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Changhsingian conodont succession and the end-Permian mass extinction event at the Daijiagou section in Chongqing, Southwest China

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ABSTRACT

Previous studies suggested rapid evolution of conodonts across the Permian–Triassic boundary (PTB), and the end-Permian mass extinction pattern varies in different sections in South China. Here we document a high-resolution conodont succession from a carbonate facies of the Changhsingian Stage and across the PTB at the Daijiagou section, about 35 km north to Chongqing City, Southwest China. Two genera and twelve species are identified. Seven conodont zones are recognized from the uppermost part of the Lungtan Formation to the lowest Feixianguan Formation. They are the *Clarkina liangshanensis*, *C. wangi*, *C. subcarinata*, *C. changxingensis*, *C. yini*, *C. meishanensis*, and *Hindeodus parvus* zones in ascending order. Based on the high-resolution biostratigraphical framework at Daijiagou, the end-Permian mass extinction was rapid and it began in the base of the *Clarkina meishanensis* Zone. Associated with the extinction, a negative excursion of $\delta^{13}C_{carb}$ started in the middle part of *Clarkina yini* Zone with a progressive shift of 1.6‰ to the middle part of the *Clarkina meishanensis*, followed by a sharp shift of 3.51‰ from the *Clarkina meishanensis* Zone to the *Hindeodus parvus* Zone. Our study also suggests that the Triassic index species *Hindeodus parvus* co-occurred with *Hindeodus changxingensis* and *Clarkina zhejiangensis* and directly overlies the *Clarkina meishanensis* Zone at the Daijiagou section. All these data from the Daijiagou section and some previous studies of other sections in Sichuan, Guizhou provinces and Chongqing City suggest that the first occurrences of *Hindeodus parvus* are slightly earlier than the sharp negative excursion of $\delta^{13}C_{carb}$ and the FAD at the Meishan GSSP section. We consider that the slight difference of the end-Permian mass extinction, chemostratigraphy and conodont biostratigraphy at Daijiagou and its adjacent areas is most likely subject to different lithofacies, fossil preservation, and the constraint on the stratigraphic resolution rather than a different tempo of the end-Permian mass extinction in a global sense. The whole Changhsingian conodont succession at Daijiagou provides a high-resolution correlation with other equivalent sections in the Palaeotethys. The controversial results of biostratigraphy and chemostratigraphy between the sections investigated in this paper and the Meishan GSSP section also provide some important implications that accurate chronocorrelation requires the evaluation of multiple, varied stratigraphcal signals rather than relying solely on the FAD of the Triassic index species *Hindeodus parvus* for recognizing the Permian–Triassic boundary (PTB). Growth series of abundant specimens for each species are figured. The taxonomy of some *Hindeodus* species in the PTB interval is updated.

1. Introduction

The end-Permian mass extinction has been widely documented as the largest in life's history (Sepkoski, 1981, 1984; Erwin, 2006; Bambach, 2006). Many fossil groups such as fusulinids, rugose corals, and brachiopods suffered great losses or became extinct around the PTB. By contrast, conodonts were relatively less affected in terms of diversity, but responded in high-speed evolution under environmental stress in terms of durations of conodont zones. Therefore, high-resolution conodont zones have been recognized around the PTB in some key sections in South China (Ji et al., 2007; Metcalfe and Nicoll, 2007; Zhang et al., 2007; Jiang et al., 2007, 2011, 2014; Chen et al., 2009a; Shen et al., 2011; Yuan and

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Shen, 2011; Yuan et al., 2014) and they have been widely used for calibration of the end-Permian mass extinction and correlation for the PTB interval (Metcalfe and Nicoll, 2007; Shen et al., 2011; Wang et al., 2014).

Although a high-resolution conodont-based biostratigraphical framework and a rapid end-Permian mass extinction have been well documented, the details of the conodont zones, identification of conodont species, and the extinction patterns remain controversial (Wang et al., 2014; Yuan et al., 2014). For instance, the conodont index species, *Hindeodus parvus*, that was defined as the base of the Triassic (Yin et al., 2001), has been documented to occur below the PTB at the Zhongzhai section in Guizhou Province based on the last occurrence of the fusulinid *Palaeofusulina sinensis* and numerous Permian brachiopods (Zhang et al., 2014), high-precision radiometric dates, and $\delta^{13}C_{carb}$ excursions (Shen et al., 2011). Various conodont species including the Lower Triassic *Clarkina carinata*, the early Changhsingian *C. subcarinata* etc. are identified from the uppermost Changhsingian in different sections or the same sections by different researchers (Ji et al., 2007; Jiang et al., 2011; Yuan et al., 2014). The end-Permian mass extinction has been calibrated within 61 ± 48 kyr as a single catastrophic extinction (Burgess et al., 2014), but others suggested the extinction consists of two phases respectively at Bed 25 and Bed 28 at the Meishan section (Song et al., 2013) and many different horizons in South China (see Wang et al., 2014, Fig. 8). In addition, the magnitude of the $\delta^{13}C_{carb}$ excursion is also variable although the excursion itself has been recognized globally (Cao et al., 2010; Korte and Kozur, 2010; Shen et al., 2013). Such variations and discrepancies are likely derived from different lithofacies in different sedimentary settings or sampling biases in South China. Thus, studying the PTB sections in different lithofacies is very important to unravel the spatial and temporal patterns of the end-Permian mass extinction.

South China possesses numerous complete marine sequences from the uppermost Permian to lowest Triassic. They include sections with shallow (e.g., the Dukou section in Sichuan Province, the Huangzishan section in Zhejiang Province), moderately deep (e.g., the Meishan sections in Zhejiang Province), deep water (e.g., the Shangsi section in Sichuan and the Majiashan section in Anhui Province), shallow marine carbonate platform facies (e.g., the Dajiang and Dawen sections in Guizhou Province), and reefal carbonate facies (e.g., the Laolongdong section in Chongqing City) in the late Changhsingian. In addition, a great number of Permian–Triassic transitional sections have been documented from South China.

Most of the previous conodont studies in South China focused on the PTB interval (Zhang, 1987; Wang, 1994, 1995; Orchard et al., 1994; Lai et al., 1999, 2001; Nicoll et al., 2002; Xia et al., 2004; Wang and Xia, 2004; Luo et al., 2006, 2008; Zhang et al., 2007; Ji et al., 2007; Jiang et al., 2007, 2011, 2014; Metcalfe and Nicoll, 2007; Metcalfe et al., 2007; Chen et al., 2008, 2009a; Yuan and Shen, 2011) except for the Meishan section (Zhao et al., 1981; Mei et al., 1998; Zhang et al., 2009; Yuan et al., 2014) and the Shangsi section (Li et al., 1989; Shen et al., 2011). Only a few other sections have been investigated in detail for conodonts through the whole Changhsingian (e.g., Tian, 1993a, 1993b; Nafi et al., 2006).

In this paper, we report and discuss our detailed study on the conodont biostratigraphy, extinction pattern, and carbon isotope profile on the basis of the Daijiagou section in northern Chongqing City and provide a comparison with other key sections in terms of conodont zonation and the end-Permian mass extinction pattern. This section represents a carbonate facies in the Changhsingian with siliciclastic facies on the topmost 1 m overlain by marls containing abundant conodonts, some surviving brachiopods, and Triassic bivalves with a few volcanic ash interbeds around the PTB.

2. Geological setting

The Daijiagou section is located at Daijiagou Village, Beibei District, Chongqing City, near a mine mining the coal from the Lungtan Formation. It is approximately 35 km north of Chongqing (Fig. 1). Geologically, it belongs to the southern part of the Huaying Mountains anticlinorium of eastern Sichuan complex fold belt on the northern shelf of the South China Block (Zeng et al., 2008; Mu et al., 2009). The Permian sequence at the section is well exposed and composed of the Guadalupian massive carbonate Maokou Formation, the Wuchiapingian coal-bearing clastic Lungtan Formation, the Changhsingian carbonate Changhsing Formation, and the Induan Feixianguan Formation. Brachiopods are extremely abundant in the Lungtan and Changhsing formations (Shen et al., 1995; Zeng et al., 1995; Chen et al., 2005; Shen and Shi, 2007). In this study, we measured and sampled the sequence for conodont and carbon isotope studies from the Changhsing to Feixianguan formations. The PTB interval has been studied in great detail.

Several other PTB sections close to the Daijiagou section have been previously studied by other colleagues (Fig. 1). The Laolongdong section is about 2 km southwest to the Daijiagou section and its PTB interval is marked by a thick microbiolite unit directly overlying the Changhsingian reefal facies (Reinhardt, 1988; Fan et al., 1996; Wignall and Hallam, 1996; Kershaw et al., 1999, 2002; Wu et al., 2006; Liu et al., 2006; Qi and Liao, 2007; Jiang et al., 2010), which is not developed at the Daijiagou section. Some conodonts and a $\delta^{13}C_{carb}$ profile were reported by Mu et al. (2009) and Qi and Liao (2007), but in relatively low resolution. Kershaw et al. (2002) reported *Hindeodus parvus* from the reefal carbonates at the Baizhuyuan section, which is about 50 km away from the Daijiagou section, but the precise PTB is not clear at that section. A few well exposed PTB sections in the suburb of Chongqing City are similar to the Daijiagou section in terms of the lithofacies around the PTB. Detailed studies of brachiopods from the Changhsing Formation at the Beifengjing and Liangfengya sections (Yang et al., 1987; Shen and He, 1991; Shen et al., 1995; Shen and Shi, 2007; Clapham et al., 2013) and conodonts from the PTB interval at the Liangfengya section have been presented (Yuan and Shen, 2011), and an extinction pattern was briefly discussed by Wignall and Hallam (1996) and Shen and Shi (2002). All those sections together provide important data for studying the changeover of faunas and the extinction patterns in southwestern China.

3. Conodont zonation

Fifty-five samples were collected from the Changhsing Formation and the lowest part of the Feixianguan Formation at the Daijiagou section and 41 samples are productive in conodonts (Fig. 2). Samples in the overlying horizons of the Feixianguan Formation were collected, but do not contain conodonts. Based on sample-population approach (see discussions by Mei et al., 2004; Shen and Mei, 2010), two genera (*Clarkina* and *Hindeodus*) with twelve species (*Clarkina liangshanensis*, *C. subcarinata*, *C. changxingensis*, *C. yini*, *C. meishanensis*, *C. zhejiangensis*, *Hindeodus typicalis*, *H. eurypyge*, *H. changxingensis*, *H. praeparvus*, *H. parvus* and *H.* sp.) and three transitional forms are recognized. Seven conodont zones are established from the upper part of the Lungtan