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Tropical marine climate during the late Paleozoic ice age using trace element analyses of brachiopods

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ABSTRACT

The late Paleozoic ice age can be considered an important analogue to the modern ice age, but comparisons between the two time intervals have been hampered by the difficulty of resolving climatic changes that occur over short (e.g., seasonal) time scales in the Paleozoic record. As a first step toward overcoming these limitations, this study employed Mg/Ca trace element ratios sampled across the growth bands of six specimens of the brachiopod *Composita* to assess differences in tropical marine mean temperature and seasonality in Viséan and Moscovian time. These time intervals bracket the onset of the late Paleozoic ice age, which occurred in mid-Serpukhovian time, and thus provide a snapshot of climate changes from a greenhouse to an icehouse world. Shells were screened for diagenetic alteration by cathode luminescence and by comparing the values of Mn, Sr, Na, and B to those reported for modern brachiopods. In addition, a $^{87}Sr/^{86}Sr$ value, measured for one specimen, agreed with a published strontium isotope curve for the late Paleozoic Era. Both the mean and range of Mg/Ca values were larger in Viséan than Moscovian time, suggesting colder and less seasonal temperatures during the late Paleozoic ice age. The decline in seasonality was due to a greater proportional reduction of maximum values (which presumably represent summer temperatures) than minimum values. These relative differences between the pre-ice age and ice age tropical climate provide a first step toward understanding the broad patterns of seasonal-scale changes in temperature during a critical time in Earth's history.

1. Introduction

As the closest deep-time analogue of the modern ice age, the late Paleozoic ice age can provide important context for our understanding of current global climate change (Isbell et al., 2008). Both glacial intervals persisted for tens of millions of years, produced comparable climatic and eustatic changes, and coincided with mass extinctions of marine life when they began (Stanley and Campbell, 1981; Prothero, 1994; Stanley and Powell, 2003). The late Paleozoic ice age lasted ~37 million years, beginning in the late Mississippian Period (~327 Ma; Smith and Read, 2000) and persisting into the early Permian Period (~290 Ma; Montañez et al., 2007). The modern ice age began in the Southern Hemisphere ~33 million years ago, during the late Eocene Epoch (Katz et al., 2008), and continues today. Glaciation in the Northern Hemisphere began more recently, ~2.7 million years ago, during the late Pliocene Epoch (Haug et al., 2005). Glacial ice extended to within ~35–40° of the equator during both the late Paleozoic ice age and during the last glacial maximum (Crowley and North, 1991; Frakes et al., 1992; Hyde et al., 1999). Eustatic fluctuation due to ice volume changes has been estimated at up to 95 m during the late Mississippian Period (Smith and Read, 2000) and ~100 m during the Pennsylvanian Period (Heckel, 1994; Soreghan and Giles, 1999; Joachimski et al., 2006), approximately equivalent to Pleistocene sea-level fall, which has been estimated at ~120 m (Fairbanks, 1989; Rohling et al., 1998). Oxygen isotopes record a decrease in tropical ocean temperatures of ~5 °C in late Mississippian time (Mii et al., 1999, 2001), comparable to the magnitudes of cooling estimated for the recent ice age. From Eocene to Oligocene time, tropical ocean temperatures cooled ~2.5 °C (Lear et al., 2008), and the difference in sea surface temperatures from the last glacial maximum (~20,000–11,000 years ago) to the present was 5 °C in the western Atlantic Ocean (Guilderson et al., 1994) and 6.5 °C in the western Pacific (Beck et al., 1997).

Despite these general similarities, however, more detailed comparisons of these intervals are hampered by the significantly poorer resolution of Paleozoic data. In particular, climate parameters that occur over ecological timescales (i.e., less than thousands of years, such as seasonal environmental variability) are difficult to obtain from the Paleozoic record. However, sclerochronology, the study of the accretionary hard parts of fossil organisms (Jones, 1983), in combination with chemical proxies for temperature based on stable isotopes or trace elements, provides an opportunity to resolve paleotemperatures on ecological timescales.

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