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A 70 million year astronomical time scale for the deep-sea bedded chert sequence (Inuyama, Japan): Implications for Triassic–Jurassic geochronology

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ABSTRACT

The astronomical time scale (ATS) has provided high-resolution geochronology. However, the early Mesozoic ATS is still under construction partly due to the lack of continuous pelagic sequences of the early Mesozoic. Here we present ca. ∼70 Myr long ATS constructed from the early Mesozoic deep-sea bedded chert sequence exposed in the Inuyama area, central Japan. The sedimentary rhythms of bedded chert display a full range of climatic precession related cycles; ∼20-kyr cycle as a chert–shale couplet and ∼100-, 405-, 2000- to 4000-, and 10,000-kyr cycles as chert bed thickness variation. The newly established ATS (Inuyama-ATS) is tuned by 405-kyr eccentricity cycle and is anchored at the end-Triassic radiolarian extinction level as 201.4 ± 0.2 Ma. This Inuyama-ATS gives ages consistent with the radiometric ages projected to the Inuyama deep-sea sequence using biostratigraphy and carbon isotope stratigraphy. The Inuyama-ATS provides the age constraints for the Triassic and Jurassic stage boundaries, which support the "Long-Norian" option of Muttoni et al. (2004). Because the deep-sea bedded chert sequence covers a long time interval before the Cretaceous, the ATS for the bedded chert will serve as a template for the astrochronology of Mesozoic and older ages.

1. Introduction

Astronomical cyclicity recorded in sediments can be used to establish a high-resolution and high-precision astronomical time scale (ATS) for geologic records (e.g. Hays et al., 1976). The ATS is nearly complete for the Cenozoic, and attempts have been made to extend it to Mesozoic and older ages (e.g. Hinnov and Hilgen, 2012). Efforts to construct the Mesozoic ATS have mainly focused on sedimentary sequences recovered by the Ocean Drilling Program (e.g. Hinnov and Ogg, 2008). However, construction of the Mesozoic ATS is hampered by a lack of continuous pelagic sequence of the early Mesozoic due to subduction of oceanic crust. For this reason, geologic records exposed on land have been used to extend the ATS to Mesozoic and older ages (e.g. Hinnov and Hilgen, 2012). Sedimentary records exposed on land are, however, generally less abundant and more fragmental.

A spectacular exception is the terrestrial sequence of the Newark Supergroup that covers over 25 Myr from the Late Triassic to Early Jurassic (e.g., Olsen, 1986). The Newark Supergroup-based astrochronology and geomagnetic polarity time scale (Newark-APTS) has allowed extension of the astronomical and geomagnetic polarity time scale to the Late Triassic (e.g., Olsen et al., 2011). Although this unique record is constrained by U–Pb ages of intercalated flood basalts (Blackburn et al., 2013), uncertainty remains in its correlation to standard marine-based chronostratigraphy (e.g. Muttoni et al., 2004). In particular, the ages of the stage boundaries in the Late Triassic are highly debated due to the uncertainties in the magnetostratigraphic correlation between the Newark-APTS and shallow marine sequences (e.g. Muttoni et al., 2004). This controversy resulted in contrasting estimates for the duration of the Norian stage of ∼10 Myr for the "Long-Carnian" option, and ∼17 Myr for the "Long-Norian" option (Muttoni et al., 2004). The "Long-Carnian" option is anchored at the Carnian/Norian boundary based on the palynology and conchostracan biostratigraphy assuming hiatus in the Rhaetian part of Newark basin (e.g. Muttoni et al., 2004; Lucas, 2010; Lucas et al., 2012). On the other hand, the "Long-Norian" option is anchored directly at the U–Pb age of the intercalated

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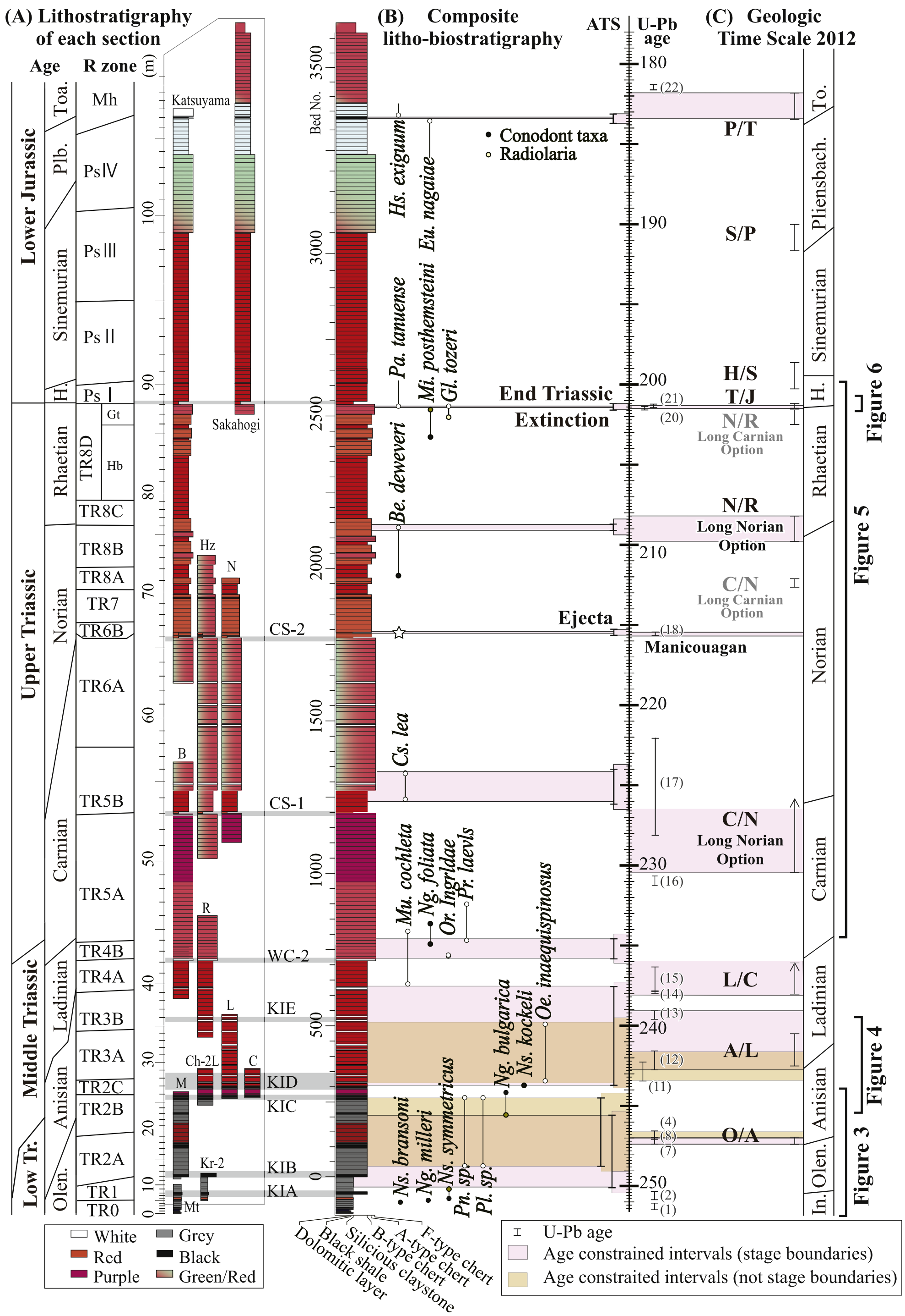

Fig. 1. (A) The lithostratigraphy of the study sections and (B) the composite litho-biostratigraphy for the Lower Triassic to Lower Jurassic deep-sea sequence in the Inuyama area, Japan, comparing with (C) Geologic Time Scale 2012 (Ogg, 2012; Ogg and Hinnov, 2012) and the published U–Pb ages (Table 1 for list of their sources). The "Long-Carnian" and "Long-Norian" options for the stages boundaries are according to Muttoni et al. (2004). Lithologic types are from Sugiyama (1997), Ikeda et al. (2010) and Sakuma et al. (2012). Radiolarian and conodont biostratigraphy are from Hori (1990, 1992, 1997), Sugiyama (1997), Ando et al. (2001), Carter and Hori (2005), Gröcke et al. (2011), Takahashi et al. (2009), Sakuma et al. (2012). Correlation of columnar sections of the Lower Triassic to Lower Jurassic deep-sea sequences at each section is based on Sugiyama (1997) and Ikeda et al. (2010). The astronomical time scale of Inuyama bedded chert (Inuyama-ATS) was anchored at purple chert bed-number 2525 as the end-Triassic radiolarian extinction level as 201.40 ± 0.20 Ma. Abbreviations; O/A = Olenekian/Anisian, A/L = Anisian/Ladinian, L/C = Ladinian/Carnian, C/N = Carnian/Norian, N/R = Norian/Rhaetian, ETE = End-Triassic Extinction, T/J = Triassic/Jurassic, H/S = Hettangian/Sinemurian, S/P = Sinemurian/Pliensbachian, P/T = Pliensbachian/Toarcian.

flood basalt in the Newark Supergroup assuming continuous sedimentation (Fig. 1; e.g. Muttoni et al., 2004; Ogg, 2012). Thereby, the ATS for the early Mesozoic continuous marine sequence needs to be established to confirm the early Mesozoic ATS.

The deep-sea bedded chert sequence will provide a new ATS for the early Mesozoic (e.g. Ikeda et al., 2010). The bedded chert accumulated continuously on the pelagic deep-sea floor before Cretaceous, covering a long-time interval of 10^7–10^8 years (e.g. Matsuda and Isozaki, 1991). The bedded chert consists of centimeter-scale rhythmic alternations of chert and shale beds, which is considered to have resulted from cyclic changes in the accumulation rate of biogenic SiO_2 within a background of slow accumulation of eolian clay (e.g. Hori et al., 1993).