Palaeogeography, Palaeoclimatology, Palaeoecology 403 (2014) 16–29

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

# Guadalupian–Lopingian conodont and carbon isotope stratigraphies of a deep chert sequence in Japan

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A R T I C L E I N F O

*Article history:*
Received 12 September 2013
Received in revised form 27 February 2014
Accepted 28 February 2014
Available online 18 March 2014

*Keywords:*
Permian
Guadalupian–Lopingian
Conodont
Carbon isotope
Deep sea
Japan

A B S T R A C T

To improve international stratigraphic correlation of the Lower Guadalupian–Lower Lopingian (Permian), we examined the stratigraphies of conodonts and organic carbon isotopes from pelagic chert sequences in the Gujo-hachiman section, Gifu, southwest Japan. Age-diagnostic conodonts, such as *Jinogondolella nankingensis* and *Jinogondolella shannoni* were found in the study section. The conodont stratigraphy in the Gujo-hachiman section was correlated with those in South China and West Texas, USA, to date the study section. From these correlations, it was found that the study section was from the upper Roadian (Lower Guadalupian) through Wuchiapingian (Lower Lopingian). Kerogen $\delta^{13}$C values were relatively high, around −29.0‰ in the upper Roadian–Wordian (Middle Guadalupian), decreasing over time to −29.4‰. A negative–positive swing in $\delta^{13}$C values of around 1‰ magnitude was recognized in the middle Capitanian (Upper Guadalupian). A similar negative–positive swing was also found in the Guadalupian–Lopingian (G–L) transitional zone in the Gujo-hachiman section, and is comparable to the isotopic change around the G–L boundary in the Penglaitan section, South China. Subsequently, $\delta^{13}$C values decreased to values below −30.0‰ above the G–L transitional zone, i.e., at the lower Wuchiapingian. Overall, $\delta^{13}$C values decreased from the lower Capitanian to the lower Wuchiapingian by over 1.4‰. A gradual increase in the $\delta^{13}$C values followed this long-term negative trend. These $\delta^{13}$C trends in the Gujo-hachiman section are comparable with time-equivalent $\delta^{13}$C records in different sections, suggesting that they record first-order variations in atmospheric $\delta^{13}$C. The high $\delta^{13}$C values during the upper Roadian–Wordian interval could reflect high primary productivity in the surface water of the pelagic Panthalassa Ocean, and imply global cooling. In contrast, the negative $\delta^{13}$C shift during the Capitanian–Wuchiapingian interval implies global warming.

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## 1. Introduction

The Guadalupian–Lopingian transition has been recognized as a mass extinction interval in the shallow marine fossil record (e.g., Stanley and Yang, 1994). Most previous studies of the Guadalupian–Lopingian boundary (G–LB) and the extinction event have focused on sections in South China where abundant fossils are present (e.g., Mei et al., 1998; Wignall et al., 2009a). Conodont fossils are particularly useful for age correlation between sections, and detailed conodont zones were established for the Permian (e.g., Henderson and Mei, 2003; Wardlaw et al., 2004; Jin et al., 2006). The Penglaitan section, in the Laibin area, Guangxi, South China, was approved as the Global Boundary Stratotype Section and Point (GSSP) for the base of the Wuchiapingian (Lower Lopingian), as defined by the first occurrence horizon of a conodont subspecies, *Clarkina postbitteri postbitteri* Mei and Wardlaw (Jin et al., 2006). However, the timing and nature of the extinction event are still being debated. Kaiho et al. (2005) and Chen et al. (2009) placed the extinction horizon in the earliest Lopingian in the Laibin area. In contrast, Wignall et al. (2009b) and Bond et al. (2010) argued that the extinction event had occurred earlier, in the middle Capitanian (Upper Guadalupian) in South China. Both extinction events were associated with significant fluctuations in the carbon isotope record (Wang et al., 2004; Kaiho et al., 2005; Wignall et al., 2009b). In the Penglaitan section, the carbon isotope record from both carbonates (Wang et al., 2004; Chen et al., 2014) and $n$-$C_{27}$ alkanes (Kaiho et al., 2005) showed marked drops in $\delta^{13}$C across the G–LB. The older extinction event was also accompanied by a significant drop in the carbonate $\delta^{13}$C (Wignall et al., 2009b), although Chen et al. (2014) doubted the global significance of this $\delta^{13}$C decrease.

Another characteristic event in the Capitanian was recorded in the Iwato Formation at the Kamura section, Miyazaki, southwest Japan, which represents a seamount-capping carbonate sequence in the pelagic Panthalassa in the Southern Hemisphere (Isozaki et al., 2007a,b; Kasuya et al., 2012). Isozaki et al. (2007a,b) found a prominent highly positive (more than +5‰) plateau in the $\delta^{13}C_{carb}$ values within the Capitanian

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http://dx.doi.org/10.1016/j.palaeo.2014.02.033
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in the Kamura section. They named this interval the Kamura event and regarded it as a cooling interval. The Kamura event was also recognized in the Brušane section, Croatia, which was deposited in the European Paleo-Tethys and can be used for global chemostratigraphic correlation (Isozaki et al., 2011). However, no age-diagnostic conodonts have been found in these sections, and the age of the Kamura event was determined by the fusuline biostratigraphy. The absence of conodonts makes this age determination of the Kamura event inconclusive.

The carbon isotope ratio is a useful proxy for estimating changes in ancient biomass and the circulation of carbon in the atmosphere/ocean system. In order to better understand these global changes during the Permian, it is necessary to exactly correlate the $\delta^{13}$C records among worldwide sections where conodont biostratigraphies can be determined.

We present a carbon isotope stratigraphy during the Lower Guadalupian–Lower Lopingian interval from the Gujo-hachiman section, Gifu, southwest Japan. This section was partially dated to around the G–LB by Nishikane et al. (2011) using conodonts. We established a new conodont stratigraphy in the lower parts of the section to date the whole section. This enabled an accurate correlation of the $\delta^{13}$C stratigraphy in the section with the shallow marine sections. The $\delta^{13}$C record presented in this study should serve as a good global standard for chemostratigraphic correlation in this interval because the study section was deposited in a pelagic ocean (Fig. 1), and therefore the isotope values should be less affected by local factors. Moreover, this is the first detailed record of organic carbon isotopes across the G–LB from pelagic chert with the exception of a preliminary study by Ishiga et al. (1993).

## 2. Geological setting and previous studies

We studied the GF, GE, and GD sections (Gujo-hachiman F, E, and D sections; Kuwahara et al., 1998) in the Gujo-hachiman area, Gifu, southwest Japan (Fig. 1). Previous conodont and radiolarian biostratigraphic studies interpreted these sections as Middle–Late Permian sequences (Kuwahara et al., 1998; Nishikane et al., 2011). The block that includes these sections consists mainly of gray to greenish–gray bedded chert within the Funafuseyama unit, part of the Tamba–Mino–Ashio Belt, and is situated at 35°44′08″N and 136°50′56″E.

The three sections are separated by minor faults. Litho- and biostratigraphically they form a complete and continuous section without tectonic disturbance within each section. Kuwahara et al. (1998) regarded the intervals as a single radiolarian zone based on the presence of the same radiolarian assemblage in the GE section and the lower part of the overlying GD section. In addition, they confirmed that there is no gap in the radiolarian zones between the GF and GE sections, although the zones are different between the sections. Therefore the GF, GE, and GD sections can be considered to represent an almost complete sequence, regardless of the presence of minor faults.

The GF, GE, and GD sections are 2.5 m, 2.2 m, and 7.4 m thick, respectively. The thickness of individual beds ranges from 1 to 25 cm. Siliceous mudstone beds are often intercalated in the upper 0.8 m of the GE section and the lower 1.5–2.4 m of the GD section. In the middle to upper part of the GD section, chert beds commonly contained non-fossiliferous, red to dark red hematite nodules or layers, parallel to the bedding planes. Such chert beds were rarely recognized in the GE or GF sections. The bedding planes are tilted to the south at high angles, approaching vertical. The 110 beds in the GD section were numbered from GD 1 to GD 110 (Nishikane et al., 2011), and samples were collected. In the present study, we numbered and collected new rock samples from the GF and GE sections bed by bed (GF 1–GF 41; GE 1–GE 37).

Nishikane et al. (2011) examined the conodont biostratigraphy in the GD section and determined that this section included the G–LB. The exact position of the G–LB in the GD section was not determined; instead, they recognized a G–L transitional zone (Fig. 2). This zone was recognized by the first occurrences of two conodont subspecies, *Clarkina postbitteri hongshuiensis* Henderson, Mei, and Wardlaw and *Clarkina postbitteri postbitteri*. The transitional zone corresponds to the interval from Bed GD 19 to GD 36 (Fig. 2).

Several comprehensive studies have recently been done on the Gujo-hachiman section, including those examining the stratigraphic distribution of pyrite, major and trace elements, and total organic

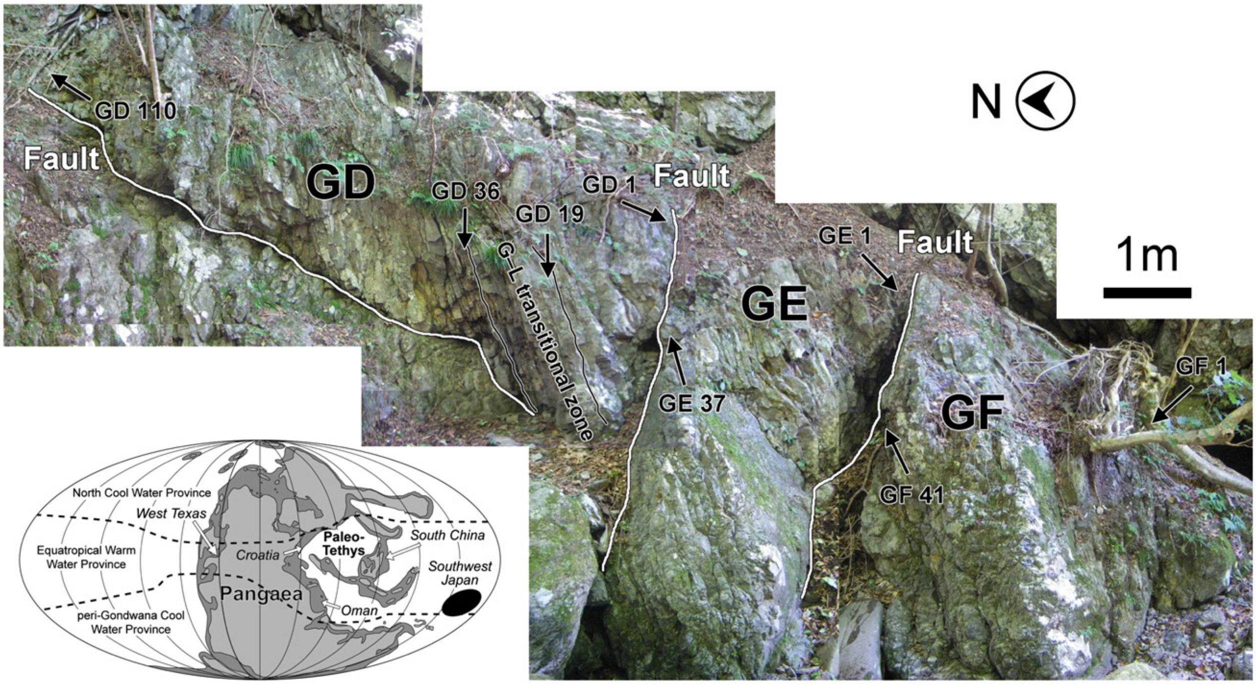

**Fig. 1.** Guadalupian paleogeography showing the locations in southwest Japan, South China, and Texas (lower left), and the outcrop exposure of the GF, GE, and GD sections of Gujo-hachiman. These sections are separated by minor faults. The distribution of conodont provinces and key geographic locations are shown in the paleogeographic map (modified after Mei and Henderson, 2001).
The Guadalupian paleogeographic map shown in the lower left map is after Weidlich (2002).

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