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# Permian ice volume and palaeoclimate history: Oxygen isotope proxies revisited

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ABSTRACT

A high-resolution oxygen isotope record based on 356 measurements of conodont apatite from several low latitudinal sections in South China, USA and Iran was composed in order to unravel Permian palaeotemperature and ice volume history. The conodont apatite $\delta^{18}O$ record is compared to published brachiopod calcite $\delta^{18}O$ records. Brachiopods and conodonts from different palaeocontinents show significantly different $\delta^{18}O$ values, suggesting differences in local climatic conditions (e.g., evaporation/precipitation ratio). As a consequence, secular changes in palaeotemperature and oxygen isotope composition of Permian sea water cannot be reconstructed from records combined from different areas, but have to be based on records from a specific area.

Oxygen isotope analyses of different conodont taxa suggest that *Streptognathodus* and *Hindeodus* lived in near-surface seawater and recorded surface water temperature, whereas the habitat of gondolellid genera was variable depending on sea level, with both near-surface and deeper waters as potential life habitat. The oxygen isotope record measured on conodonts from South China exhibits relative high values between 22 and 23‰ VSMOW during the glaciated Early Permian, translating into warm seawater temperature between 26 and 30 °C, assuming that the Late Palaeozoic ice volumes were comparable to the Pleistocene glacial maxima. In contrast to the earlier view that the Late Palaeozoic Ice Age (LPIA) terminated in the late Sakmarian, the South China conodont apatite oxygen isotope record suggests waning of the ice sheets in the Kungurian. Ice melting is indicated by a pronounced decrease in $\delta^{18}O$ of 2‰ VSMOW, which is interpreted as reflecting the combined effect of climatic warming and glacial ice melting. Significant temperature fluctuations (4 °C warming succeeded by 6 to 8 °C cooling) are observed during the Guadalupian–Lopingian transition, interpreted as combined climate changes induced by Emeishan volcanism and changes in habitat depth of gondolellid conodonts. Oxygen isotope values increase to 22‰ VSMOW in the Changhsingian, which suggests climate cooling and *Clarkina* moving to deeper waters because of the Changhsingian sea level rise. Across the Permian–Triassic boundary, $\delta^{18}O$ values decrease from 22 to 19‰ VSMOW, parallel to the significant negative carbon isotope excursion and the eruption of the Siberian Traps. The latter is pointing to a cause–effect relationship as a consequence of the massive release of volcanic greenhouse gases derived from the Siberian volcanism and related processes.



**Contents**



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## 1. Introduction

The Permian (298.9 to 252.2 Ma) represents a transitional interval between the Paleozoic and Mesozoic eras in which global tectonic, environmental and faunal communities underwent dramatic changes that had a profound impact on the subsequent evolution of the Earth system. Following the final collision of Laurussia and Gondwana in the Late Carboniferous (Stampfli and Borel, 2002), the assembly of the supercontinent Pangea was accomplished with the amalgamation of Siberia during the Uralian orogeny (Scotese, 2001). The Palaeotethys was narrowing during the Permian as a consequence of the opening of the Neotethys, a new oceanic basin that resulted from the northward-drifting Cimmerian terranes, which had split off from Gondwana (Fig. 1A). The formation of the supercontinent Pangea, as well as its later breakup, has been suggested to have played an important role in the origin of the Late Palaeozoic Ice Age (LPIA) and global scale environmental changes (Link, 2009).

In contrast to earlier interpretations arguing that the LPIA was a single, widespread glacial event spanning the late Mississippian to Early Permian (Veevers and Powell, 1987), recent studies have shown that the LPIA can be differentiated into discrete glacial intervals separated by warmer periods of time. The Permian acme of the LPIA was dated as Asselian to early Sakmarian (Isbell et al., 2003, 2012; Fielding et al., 2008a, 2008b, 2008c), with the ice caps probably waning in the Sakmarian (Veevers and Powell, 1987; Isbell et al., 2003; Korte et al., 2005; Zeng et al., 2012). However, the exact timing of this deglaciation is still controversial since glacial deposits are found to appear intermittently in late Early and Middle Permian strata in Australia and Siberia (Fielding et al., 2008c).

The late Middle through latest Permian are characterized by the end-Guadalupian (259.0 Ma) and end-Permian (252.28 Ma) mass extinction events (Shen et al., 2010, 2011). Both events significantly affected global ecosystems, with 90% of all marine species becoming extinct, and a dramatic decline in terrestrial diversity registered during the end-Permian mass extinction (Retallack, 1995; Erwin et al., 2002). The triggering mechanisms for these mass extinctions are not clear. However, important environmental fluctuations, for example major sea level changes (Chen et al., 1998; Haq and Schutter, 2008; Wignall et al., 2009a), marine anoxia (Wignall and Twitchett, 1996; Isozaki, 1997; Wignall et al., 2009a), climate warming (Svensen et al., 2009; Shen et al., 2011; Joachimski et al., 2012, Retallack, 2013) as well as climate cooling (Campbell et al., 1992; Isozaki et al., 2007a, 2007b) or perturbations of the Earth's carbon cycle (Chen et al., 1991; Jin et al., 2000; Cao et al., 2002, 2008; Payne et al., 2004; Wang et al., 2004; Xie et al., 2007; Korte et al., 2010; Chen et al., 2011; Luo et al., 2011; Shen et al., 2011) have been demonstrated to have been coincident with or to have occurred close to the mass extinction events. Interestingly, the Emeishan and Siberian Large Igneous Province are dated to have erupted during the end-Guadalupian (Zhou et al., 2002; Wignall et al., 2009b; Sun et al., 2010) and latest Permian, respectively (Campbell et al., 1992; Renne et al., 1995; Kamo et al., 2003; Mundil et al., 2004; Reichow et al., 2009; Svensen et al., 2009). The close temporal association between the volcanic events and the biotic crisis have led many researchers to assume a cause–effect relationship between volcanism and mass extinctions, with the volcanism resulting in the emission of greenhouse gases, destabilization of gas hydrates (Retallack and Jahren, 2008), and/or contact metamorphism of organic carbon-rich sediments (Ganino and Arndt, 2009; Svensen et al., 2009), all processes that potentially could have contributed to higher atmospheric greenhouse gas ($CO_2$, $CH_4$) levels.

Climatic and environmental changes can be recorded in the stable isotope compositions of marine skeletons with variations in carbon and oxygen isotopes documenting changes in the global carbon cycle and palaeotemperature or ice volume, respectively. Brachiopod

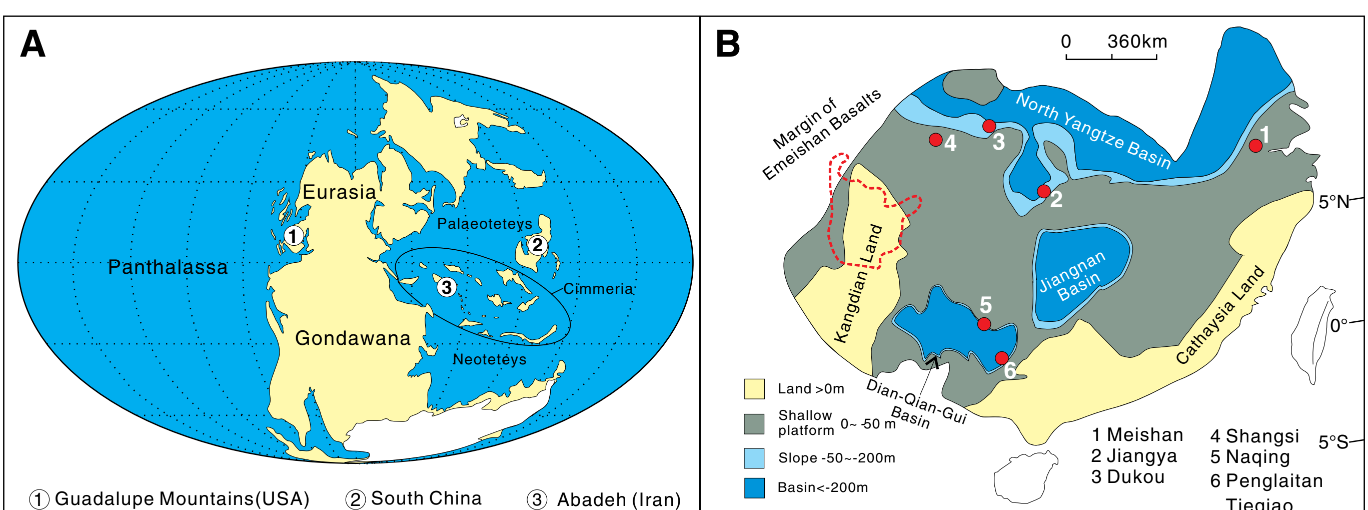


**Fig. 1.** (A) Late Permian palaeogeographic reconstruction showing location of the Guadalupe Mountains (USA — 1), South China Block (2),, and Abadeh section (Iran — 3) (http://www2.nau.edu/rcb7/260moll.jpg). (B) Palaeogeography of South China during the Wuchiapingian, location of studied sections, and modern outcrop area of Emeishan volcanic province (Ali et al., 2002).
Panel B is modified after Wang and Jin (2000) and Shen et al. (2007), and palaeolatitude after Zhang (1997) and Fang et al. (1992).