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Astronomical forcing of a Middle Permian chert sequence in Chaohu, South China

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ABSTRACT

Astronomical forcing has been shown to be a fundamental driver of climate change through geological time. Pelagic, bedded cherts deposited in Mesozoic ocean basins with chert–mudstone cycles have been shown to contain the imprint of Milankovitch astronomical climate forcing. In the Chaohu region, South China, we studied a Middle Permian radiolarian chert sequence (Gufeng Formation) with chert–mudstone couplets reminiscent of the Mesozoic cherts, but deposited on a continental shelf. Spectral analysis of lithologic bed thickness data from two sections of this chert sequence reveals that 13 cm to 20 cm chert–mudstone cycles in the stratigraphic domain match theoretical 32-kyr Middle Permian obliquity cycling, together with a hierarchy of other cycles with 12 cm, 9 cm, 7 cm, 6.6 cm and 5.4 cm wavelengths. Tuning the 13 cm to 20 cm stratigraphic cycles to Earth's obliquity cycle periodicity indicates that the cm-scale cycles are precession-scale variations with a strong ∼400 kyr amplitude modulation. Tuning to theoretical precession terms provides further support for the astronomical forcing of the chert sequence. We propose that monsoon-controlled upwelling contributed to the development of the chert–mudstone cycles. A seasonal monsoon controlled by astronomical forcing (i.e., insolation) influenced the intensity of upwelling. Stronger upwelling increased radiolarian productivity in the surface ocean, increasing silica deposition. Glacio-eustatic oscillations from ice sheet dynamics in southern Gondwana modulated terrigenous mud flux to the basin. The two processes jointly contributed to the astronomical rhythms of these tropical chert–mudstone sequences, which are characterized by comparably strong obliquity and precession responses. Subsequent diagenesis distorted the chert and mudstone layering, but not enough to destroy the original stratigraphic patterns. The resulting astronomical time scale (ATS) assumes a Roadian/Wordian boundary age of 268.8 Ma for the onset of the first chert layer at the base of the sequence and ends at 264.1 Ma, for a total duration of 4.7 myr.

1. Introduction

Astronomical insolation forcing is a fundamental driver of paleoclimate change, and is preserved in the stratigraphic record (Hilgen et al., 2014). The identification of astronomical cycles in the stratigraphic record, i.e. cyclostratigraphy, is essential in reconstructing climate change. Moreover, the calibration of the time-scale with astrochronologic reconstructions helps to resolve key geological problems (e.g., Hinnov, 2013). The majority of cyclostratigraphic research has focused on marine carbonates. Ancient oceanic cherts have also been the subject of possible astronomical forcing (Fischer, 1976; Decker, 1991; Hori et al., 1993). Spectral analysis by Ikeda et al. (2010), Ikeda (2013), Ikeda and Tada (2013, 2014), and Ikeda and Hori (2014) affirms the hypothesis that rhythms in the Triassic–Jurassic Inuyama bedded pelagic chert were paced by astronomical forcing, demonstrating similarity in dominant bedding cycles with those of early Mesozoic astronomical parameters, developing a 70 myr long astronomical time scale for the early Mesozoic.

Here we report on a Middle Permian chert sequence with similar cyclic features, and document the imprint of potential astronomical (Milankovitch) cycles. In the Lower Yangtze area (Chaohu City), South China, the Gufeng Formation, of late Roadian to middle Capitanian age, is characterized by rhythmic chert–mudstone couplets and deposits on a continental shelf (Hu, 2000; Kametaka et al., 2005; Yang and Yao, 2008; Zhu et al., 2013). The motivation for studying this sequence is multi-fold. First, the Gufeng

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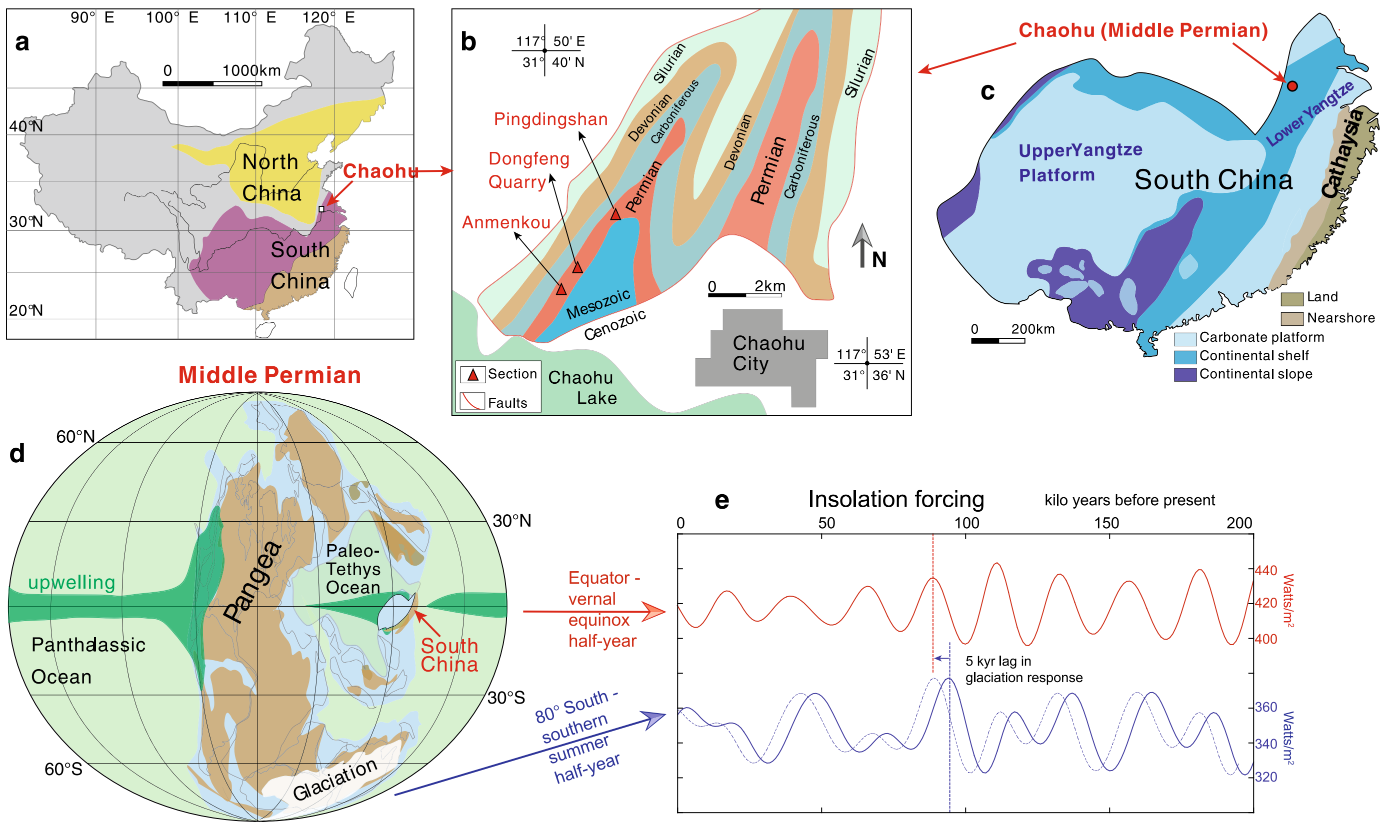

Fig. 1. Geographic location, geological setting and paleogeography of the study area. **(a)** Location of Chaohu region in the Lower Yangtze area, South China. **(b)** Geological setting of three sections of Middle Permian chert sequences: Anmenkou (Section A, GPS: 31°37′00″N, 117°48′30″E), Dongfeng Quarry (Section D, GPS: 31°37′17″N, 117°48′44″E) and Pingdingshan (GPS: 31°38′17″N, 117°49′50″E) in Chaohu region. The distance between Section A and Section D is about 500 m. Anmenkou is the research site of Kametaka et al. (2005, 2009), Takebe et al. (2007), and Pingdingshan was studied by Xia et al. (1995), Yang and Yao (2008), and Zhu et al. (2013). The three sections studied in this paper are indicated by the triangles. **(c)** The Chaohu region was located within an intra-platform basin on a continental shelf in the Lower Yangtze area, separated from the Cathaysian ancient landmass by a more than 200 km wide NE-SW trending carbonate platform (Wang and Jin, 2000; Liu et al., 2014). **(d)** During the Middle Permian, South China was located in the eastern Paleo-Tethys Ocean in the equatorial area (Enkin et al., 1992), experiencing tropical climate and equatorial upwelling (Winguth et al., 2002). Middle Permian distribution high-latitude glaciation in southern Gondwana according to Blakey (2008; http://www2.nau.edu/rcb7/) and Montañez and Poulsen, 2013. **(e)** Average insolation for spring (vernal) half-year at the Equator (red curve) compared with average insolation for southern summer half-year at 80°S (solid blue curve; 5 kyr lag is shown as a dashed blue curve) for the past 200,000 years based on the La2004 solution, calculated with Analyseries 2.0.8 (Paillard et al., 1996). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Formation chert is older than Mesozoic, and represents the first report of astronomical forcing of a chert–mudstone rhythmic sequence from an earlier age (269 Ma to 264 Ma). Second, this chert sequence is not pelagic but was deposited within a continental shelf. Third, existing petrologic, geochemical, biostratigraphic and geochronologic data provide important constraints on chronology and genesis. Fourth, there are long-standing debates on the origin of Middle Permian chert, for which the results reported here provide key insights.

The origin of Permian chert in South China is a matter of long-standing controversy. Middle Permian chert in South China is archetypal of the global Permian Chert Event (Murchey and Jones, 1992). Upwelling caused by seasonal melting of sea ice at the North Pole has been proposed to supply the nutrients and silica for siliceous productivity along the northwestern margin of the Panthalassic Ocean (e.g., Phosphoria Formation in the Western USA, Murchey and Jones, 1992; Beauchamp and Boud, 2002; Hein, 2004). By contrast, trade wind upwelling and equatorial upwelling have been proposed to generate siliceous productivity in the eastern Paleo-Tethys Ocean (e.g., the Gufeng Formation in South China, Xia et al., 1995; Lv and Zhai, 1990; Kametaka et al., 2005; Yang and Yao, 2008; Lv et al., 2010; Yao et al., 2013). Alternatively, regional volcanic-hydrothermal activity may have been associated with chert deposition. The evidence against a biogenic origin for Permian chert include: lack of siliceous organisms in some cherts, anomalous geochemical data in the cherts (high Fe content, low Al content, left-sloped REE patterns), and chert associations with volcanic tuffs and warm-water carbonates (Xia et al., 1995; Lei et al., 2002; Liu and Yan, 2007; Zhou et al., 2009, 2012; Qiu and Wang, 2011; Lin et al., 2010; Zhu et al., 2013; Yao et al., 2013).

Here we assess the astronomical forcing of the chert sequence in the Gufeng Formation, develop a Middle Permian astronomical time scale (ATS) and interrogate the origins of the chert–mudstone cycles: 1) we formulate the sequence of chert–mudstone layers as a binary series; 2) we transform the binary series from the stratigraphic to time domain by obliquity tuning; 3) we review the obliquity-tuned time series with precession tuning.

2. Geological background

2.1. Stratigraphic framework

The Permian formations in the Chaohu region, Lower Yangtze area, South China (Fig. 1a, b) are divided into the Qixia (Chihsia), Gufeng (Kuhfeng), Yinping, Longtan, and Dalong formations in ascending order (Fig. S2). The Gufeng Formation includes the targeted chert sequence, unconformably overlying the Qixia Formation of shallow-marine limestone, and succeeded by the Yinping Formation.

The Gufeng Formation (Fig. 2) is divided into two members, the Lower Mudstone Member (LMM) and Upper Chert–Mudstone