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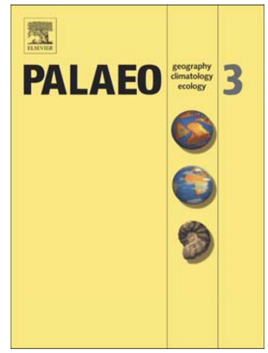

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Reply to the comment on "Terrestrial Permian-Triassic boundary in southern China: New stratigraphic, structural and palaeoenvironment considerations" by H. Zhang, Z. Feng, J. Ramezanik, S-Z Shen

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Abstract

In their comment, Zhang et al. (2018) question the existence of the deformation structures that we report for the upper part of the Chahe Permian-Triassic Boundary reference section. These authors further suggest that this deformation contradicts the regional litho, bio- and chemostratigraphic results. Here again, and based on the outcrop picture provided by

Zhang et al. (2018), we present new arguments attesting for a major tectonic deformation in the upper part of the Chahe section. We argue that the color pattern of the outcrop, the flora description, the $\delta^{13}C_{org}$ isotope profile showing a negative excursion and the lack of coal bed in the upper part of series cannot be used as definitive arguments for a continuous succession. In consequence, we maintain that, above Bed 66, the succession is affected by numerous fold-accommodation faults, preventing any continuous logging and coherent stratigraphic analysis in the Kayitou and Dongchuan formations along that section.

Keywords: Deformation; Chahe section; South China; Permian-Triassic transition

We agree that, as pointed out by Zhang et al. (2018), the Chahe section has been intensively studied for more than 20 years. However, we have extensively searched the available literature and could not find any structural analysis for this section (Bourquin et al., 2018), although the existence of major faults has long been proven in this region (e.g. Liu et al., 2012; Deng et al., 2015; Faure et al., 2016). A large number of published studies consider that field areas in Southwest China, and especially the Chahe and Zhejue sections, represent key reference sections to study the terrestrial PTB, the end-Permian mass extinction on land, the gradual transition from terrestrial to marine facies from Permian to Triassic, and to provide correlations with the Meishan marine reference section across the Yangtze Platform (Peng et al., 2005, 2006; Yu et al., 2007, 2008; Peng and Shi, 2008; Shen et al., 2011; Bercovici et al., 2015, 2016; Zhang et al., 2016; Cui et al., 2017). All these studies are based on sedimentological sections considered as stratigraphically continuous across the PT boundary and laterally continuous from the terrestrial environments to the west to the marine deposits in the east.

Based on outcrop pictures, Zhang et al. (2018) describe a largely intact PTB interval in the Chahe section. While these authors, and others (Peng et al., 2005, 2006; Bercovici et al., 2015; Cui et al., 2017), have published continuous stratigraphy, geochemistry and paleontology data from the base to the top of this section (see our synthesis Fig. 4 in Bourquin et al., 2018), they admit that exposures throughout the section are of variable quality and that parts of the stratigraphy are not equally well-exposed, such as the tectonically disrupted lower part of the Chahe section (see Fig. 7 in Bourquin et al., 2018) and the middle-upper part of the Kayitou Formation, that we considered in our work as a damaged zone (see Fig. 8C in Bourquin et al., 2018). Nonetheless, they consider that the PTB interval is continuous and exceptionally well preserved from the upper part of the Xuanwei Formation to the lower and middle part of the Kayitou Formation. However, figure 1A of Zhang et al. (2018), shows well developed folds and faults affecting the Kayitou Formation (Fig. 1A). As indicated in the Figure 4D of Bourquin et al. (2018), we confirm that within the upper part of the Xuanwei Formation, up to Bed 66, a continuous section can be logged. However, as shown in the Figure 10E of Bourquin et al. (2018) and as again visible on the Figure 1A of Zhang et al. (2018), above Bed 66, faults and folds are disrupting the series making it impossible to log a continuous section. Furthermore, the bedding being nearly vertical, layers parallel to the fault planes occurs, so that the amount of material substracted through deformation cannot be assessed. In consequence, the transition from the Xuanwei Formation to the Kayitou Formation (Fig. 1) is not exceptionally well preserved in the Chahe section. Moreover, Zhang et al. (2018) considered that the Kayitou and the lower part of Dongchau Formation are very well exposed in the Chahe 2 section, without any structural deformation. The picture presented in their Figure 1B is a Google Earth satellite image. Therefore, they do not provide a detailed outcrop picture that could prove the absence of deformation. The field picture published in Zhang et al. (2016) shows a poor quality outcrop exposure of the supposed limit between the Kayitou and Dongshun formations in Chahe 2 that, again, prevents assessing the stratigraphic continuity (Figs. 2B, 3C of Zhang et al., 2016).

Zhang et al. (2018) also consider that our structural results contradict litho- and biostratigraphic criteria. We do not question the lithostratigraphic attribution nor the name of the formations within the Chahe section that are defined based on rock colors. The Kayitou Formation is described in the Chahe section as showing a progressive change from olive/brownish to maroon siltstone and sandstone without coal (Peng et al., 2005) and calcareous mudstone nodules indicating soil erosion after collapse of vegetation systems (Zhang et al., 2016). However, these nodules (see Fig. 4A of Zhang et al., 2016) do not appear to be characteristic of any pedogenic feature but rather to correspond to mud clast underling stratification, induced by tractive current, which reworked floodplain deposits. Moreover, in the Chahe section, some coal lenses are observed within the Kayitou Formation above Bed 68 (Fig. 1B). These coal lenses are underlying one or several fault planes in a several meters wide fault zone (Fig. 1C). The Dongchuan Formation is described as composed of purely maroon sandstone, containing numerous calcareous nodules indicative of seasonally dry climate conditions (Shen et al., 2011; Zhang et al., 2016). Zhang et al. (2016) effectively show calcareous nodules within the basal part of the Dongchuan Formation (see Fig. 4B of Zhang et al., 2016), but as for mud clast nodules of the upper part of the Kayitou Formation, these are in fact loose samples that are not located on the general outcrop picture. Moreover, the previously published sedimentological sections (Peng et al., 2005, 2006; Bercovici et al., 2015) did not describe such pedogenic features within the Kayitou and Dongchan formations. In any case, provided that in the Chahe section, the top of the Kayitou and the base of the Dongchuan formations display some pedogenic features, these, as described by Zhang et al. (2016), can only be found in what appears to be a folded and faulted transition area (Fig. 1). This is therefore not a valid argument to prove the stratigraphic continuity of the succession.

Moreover, we agree that there is an evolution in the floristic contents from the Xuanwei Formation to the Kayitou Formation. However, as indicated in Bourquin et al. (2018), the plant fragments described above Bed 68 belong to species known from the late Permian to the Late

Triassic and, consequently, they cannot be used as definitive biostratigraphic arguments to propose an Early Triassic age (Yu et al., 2010, 2015) nor to assess the stratigraphic continuity of the succession.

The third argument of Zhang et al. (2018) concerns the $\delta^{13}C_{org}$ evolution. It is always possible to measure geochemistry data, even from a deformed section, but once again a continuous series of data points is not an argument to prove the stratigraphic continuity of the succession. Several sharp negative $\delta^{13}C_{org}$ excursions occur at different stages within the Early Triassic series (e.g. Tanner, 2010), as well as further within the uppermost Triassic (e.g. Morante and Hallam, 1996, Tanner 2010). Based on the same $\delta^{13}C_{org}$ evolution obtained on the Chahe section, Cui et al. (2017) modified the location of the PTB well below the boundary between the Kayitou and Dongchuan formations as proposed by Shen et al. (2011) and Zhang et al. (2016) (see Fig. 4C in Bourquin et al., 2018).

Finally, we agree that Bed 68 is associated with a thin coal lens but without lateral continuity (Fig. 1D). We do not question the U-Pb date of 252.30 ± 0.07 Ma obtained by Shen et al. (2011) on zircon grains from Bed 68 and we agree that this date is very precise. Nonetheless, whatever its precision, this late Permian date does not prove (nor disprove) that there is no gap in the sedimentary succession. Furthermore, there is no indication whether the zircon grains contained in that sediment belong to syn-sedimentary volcanic ashes (i.e., from volcanic ashes deposited directly within the sedimentary sequence without subsequent reworking by alluvial processes) or to reworked tuff deposits. Finally, even if Bed 68 is late Permian in age (assuming that the dated zircon grains belong to syn-sedimentary volcanic ashes), no further argument is provided by Yu et al. (2008), Shen et al. (2011), Bercovici et al. (2015) nor Cui et al. (2017) to consider the location of the PTB above Bed 68 (see Fig. 4 in Bourquin et al., 2018). The field picture (Fig. 1A) provided by Zhang et al. (2018) clearly demonstrates that deformation occurs in that part of the section and their Figure 1D lacks the details evidenced in the pictures published in Bourquin et al. (2018) that indeed show tectonic disruption in this part of the series (see also Fig. 1, this reply), preventing any continuous logging.

Our study (Bourquin et al., 2018) is the first structural analysis of the Chahe and Zhejue sections and it indeed questions the pertinence to use them as reference sections for $\delta^{13}C$ evolution, plants diversity variations, sequence stratigraphy analysis or large-scale palaeogeographic reconstructions. The Permian-Triassic transition claimed in many of the previous studies is effectively exposed in a strongly faulted area where it is not possible to assess the amount of missing stratigraphic material nor to build a continuous section. Moreover, there are no criteria allowing to correlate the terrestrial and marine deposits.

In conclusion, regionally, major faults, such as the Chahe Fault, are affecting the crystalline basement. It is largely accepted that most of them are inherited from the complex tectonic history of SE China and that they have been reactivated several times during the Mesozoic and the Cenozoic (see Figs. 1, 2, 3 in Bourquin et al., 2018). These major faults branch towards the surface and generate arrays of secondary faults associated with fault ramp folds that crosscut and displace significantly the late Paleozoic – Cenozoic cover series. In the Chahe section, these faults and folds affect the base (below Bed 34, see Fig. 4 in Bourquin et al., 2018) and the upper part of the succession (above Bed 66, Fig. 4 in Bourquin et al., 2018): the Kayitou and Dongchuan formations are affected by faults and no continuous stratigraphic section can be realized (Fig. 1). Above Bed 66, an unknown thickness of the end Permian succession is missing. Moreover, the Kayitou and Dongchuan formations are probably Triassic in age but no data can confirm whether they are Early Triassic or younger. Neither the lithology nor the carbon isotope composition curve can indubitably prove that the series are continuous. The negative $\delta^{13}C$ incursion (Zhang et al., 2016; Cui et al., 2017) occurs above Bed 72, exactly in the zone that we proved to be a fault-damaged zone (Fig. 1). Furthermore, no data allow to discuss the age of this incursion nor the stratigraphic correlations or the palaeoenvironmental reconstruction of the Permian-Triassic transition in the western Guizhou and eastern Yunnan.

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Figure caption

Figure 1: A. bedding variation within the Kayitou Formation, B: detailed picture showing the succession from the upper part of the Xuanwei Formation to the middle part of the Kayitou Formation with location of coal lenses within and above Bed 68; C: same detailed picture with some fault locations; D: detailed picture of Bed 68.