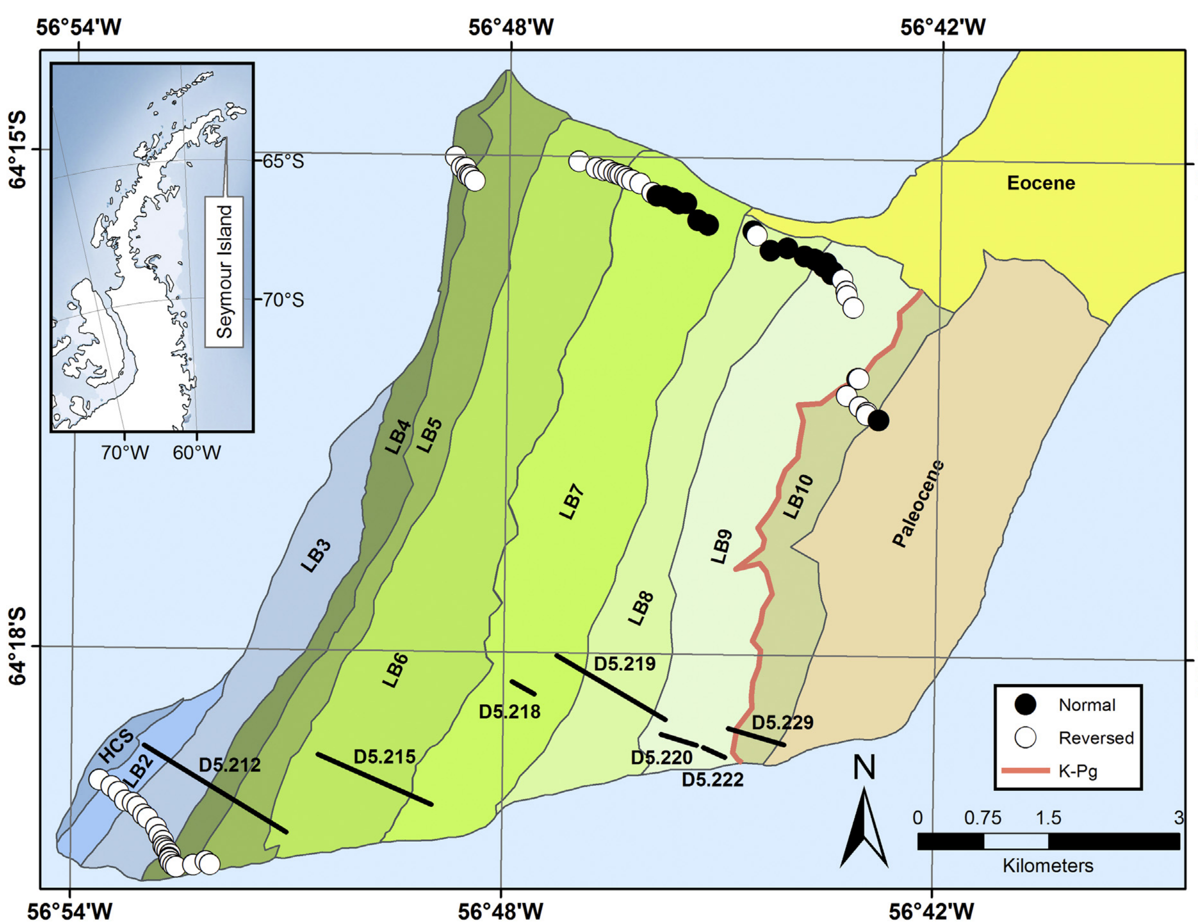

Fig. 1. Simplified geologic map of Cretaceous–Paleogene strata on Seymour Island (after Montes et al., 2013). LBX indicates the informal units of the Lopez de Bertodano Fm. (Macellari, 1988). HCS = Haslum Crag Sandstone. Black and white dots indicate locations of paleomagnetically normal and reversed samples from the T12 section, D5.2XX are schematic subsections of the BAS section trace.

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