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No abrupt change in redox condition caused the end-Permian marine ecosystem collapse in the East Greenland Basin

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ABSTRACT

Multiple observations have revealed that environmental disturbances may have been linked to the end-Permian mass extinction and delayed biotic recovery. Biogeochemical constraints on the temporal and spatial changes of oceanic redox chemistry during the Permian–Triassic interval are essential to evaluate global significance of previous hypotheses and to improve our understanding of extinction and recovery processes. To investigate redox ocean chemistry change associated with the end-Permian extinction and subsequent delayed biotic recovery, we examine framboidal pyrites as well as sulfur isotopic compositions of pyrites from the East Greenland Basin. The size distributions of framboidal pyrites in sediments from a continuous section across the Permian–Triassic boundary reveal that sulfidic conditions in water columns were established about 0.7 m above the extinction event in the East Greenland Basin. Our detailed examination of framboidal pyrites challenges a leading hypothesis that euxinia in the photic zone caused the end-Permian ecosystem collapse. We identify several positive and negative S-isotopic shifts before and after the extinction event and demonstrate that a positive S-isotopic shift is not indicative of an abrupt change of redox chemistry in water columns, in contrast to previous claims. The integration of isotope and framboidal pyrite data provides a nearly continuous record of ocean chemistry evolution and new insights into the end-Permian extinction and delayed biotic recovery in the East Greenland Basin.

1. Introduction

The end-Permian mass extinction (~251 Ma ago) is the greatest crisis in the history of animal life, with a loss of nearly 90% of marine species on a global scale; however, the trigger and kill mechanisms of the mass extinction remain enigmatic (Jin et al., 2000; Erwin, 2006). Numerous hypotheses have been proposed to explain the end-Permian extinction (Knoll et al., 2007; Yin et al., 2007; Bottjer et al., 2008 and references therein) and subsequent delayed onset of biotic recovery (Hallam, 1991; Pruss et al., 2006; Payne et al., 2006; Bottjer et al., 2008) which was associated with large perturbations of the carbon cycle (Payne et al., 2004; Payne and Kump, 2007; Tong et al., 2007). Among them, oceanic anoxia or euxinia has been advocated to have triggered the extinction of end-Permian marine animals (Knoll et al., 1996; Wignall and Twitchett, 1996; Isozaki, 1997; Kump et al., 2005; Meyer et al., 2008).

Sulfidic depositional conditions have been documented from the Permian–Triassic sedimentary rocks in southwest Japan (Isozaki, 1994, 1997; Kajiwara et al., 1994; Kato et al., 2002), in the East Greenland Basin (Nielsen and Shen, 2004), and in the Paleotethys and Neotethys oceans (Wignall and Twitchett, 1996; Newton et al., 2004; Riccardi et al., 2006; Algeo et al., 2007, 2008), among other marine basins. Recently, Grice et al. (2005) reported isorenieratane and aryl isoprenoids in the latest Permian sediments in Western Australia and South China, and they concluded that euxinia may have reached into the photic zone, killing the end-Permian marine animals. However, it appears that isorenieratane also occurred in rocks that predate the end-Permian extinction, suggesting that photic zone euxinia cannot by itself have caused the extinction. More recently, Fenton et al. (2007) reported a positive shift in $\delta^{34}S$ of pyrite above the extinction level, and argued that the positive S-isotopic shift represented a sudden change of the redox condition from oxic to euxinic, causing the collapse of the marine ecosystem in the East Greenland Basin. As such, Fenton et al. (2007) concluded that the results from East Greenland support the hypothesis of Grice et al. (2005).

Here we report the sizes and distributions of framboidal pyrites in the Late Permian–Early Triassic sediments from a continuous section in the East Greenland Basin, and the results allow us to constrain a nearly continuous temporal change of redox chemistry. We integrate high resolution S-isotopic data with framboidal pyrite data to test previous hypotheses. Our data from the middle–high paleolatitude region

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provide new insights into environmental influence on the end-Permian extinction and delayed biotic recovery.

2. Geology and stratigraphy

The East Greenland Basin (~400 km long and up to 80 km wide) was formed by rifting and thermal contraction of the crust (Surlyk et al., 1986) and was located at a northern paleolatitude of approximately 35° N (Scholle et al., 1993). The Upper Permian sedimentary record of the lower Foldvik Creek Group in the East Greenland Basin consists in the lower part of fluviomarine conglomerates of the Huledal Formation and hypersaline shallow-marine carbonates and evaporites of the Karstryggen Formation (Surlyk et al., 1986; Stemmerik et al., 2001) (Fig. 1). A subsequent sea level rise resulted in deposition of the basinal shales of the Wuchiapingian Ravnefjeld Formation and coeval marine carbonates of the Wegener Halvø Formation along basin margins and over structural highs (Surlyk et al., 1986; Piasecki and Stemmerik, 1991; Stemmerik, 2001) (Fig. 1). The basinal black, bituminous shales of the Ravnefjeld Formation record episodic sulfidic deep-water conditions in the East Greenland Basin (Nielsen and Shen, 2004), and were overlain by the bioturbated shales and siltstones of the Changhsingian Schuchert Dal Formation followed by the Lower Triassic Wordie Creek Formation (Fig. 1).

Our samples were collected from a stratigraphically complete basinal section at Fiskegrav (Figs. 1 and 2). At Fiskegrav, the upper 10–15 m of the Schuchert Dal Formation contains a Late Permian invertebrate fauna of brachiopods (*Martinia*), solitary rugose corals (*Calophyllum*), ammonoids (*Paramexicoceras*), and foraminifera, including *Ammobaculites*, unidentified nodosariids, *Ammodiscus*, and *Glomospira* (Pattison and Stemmerik, 1996). It is in this part of the formation that trilete spores begin to appear, and the topmost ~50 cm of the Schuchert Dal Formation are characterized by the presence of spore-dominated microflora including *Uvaesporites imperialis*, *Lundbladisporites obsolete*, *Densoisporites playfordii*, and *Densoisporites nejburgii* of Triassic affinity that heralds the floral changes (Utting and Piasecki, 1995). At the transition between the Schuchert Dal Formation and the Wordie Creek Formation, rapid collapses of marine and terrestrial ecosystems appear to have occurred simultaneously ~50 cm below the top of the Schuchert Dal Formation, in a monotonous interval of bioturbated, grey shelf siltstone (Stemmerik et al., 2001; Twitchett et al., 2001) (Fig. 2).

While the extinction interval is well defined, the precise placement of the Permian–Triassic boundary in the East Greenland Basin remains to be resolved (Stemmerik et al., 2001; Twitchett et al., 2001). The Permian–Triassic boundary is defined by the First Appearance Datum (FAD) of conodont *Hindeodus parvus* (Yin et al., 2001). It was reported that conodont *H. parvus* appeared 23.5 m above the base of the Wordie Creek Formation. However, the Permian–Triassic boundary could be placed lower because of possible preservation biases of conodonts (Twitchett et al., 2001). This is similar to the Global Stratotype Section and Point (GSSP) for the Permian–Triassic boundary at Meishan in south China (Jin et al., 2000; Yin et al., 2001). The end-Permian extinction at Meishan occurred at beds 25–26, however, the FAD of conodont *H. parvus* was discovered at bed 27 marking the Permian–Triassic boundary, which is ~10 cm above the extinction interval at beds 25–26 (Yin et al., 2001; Jin et al., 2000).

At Fiskegrav, the only marine fossils in the topmost Schuchert Dal Formation are agglutinated foraminifers, abundant acritarchs and *Tasmanites*, together with the Triassic-type fish *Bobasatrania*. The low diversity remains unchanged in the topmost 50 cm of the Schuchert Dal Formation. At the base of the Wordie Creek Formation, typical Lower Scythian (Griesbachian) fishes like the actinopterygiids *Bobasatrania*, *Boreosomus*, *Pteronisculus*, and *Australosomus* occur together with the coelacanth ?*Whiteia* and remains of the elasmobranch ?*Parahelicampodus* (Stemmerik et al., 2001).

3. Analytical methods

We performed S-isotopic analysis of pyrite ($\delta^{34}S$) for 69 samples from the Schuchert Dal and Wordie Creek formations. Pyrite was extracted by the chromium reduction method of Canfield et al. (1986). H_2S generated from pyrite reduction by $CrCl_2$ was trapped as Ag_2S in $AgNO_3$ solution. The Ag_2S was centrifuged, washed three times using deionized water, and dried at room temperature. S-isotopic ratios were measured using a GV Isoprime mass spectrometer at the Coastal Science Laboratories, United States. The S-isotope results are reported in the δ notation as per mil (‰) deviations from the Cañon Diablo troilite meteorite (CDT) standard. The $\delta^{34}S$ measurements were with reproducibility better than ±0.5‰.

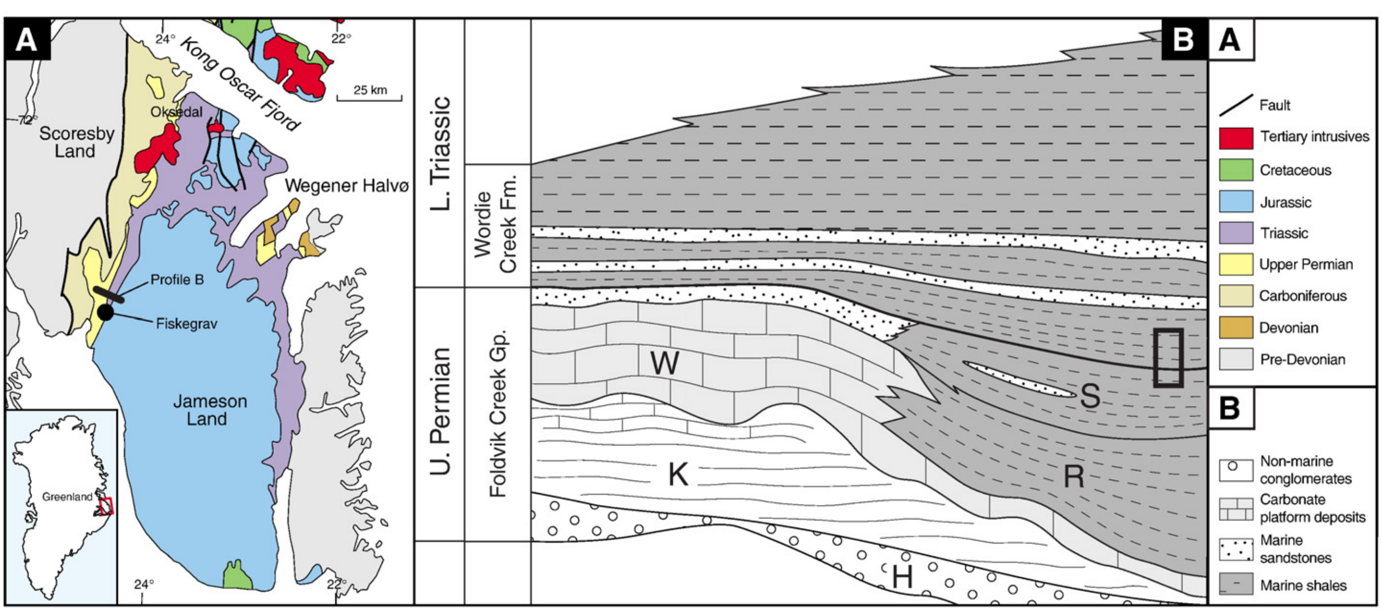

Fig. 1. A: Simplified map of the studied area (location shown in inset) in the East Greenland Basin showing location of the studied section. B: Cross section of Upper Permian–Early Triassic strata (modified from Surlyk et al., 1986); vertical extent of the studied succession is shown by box (not to scale). H = the Huledal Formation, K = the Karstryggen Formation, W = the Wegener Halvø Formation, R = the Ravnefjeld Formation, S = the Schuchert Dal Formation.