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Astrochronology of the Anisian stage (Middle Triassic) at the Guandao reference section, South China

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ABSTRACT

A high-precision global timescale for the Early and Middle Triassic is the key to understanding the nature, pattern and rates of biotic recovery following the end-Permian mass extinction. The Guandao section of Guizhou Province of South China is an important reference section for the magnetic polarity pattern, conodont datums, geochemical anomalies and interpreted temperature history through the Anisian (Middle Triassic). We analyzed the high-resolution gamma-ray and magnetic susceptibility series from the complete Anisian stage. Intensity variations are indicative of fluctuating terrestrial clay influxes showing strong signals that match predicted astronomical solutions for eccentricity and precession. Astronomical tuning of these series to interpreted 405-kyr long-eccentricity cycles yields a 5.3 Myr duration for the Anisian at Guandao. When combined with the astrochronology of the Early Triassic, then the projected age of the Anisian–Ladinian boundary relative to the base-Triassic date of 251.9 Ma is 241.5 ± 0.1 Ma. This provides a 10-Myr reference timescale for other key geological events, including conodont zones, geomagnetic polarity chrons, rates of marine carbon- and oxygen isotope excursions and global sea-level changes, that were associated with the repeated biotic crises and recovery episodes after the end-Permian mass extinction. The middle Anisian humid phase in ca. 244–244.5 Ma was probably a global event, which may have been linked to the middle Anisian warming event and sea-level change. Sea-level fluctuations at Guandao generally correlate with those in western Tethyan and Boreal regions in time, confirming sea-level changes during the Anisian were of eustatic origin.

1. Introduction

In the aftermath of the end-Permian mass extinction, Early Triassic environments experienced a succession of extreme temperature swings (Sun et al., 2012; Trotter et al., 2015), anoxic episodes (e.g., Song et al., 2014), global carbon perturbations (Payne et al., 2004) and other episodes that were associated with crises in both continental and marine ecosystems (e.g., Wignall, 2015), which delayed the rise of the modern marine ecosystems with metazoan reefs and efficient nutrient upwelling until the middle Anisian of the Middle Triassic (e.g., Benton et al., 2013; Chen and Benton, 2012; Grasby et al., 2016).

The timing and rates of these Early Triassic through Anisian crises requires a precise global timescale, but published radio-isotopic dating provides only a few sporadic constraints for stage boundaries and biozones during this interval, e.g., the Permian–Triassic system or Changhsingian–Induan stage boundary (Baresel et al., 2017; Burgess et al., 2014), the beginning of the Olenekian stage (Galfetti et al., 2007a), the beginning of the Anisian stage (e.g., Lehrmann et al., 2015; Ovtcharova et al., 2015), and the Anisian–Ladinian stage boundary (Brack et al., 2005; Mundil et al., 2010; Wotzlaw et al., 2017). By contrast, this interval has well-established carbon-isotope chemostratigraphy and magnetostratigraphy that enable global correlations (e.g., Hounslow and Muttoni, 2010; Payne et al., 2004; Sun et al., 2012; Szurlies, 2007; Wignall, 2015).

The sedimentary record of Milankovitch cycles of precession, obliquity, and orbital eccentricity can be used to generate

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a high-resolution continuous astronomical timescale framework for these geochemical proxies and magnetostratigraphic scales (Hinnov and Hilgen, 2012; Strasser et al., 2006). An astronomically-tuned magnetostratigraphy in South China and Germany now provides an integrated timescale for the Early Triassic (e.g., Li et al., 2016a, 2016b; Szurlies, 2007) and for most of the Late Triassic (e.g., Li et al., 2017; Kent et al., 2017; Olsen et al., 2011; Zhang et al., 2015). However, an astronomically-tuned magnetic time scale for the majority of the Middle Triassic has not yet been established, which hinders global correlation and a precise time frame for the environmental changes and biotic recovery.

Establishing an astrochronology for the Middle Triassic has encountered many difficulties. For example, the Latemar atoll-like platform in the Italian Dolomites displays over 500 meter-scale depositional cycles spanning the late Anisian-early Ladinian, which were interpreted as a record of 20-kyr precession cycles modulated by short-term (100-kyr) eccentricity cycles based on stacking patterns and spectral analysis (Hinnov and Goldhammer, 1991). However, these were re-interpreted as millennial-scale cycles based on constraints from U–Pb ages from coeval tuffs, magnetostratigraphy, and quantitative analysis of sedimentary cycles (e.g., Kent et al., 2004; Meyers, 2008; Mundil et al., 1996; Wotzlaw et al., 2017). The deep-sea bedded chert sequence of Japan enables a ∼70 Myr long astronomical time scale for the Triassic–Jurassic (Ikeda and Tada, 2014), nevertheless, a reliable correlation of the Japanese sections to other locations will be possible only once magnetostratigraphy and/or global correlative bio-zones can be defined. Only a partial astronomical tuning of the earliest Anisian magnetic polarity zones has been accomplished in the Germanic Basin (Szurlies, 2007) and South China (Li et al., 2016b).

The Nanpanjiang Basin of South China received a nearly continuous deposition of conodont-bearing marine sediments throughout the Early and Middle Triassic. The Guandao road-cut sections on the outer depositional apron of the Great Bank of Guizhou in this Nanpanjiang Basin are some of the best exposed and intensely studied Anisian outcrops in the world. The array of biostratigraphy, magnetostratigraphy, stable-isotope stratigraphy, cyclostratigraphy (for the late Olenekian and the earliest Anisian) and radio-isotope geochronology enable the Guandao sections to serve as a global reference for the Anisian stage (e.g., Lehrmann et al., 1998, 2006, 2015; Li et al., 2016b; Payne et al., 2004; Wang et al., 2006).

Here, we present the astrochronology of the Anisian portion of the Guandao section to calibrate its conodont biostratigraphy, magnetic polarity zones, sea-level changes and stable-isotope trends. We also estimate the durations of the Anisian substages based on both their proposed correlations to conodont datums and magnetic polarity zones. When merged with the Early Triassic timescale (Li et al., 2016b), this provides a continuous 10-Myr astrochronology for biotic recovery and climate change after the end-Permian great dying.

2. Geological setting, stratigraphy and Anisian substages of the Guandao section

2.1. Geological setting

The South China block was characterized by shallow-water carbonate deposits during much of the late Proterozoic through the Middle Triassic, and terrestrial strata during the Late Triassic. The depositional environment evolved from marine to terrestrial conditions as a result of collision between the South China and North China blocks during the Middle–Late Triassic (Dong et al., 1997; Feng et al., 1997). During the Late Permian–Early Triassic South China was an isolated carbonate platform in the equatorial eastern Tethys (ca. 6–9°N) apart from the Pangaea supercontinent (e.g., Sun et al., 2009; Zhang et al., 2015). The South China block drifted northward during the Triassic and reached ca. 30°N in Late Triassic time (Li et al., 2017).

The Guandao section for our Anisian study is situated 2 km south of Bianyang town, Luodian County, Guizhou Province, South China. During the latest Permian through the earliest Late Triassic (early Carnian), the Guandao section was situated on the northern flank of the Great Bank of Guizhou in the Nanpanjiang Basin of South China (Lehrmann et al., 2015). Drowning of the southern margin of the Yangtze platform formed a deep-marine embayment, the Nanpanjiang Basin in the Permian–Triassic transition, during which initial accumulation of the Great Bank of Guizhou occurred (Lehrmann et al., 1998). After a low-relief bank stage during the Early Triassic, the Great Bank of Guizhou came to be characterized by a progressively steepening bank to reef-rimmed architecture during the Middle Triassic (Lehrmann et al., 1998) making it the oldest-known platform-margin reef complex of the Mesozoic Era (Payne et al., 2006) (Fig. 1). The Great Bank of Guizhou was terminated at the beginning of the Late Triassic as sea level increased over the platform top and the platform was buried by marine shales and siliciclastic turbidites (Lehrmann et al., 1998). This platform was later uplifted and tilted, and the Guandao road sections are a continuous exposure through its outer depositional apron (Fig. 1D).

2.2. Stratigraphy of the Guandao section

The Guandao section has more than 770 m from the Late Permian to the Carnian of the Late Triassic (Lehrmann et al., 2015). The Late Permian Wuchiaping Formation is characterized by cherty bioclastic limestone and overlain by the latest Permian Talung (Dalong) Formation. The Talung Formation mainly consists of black chert and shale and represents the drowning of the Yangtze Platform (Dong et al., 1997; Lehrmann et al., 2015). During the Early and Middle Triassic the section was deposited in a dysaerobic, quiet, deep marine environment. The Early Triassic through earliest Anisian Luolou Formation consists of thin-bedded pelagic micritic to wackestone limestone with thin shale interbeds and a few carbonate packstone–grainstone turbidite deposits and debris-flow breccia beds (Lehrmann et al., 1998). Grains of the problematic reef-forming taxa *Tubiphytes* occur below the first occurrence (FO) of the Olenekian–Anisian boundary conodont marker *Chiosella timorensis* (Payne et al., 2006). Several beds of volcanic ash layers occur regionally near this Olenekian–Anisian boundary, and some of these have been dated at Guandao (e.g., Lehrmann et al., 2015).

The Anisian–Ladinian portion of the Guandao section consists of marine slope deposits of pelagic micrite-rich limestones punctuated during the Anisian by carbonate packstone–grainstone turbidites and debris flow breccia beds (Lehrmann et al., 1998, 2015). *Tubiphytes* reefs developed rapidly at the platform margin in the early Anisian (Payne et al., 2006). A gradual thickening of the breccia beds at Guandao during the Anisian reflects the steepening of the basin-margin slope (Lehrmann et al., 1998, 2015). Beneath these breccia beds, the pelagic micritic limestone intervals display some soft-sediment deformation. A notable shift in facies to grainstone breccia with *Tubiphytes* boundstone clasts and fragmented *Tubiphytes* debris occurred during the late Ladinian (Payne et al., 2006). Our study interval at Guandao is overlain by the Carnian Bianyang Formation, which is dominated by shallow-marine to terrestrial siliciclastic sediments interbedded with breccia at the base (Dong et al., 1997).