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Terrestrial paleoenvironment characterization across the Permian-Triassic boundary in South China



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ABSTRACT

Well-preserved marine fossils in carbonate rocks permit detailed studies of the end-Permian extinction event in the marine realm. However, the rarity of fossils in terrestrial depositional environments makes it more challenging to attain a satisfactory degree of resolution to describe the biotic turnover on land. Here we present new sedimentological, paleontological and geochemical (X-ray fluorescence) analysis from the study of four terrestrial sections (Chahe, Zhejue, Mide and Jiucaichong) in Western Guizhou and Eastern Yunnan (Yangtze Platform, South China) to evaluate paleoenvironmental changes through the Permian–Triassic transition.

Our results show major differences in the depositional environments between the Permian Xuanwei and the Triassic Kayitou formations with a change from fluvial-lacustrine to coastal marine settings. This change is associated with a drastic modification of the preservation mode of the fossil plants, from large compressions to small comminuted debris. Plant fossils spanning the Permian-Triassic boundary show the existence of two distinct assemblages: In the Xuanwei Formation, a Late Permian (Changhsingian) assemblage with characteristic Cathaysian wetland plants (mainly Gigantopteris dictyophylloides, Gigantonoclea guizhouensis, G. nicotianaefolia, G. plumosa, G. hallei, Lobatannularia heinanensis, L. cathaysiana, L. multifolia, Annularia pingloensis, A. shirakii, Paracalamites stenocostatus, Cordaites sp.) is identified. In the lowermost Kayitou Formation, an Early Triassic (Induan) Annalepis-Peltaspermum assemblage is shown, associated with very rare, relictual gigantopterids. Palynological samples are poor, and low yield samples show assemblages almost exclusively represented by spores. A \sim 1 m thick zone enriched in putative fungal spores was identified near the top of the Xuanwei Formation, including diverse multicellular forms, such as Reduviasporonites sp. This interval likely corresponds to the PTB "fungal spike" conventionally associated with land denudation and ecosystem collapse. While the floral turnover is evident, further studies based on plant diversity would be required in order to assess contribution linked to the end-Permian mass extinction versus local paleoenvironmental changes associated with the transition between the Xuanwei and Kayitou formations.

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1. Introduction

The end-Permian (~252.2 Ma) is associated with the largest mass extinction event in Earth's history, representing the extinction of more than 90% of marine species, ~70% of terrestrial vertebrates, and drastic restructuring of ecosystems (Erwin, 2006; Vajda and Bercovici, 2014). Numerous studies have been conducted to characterize the biotic changes (Payne and Clapham, 2012; Chen and Benton, 2012; Crasquin and Forel, 2014; Chen et al., 2014a, 2014b; and references therein) and environmental disturbances

(Xie et al., 2007; Sun et al., 2012; Romano et al., 2012; Retallack, 2013; Cui et al., 2013; Benton and Newell, 2014; Cui and Kump, 2014; Feng and Algeo, 2014) associated with the end-Permian extinction event (EPE, Burgess et al., 2014) within marine successions. In recent years, emphasis has been directed to exposures located along the Yangtze Platform in South China, culminating in the definition of the Global Stratotype Section and Point (GSSP) for the Permian–Triassic boundary (PTB) at the Meishan section (Zhejiang province, west of Shanghai, Yin et al., 2001). One unique aspect of the Yangtze Platform is the occurrence of multiple sections preserving the PTB, representing the complete transition from marine, through coastal, and to terrestrial depositional environments. This enables correlation between the marine and terrestrial biostratigraphic records. The second unique aspect is the presence

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of seemingly continuous sections, i.e. a Permian part free of red beds, as opposed to the vast majority of terrestrial successions of Late Permian and PTB age elsewhere in the paleotropics (Lucas et al., 2006; Bourguin et al., 2011 and references therein). This implies better preservation of organic matter and the existence of latest Permian plant fossils in strata preceding the mass extinction event. The terrestrial and transitional PTB sections of Guizhou, Sichuan and Yunnan provinces have thus received increasing attention over recent years. However, the PTB interval remains poorly resolved in the terrestrial realm due to the lack of systematic paleontological studies and paleoenvironmental interpretation. Fossil plants and palynological assemblages spanning the PTB are exceedingly rare, but well-preserved macrofloral assemblages exist in South China. Early description of the macroflora and miospores was published in the 80's (Ouyang and Li, 1980; Ouyang, 1982, 1986). Most recent work has been directed towards the definition of a continental parastratotype completing the Meishan PTB GSSP. and there is growing interest in defining an equivalent biostratigraphic zoning within terrestrial settings. In support of this objective, description of the paleobotanical and palynological assemblages has been conducted over the past decade (Wang and Yin, 2001; Zhang et al., 2006; Peng et al., 2006; Yin et al., 2007; Yu et al., 2007, 2008, 2010; Peng and Shi, 2009; Xiong and Wang, 2011, and references therein). Recently, Shen et al. (2011a) presented new high-resolution radiometric dates of several bentonite layers from the Meishan GSSP and other coastal marine and terrestrial PTB sections in South China, facilitating correlations between the PTB sections of the Yangtze Platform.

We document new data from the study of two classical sections (Chahe and Zhejue, Western Guizhou) and one coastal transitional PTB section (Mide, Eastern Yunnan). We also describe a new PTB section (Jiucaichong, Western Guizhou) within the Yangtze Platform. Paleoenvironmental characterization of the PTB transition was performed using detailed sedimentological analysis complemented by paleobotanical and palynological studies. Additionally, major element geochemistry was performed using X-ray fluorescence (XRF) analysis. Results are discussed in the context of the previously proposed placement of the PTB and demise of the terrestrial ecosystems associated with the end-Permian mass extinction event. Palynofacies analysis has been carried out for the first time on organic residues from these PTB successions. Palynofacies analysis is an especially valuable tool when studying poorly preserved palynological assemblages as it can provide important paleoenvironmental information and complement lithological and biostratigraphical data to improve correlations.

2. Geological background

2.1. General stratigraphy

Three main formations are recognized through the terrestrial PTB successions of South China: the Xuanwei, the Kayitou and the Dongchuan formations. The Xuanwei Formation rests unconformably on the Emeishan basalts and is of latest Permian age (Wuchiapingian and Changhsingian) age (He, 2007). The Xuanwei Formation consists mainly of terrigenous siliciclastic deposits with intercalations of organic-rich mudstones and coal seams. Eastwards, coeval formations are represented by marine limestones of the Wangjiazhai Formation (Sichuan) and Changhsing Formation (Meishan). The Xuanwei Formation is conformably overlain by the Kayitou Formation, which is a 10–30 m massive and homogeneous silty sandstone succession. The rocks of the Kayitou Formation are finely variegated and grade from tan-green to yellow to purple-red towards the top. The Kayitou Formation gradually changes to facies typical of the overlying Dongchuan Formation

represented by a thick succession of purple-red terrigenous siliciclastic sandstones and mudstones. Eastwards, lateral correlative strata are represented by marine limestones of the Feixianguan Formation (Sichuan) and Yinkeng Formation (Meishan).

2.2. The Permian-Triassic boundary in South China

Accurate chronological correlation is crucial for establishing a precise sequence of events spanning the PTB. The primary marker of the PTB at the Meishan GSSP is the First Appearance Datum (FAD) of the conodont Hindeodus parvus, identified in the middle of limestone Bed 27 (Yin et al., 2001, 2007). The EPE is, however, spread over an interval of \sim 50 cm starting prior to the PTB at the top of Bed 24, and extend up to Bed 29 (Xie et al., 2005; Yin et al., 2007; Crasquin et al., 2010; Forel and Crasquin, 2011; Song et al., 2013). This interval is marked by the disappearance of many animal and plant groups, each recorded by their Last Appearance Datum (LAD). The EPE is also characterized by widespread oceanic anoxia and rapid carbon isotopic excursions, broadly used as a geochemical correlation tool. On land, the collapse of terrestrial ecosystems and floras has been characterized by the proliferation of Reduviasporonites sp., variably interpreted as a saprophytic fungus (Sephton et al., 2008; Visscher et al., 2004, 2011) or as an opportunistic algae (Afonin et al., 2001; Foster et al., 2002), but nonetheless occurring worldwide (Eshet et al., 1995; Visscher et al., 1996; Steiner et al., 2003; Sandler et al., 2006).

Other methods for correlating the PTB have been suggested, mostly based on lithostratigraphy and clay mineral signatures (Zhang et al., 2006). The concept of the Permian–Triassic Boundary Stratigraphic Set (PTBST) was defined by Peng et al. (2005) as representing a threefold lithostratigraphic succession encompassing the PTB. At the marine Meishan section, the PTBST is represented by a claystone unit (Beds 25 and 26), followed by a limestone bed that contains the PTB as defined by the FAD of Hindeodus parvus (Bed 27), overlain by another claystone (Bed 28). This threefold lithostratigraphic succession was conventionally correlated between exposures across the entire Yangtze platform and referred to as "eventostratigraphy" (Peng et al., 2005). Westward, the PTBST was defined at coastal sections, such as Zhongzhai (where the PTBST is represented by a clay bed, a sandy limestone unit and another clay bed, respectively Beds 12, 13 and 14), and terrestrial sections, such as Chahe (where the PTBST is represented by a clay bed, a silty sandstone unit and another clay bed, respectively Beds 66, 67 and 68).

3. Study area and methods

Exposures of the terrestrial PTB are accessible in rural areas around Xuanwei city, Yunnan province (Fig. 1). The terrestrial sections Chahe (48R 0385932, UTM 2953327) and Zhejue (48R 0394488, UTM 2943109) are located along roadcuts, whereas the newly described Jiucaichong section represents hill face exposure (48R 0398849, UTM 2944904), all in Western Guizhou. The transitional coastal Mide section (48R 0444118, UTM 2888507) in Eastern Yunnan is located along a dirt road. It is noteworthy that the Mide section corresponds to two different sections in the literature, Mide A and Mide B (Yu, 2008). Mide A is no longer accessible, but a new outcrop spanning the PTB interval was identified at a distance of several hundred meters. Therefore, "Mide" in this paper refers to the newly studied Mide B section.

3.1. Sedimentology and facies analysis

The four sections were logged at a scale of 1:40 using a measuring tape and Jacob staff (Figs. 2–5). Six main facies were identified



Fig. 1. Topographic map of Western Guizhou and Eastern Yunnan showing the position of Chahe, Zhejue, Jiucaichong and Mide sections in bold. Geographic coordinates are given as a 10 km UTM grid.

(Table 1). Previous work on the Chahe, Zhejue and Mide sections established a stratigraphic bed numbering scheme (Zhao, 2003; Yu, 2008) that we applied to the ordination of beds in our study. For the new Jiucaichong section we propose a bed numbering scheme in which each sedimentary package is defined as a fining upward genetic sequence representing a coarse rock unit (sandstone to siltstone) capped by a fine unit (siltstone to mudstone). Sedimentological characterization involved analysis of texture, sedimentary structures, paleosol development, paleocurrent orientation, erosional surfaces and paleontological content (mainly plant fossils and bivalves). At the Mide section, abundant ostracods were observed and sampled from the Kayitou Formation (Bed 25), providing additional data for paleoenvironmental interpretation.

3.2. Paleobotany

A traditional field census of plant fossil was performed on a total of six hundred and two specimens, most identified at the genus level. Each stratigraphic occurrence was given a census number (30 for Chahe, 10 for Jiucaichong and 10 for Zhejue, Figs. 2–5 and Table 2). Other intervals hosting unidentified plant fossil debris are also indicated on the stratigraphic logs.

3.3. Palynology

The sections were sampled for palynology at regular intervals focusing on the mudstone units. One hundred and sixteen samples were processed according to standard palynological procedures (Traverse, 2007) at the China University of Geosciences, Wuhan

(China). Each 10 g sample was crushed to 1 mm diameter granules and treated with dilute hydrochloric acid (HCl) to remove calcium carbonate. Each sample was subsequently macerated in 40% hydrofluoric acid (HF) for 72 h. Fluorosilicates were removed by immersing the residues in hot HCl for 10 min. The remaining part of the processing was conducted at Lund University, Sweden, where residues were sieved through 160 µm and 10 µm meshes. Abundant humic acids in some of the samples were removed with 10% NaOH for 16 h followed by multiple rinses through a 10 μ m mesh. The oxidation process was controlled and each sample was verified for palynological content before and after the procedure (Supplement Table 1). Residues were permanently mounted in polyester resin on a minimum of three microscope slides per sample. A representative selection of palynomorphs was photographed and post-processed using extended depth of field reconstruction (Bercovici et al., 2009a). Sample 11J012 was also sent for independent processing to Global Geolab in Canada to compare process quality and yield. Out of the 116 samples processed, 47 (40.5%) were barren of organic matter. Out of the remainders, 47 (40.5%) were barren of spores and pollen, leaving only 22 samples (19.0%) with very little recovery (Supplement Table 1). Because of the poor recovery and few visible palynomorphs on each slide, relative abundance and diversity studies were not carried out.

The stratigraphic positions of samples are precisely logged (Figs. 2–5), except for the basal samples from the Zhejue section (11Z001 to 11Z007), which were collected without stratigraphic positioning in the unmeasured lower part of the section. They correspond to a series of "coal beds" or organic rich mudstones located approximately 20–30 m below Bed 27 (Fig. 3).

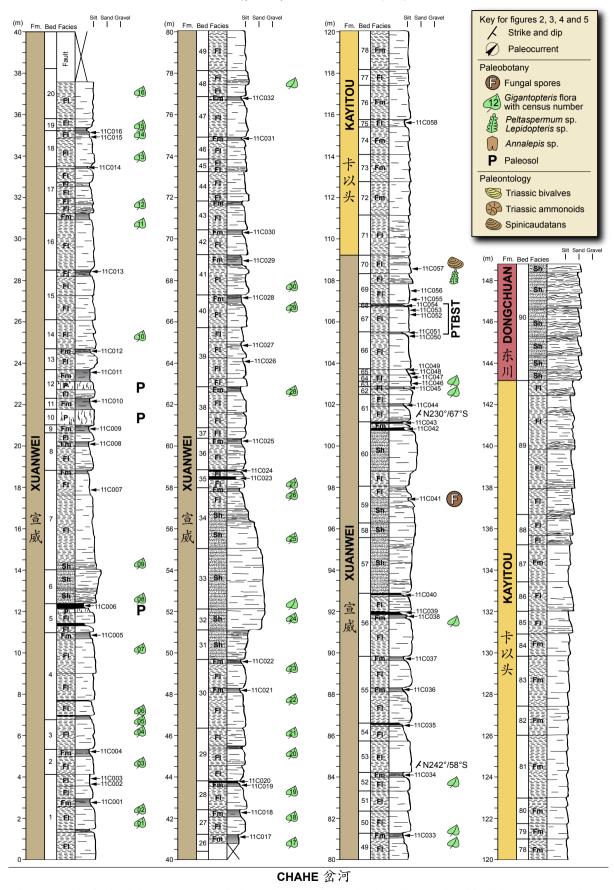
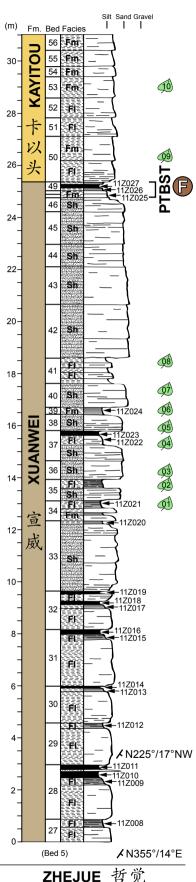


Fig. 2. Sedimentological log for the Chahe section (see Fig. 1 for location). Position of each palynological/XRF sample and fossil plant census intervals are indicated.



 $\label{eq:Fig. 3.} \textbf{Fig. 3.} Sedimentological log for the Zhejue section (see Fig. 1 for location). Position of each palynological/XRF sample and fossil plant census intervals are indicated.$

3.4. Palynofacies analysis

Palynofacies analysis involved identification of the various organic components; relative abundance calculations of the organic components were based on 300 counts per sample. Classification of palynological matter was tailored for the specific palynofacies of the studied assemblages. As phytoclasts are extremely dominant in most samples, these were subdivided according to color and shape (Supplement Table 1). The following palynofacies elements were distinguished; I, Phytoclasts black (opaque); II, Phytoclasts brown; III, Phytoclasts black shards; IV, Charcoal rounded; V, Charcoal shards; VI, Fungal spores; VII, Fungal Hyphae, and VIII, Miospores (pollen and spores). The slides and residues are deposited with AB and at the China University of Geosciences, Wuhan (China).

3.5. X-ray fluorescence

Analyses of major elements were conducted in the laboratory at the Department of Geology, Lund University, using a Thermo Scientific Niton XL3t GOLDD + portable XRF analyzer. Samples were powdered, and one cubic centimeter conditioned into plastic cells equipped with an interchangeable 4 µm polypropylene film window. A series of four measurements were performed for each sample and averaged, with anomalous readings, if occurring, removed from the dataset (Supplement Table 2). Accuracy and drift of the absolute concentration readings were verified by regularly measuring a standard calibration sample. Data exploration was performed by principal component analysis (PCA) using standardized variables for emphasizing trends in the variations of trace elements having concentration several orders of magnitude lower than major elements.

4. Results

4.1. The Xuanwei Formation

The Xuanwei Formation is exposed at all four studied sections and comprises light-colored tan and grey siltstones alternating with sandstone units (Fig. 6A). The rocks are highly fractured, generally hampering the identification of small sedimentary features within the siltstone and mudstone facies, and several small, normal and reverse faults were identified. The bedding is sub-vertical at Chahe (58–67°) and sub-horizontal at Zhejue, Jiucaichong and Mide (14–22°), with variable strike in each section.

The maximum measured thickness of the Xuanwei Formation is at the Chahe section where it reaches 109 m, although the basal part was not exposed. Strike and dip are consistent (N242°, 58°S and N230°, 67°S; Fig. 2). At the Zhejue section, the Xuanwei Formation is split into two compartments delineated at the base of Bed 27 (Fig. 3). This is indicated by a different strike and dip (N355°, 14°E) measured for the lower compartment compared to the upper compartment (N225°, 17°NW). This represents a 85° angle difference between compartments, and because of the lack of continuity only the top part was measured. At the Jicuai section, 46 m of the Xuanwei Formation are exposed with strike and dip measured at N95°, 18°N and N65°, 14°S (Fig. 4). At the Mide section only four meters of the Xuanwei Formation are exposed with strike and dip measured at N10°, 22°NW (Fig. 5).

4.1.1. Sedimentological analysis

The Xuanwei Formation comprises six main facies of terrigenous sandstones, siltstones, mudstones and paleosols (Table 1).

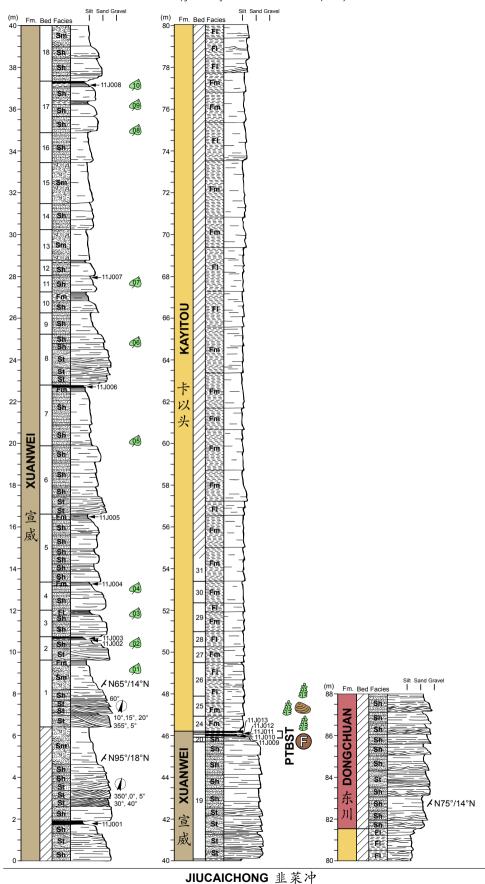


Fig. 4. Sedimentological log for the Jiucaichong section (see Fig. 1 for location). Paleocurrent directions are indicated where measured, as well as the position of each palynological/XRF sample and fossil plant census intervals.

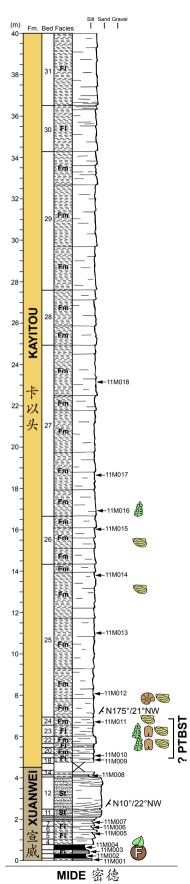


Fig. 5. Sedimentological log for the Mide section (see Fig. 1 for location). Position of each palynological/XRF samples and occurrence of plant fossils are indicated.

The FI and Fm facies (Table 1, Fig. 6B) are dominant throughout the formation and are represented by 0.1–2-meter-thick units. They comprise homogeneous siltstones to silty-mudstones, crudely laminated with sub-centimeter-scale sets (FI facies, Table 1, Fig. 6B and C) or more rarely, massive to crudely laminated and heterolithic packages (Fm facies, Table 1, Fig. 6B). Due to fracturing, few sedimentary structures were observed, with the exception of some current ripples. The color of the sediments ranges from brown, tan, to organic-rich grey and dark grey facies. Several 5–40-cm-thick units of black organic-rich beds were observed (Fig. 6C). They are sometimes referred to as "coal facies" but they contain a significant proportion of terrigenous silica (13–37% Si, Supplement Table 2). The Fm facies is interpreted to signify deposition within calm aqueous environments and the FI facies to represent overbank or waning flood deposits (Miall, 1978; Einsele, 2000).

Coarser lithologies correspond to three distinct sandstones facies; the most common being the Sh facies (Table 1, Fig. 6B and C), which occurs as 0.5–2-meter-thick units with sharp boundaries. The lithology chiefly comprises medium to coarse-grained sandstone showing centimetric to multi-centimetric horizontal laminations and sporadic small scale current ripples. Deposition of the Sh facies corresponds to tractive current or repeated sediment discharges within aqueous environments (Miall, 1978; Einsele, 2000).

The St facies (Table 1, Fig. 6D) occurs in 0.2–1-meter-thick units, and is composed of fine to coarse-grained sandstones with 3D mega ripples. Typical bedforms are comprised between 20–70 cm high and 50–130 cm long, with centimetric laminations. The St facies is most common at the Jiucaichong section. Eleven paleocurrent measurements were taken from the trough cross-bedded sandstone unit at the base of the Jiucaichong section (Fig. 4), giving a consistently northward flow direction. Deposition of the St facies corresponds to fluvial channel bedforms.

The Sm facies (Table 1), occurs as 0.5–2-meter-thick units of massive, structureless, silty sandstones to coarse-grained sandstones with sharp boundaries. The Sm facies corresponds to either deposition from turbulent suspension with insufficient time for bedform development (Lowe, 1982), subaerial hyperconcentrated flows, or subaqueous high-density turbidity currents (Ghibaudo, 1992).

Our observations of the sedimentary successions revealed no "lentoid sandstone" (Zhang et al., 2006) or "lenticular sandstone" (Peng et al., 2006) later reinterpreted as "wedge shaped cross-beddings" (Yin et al., 2007). The sandstone units do not appear to be lenticular (indicating erosional channeling) at the scale of the outcrop. However, modern nodular weathering and fracturing of the sandstone units are extensive.

Paleosols (P facies, Table 1, Fig. 6E) are evident within red silty mudstone facies with no visible primary sedimentary structures. Soil formation is indicated by the presence of very thin vertical rhizoliths, which do not exceed 3 mm in diameter and 5–10-cm-long. They are visible as white protruding filaments within the red matrix (Fig. 6E). P facies is developed in 20–50-cm-thick units evident only at three stratigraphical positions in the lower part of the Chahe section (Beds 5, 10, 12). P facies is interpreted as an Entisol (immature paleosol with little or no evidence of pedogenic horizons). Indirect evidence of soil formation is indicated throughout the Xuanwei Formation by the presence of *Stigmaria* sp. rhizomes preserved within some of the fossil plant associations.

The top of the Xuanwei Formation is usually marked by the occurrence of a greenish-grey claystone layer at Bed 68 (Chahe) and Bed 49 (Zhejue), and we were able to locate it at Bed 21a of the Jiucaichong section (Fig. 6F). This so called "eventostratigraphic clay" is part of the upper PTBST complex (Peng et al., 2005).

 Table 1

 Description of the main sedimentological facies and associated abbreviations.

Code	Facies	Description	Interpretation
Xuanv	vei Fm.		
Sh	Horizontally stratified sandstone	Fine- to coarse-grained tan to brown sandstone, with faint horizontal laminations and occasional erosive base	Fluvial sand-sheet deposits
St	Trough cross-bedded sandstone	Fine- to coarse-grained tan to brown sandstone, with 3D megaripples and occasionally erosive base	Sinuous-crested or linguoid bedform, braided river deposits
Sm	Massive sandstone	Fine- to coarse-grained sandstone, with no apparent lamination	Subaqueous high-density turbidity current
Fl	Laminated mudstone	Laminated siltstone to silty mudstone, greenish-grey to dark grey color	Deposition from suspension, shallow lake or floodplain
Fm	Massive mudstone	Massive siltstone to silty mudstone with little or no apparent lamination, greenish-grey to dark grey color. Unit average thickness 5 cm	Deposition from suspension, floodplain
P	Paleosol	Red siltstone with visible rhizoliths	Paleosol
Kavito	u Fm.		
Fl	Laminated mudstone	Laminated siltstone to silty mudstone, yellow mustard color	Deposition from suspension, permanently flooded with shallow water
Fm	Massive mudstone	Massive siltstone to silty mudstone with no apparent lamination, yellow mustard color	Deposition from suspension, permanently flooded with shallow water
Dongc	huan Fm.		
Sh	Horizontally stratified sandstone	Fine- to medium-grained purple-red sandstone, with well-defined horizontal laminations and non-erosive base. Current ripples common at bed top	Fluvial sand-sheet deposits
St	Trough cross-bedded sandstone	Fine- to coarse-grained purple-red sandstone, with 3D megaripples	Sinuous crested or linguoid bedform, braided river deposits

4.1.2. Paleobotany

The Xuanwei Formation is very rich in plant fossils preserved as large compressions (Fig. 7C). They represent the typical Late Permian Gigantopteris flora. This assemblage was extensively described by Yu (2008). The floral assemblages are dominated by Cordaitales (Cordaites sp.) and pteridosperms (Gigantopteris dictyophylloides, Gigantonoclea guizhouensis, G. nicotianaefolia, G. plumosa, G. hallei, Compsopteris sp., Neuropteris sp., Taeniopteris sp.), with secondary occurrence of equisetales (Lobatannularia heinanensis, L. cathaysiana, L. multifolia, Annularia pingloensis, A. shirakii, Paracalamites stenocostatus), noeggerathiales (Tingia sp.), lepidodendrales (Lepidodendron sp.), ginkgoales (Ginkgoites sp.) and filicales (Pecopteris sp., Fascipteris sp.). Among these, Lobatanularia (Fig. 7D) and gigantopterids (Fig. 7E) represents typical elements of the Cathaysian paleobiogeographic province. No conifers were found. Several Stigmaria (Fig. 7F) occur among the plant compressions. Stigmaria is more abundant in the middle part of the Chahe section, between Beds 26 and 35. Six hundred and two fossil plant specimens from the Chahe, Zhejue and Jiucaichong sections were identified, mainly to genus level (Table 2). Identification of the specimens has been conducted according to Yu (2008). Plant fossils occur most commonly in the laminated silty sandstone (Sh) facies, within the phase of decreasing water flow regime just before deposition of the mudstone and organic-rich units (Fm facies). As such, they indicate transport and accumulation in shallow, slow-moving water.

The fossil plant assemblages served as a tool for paleoenvironmental categorization based on taxonomical composition, preservational mode and taphonomy. We also conducted a detailed field census of the plants in the productive beds at the Chahe section where 475 specimens were counted (Table 2). This dataset covers a large portion of the Xuanwei Formation and provides an estimate of diversity through the latest Permian, but it does not cover the PTB. Variation in diversity across the PTB has been documented from the same locality, but without corrections over variations on sample size (Zhang et al., 2006; Peng et al., 2006; Yin et al., 2007; Yu et al., 2007, 2008, 2010; Peng and Shi, 2009). In this study, statistical correction methods, such as rarefaction, were used in order to compensate for variations in sample size (Gotelli and Colwell, 2001; Colwell et al., 2004).

Our new data is best resolved at the Chahe section, so statistical data on variations in diversity is only evaluated for the plant fossils from this section. Given the relatively low number of counted specimens, a sliding window data binning was performed for each six

consecutive census intervals. Individual sample rarefaction was applied on each bin using the software package PAST using n=40 and n=80 specimens. Two different rarefied values were used because the lower part of the Xuanwei Formation was more thoroughly sampled. Hence the n=80 curve best describes the diversity in the lower part whereas the n=40 curve includes data bins in the upper part that could not reach the minimum of 80 required specimens. Our results show that assemblages from Beds 1 to 40 vary in diversity, albeit the average diversity remains fairly consistent at around six taxa recovered per 40 specimens (Fig. 8). A drop in diversity is evident around Bed 29, associated with the onset of a thick sandstone unit indicating flash discharge (Beds 32, 33 and 34, Section 4.1.1).

4.1.3. Palvnology

Palynomorphs were recovered only from the Xuanwei Formation where they are rare but relatively well preserved and dark colored, denoting an early grade of thermal maturation. The assemblages are all dominated by spores including a wide variety of both trilete (Fig. 9 and 1–21) and monolete forms (Fig. 9 and 22–29). Several larger >50 μm ornamented spores were identified in samples 11Z006, 11C045, 11J004, and more abundantly in sample 11J012 (Fig. 9). Pollen grains are scarce, and only three specimens were recorded (Fig. 9 and 30–32). They are represented by nontaeniate, bisaccate pollen grains, produced by pteridosperms (*Vesicaspora* sp.), conifers (*Klausipollenites* sp.), and caytoniales (*Vitreisporites pallidus*).

Additionally, freshwater algal cysts, mainly *Chomotriletes* sp. (Fig. 9, 33 and 34) were encountered in sample 11C023. Many other, very small \sim 15 µm diameter, circular, thin-walled inaperturate palynomorphs may also be related to algae. This indicates that the accumulation of organic matter in the dark, organic rich "coal seams" did not take place within peat-swamp terrestrial environments but rather in lacustrine settings.

At the Mide section, acritarchs (Fig. 9, 35 and 36) and a possible foraminiferal organic lining (Fig. 9 and 37) were recovered from the palynological assemblages of the uppermost Xuanwei Formation (Samples 11M002 and 11M004). They indicate that marine influence began just before the deposition of the Kayitou Formation.

Fungal remains occur close to the top of the Xuanwei Formation in samples from all four sections. They represent a wide range of spores and hyphae (Fig. 9 and 38–53). The recovery is low but their

 Table 2

 Field census of the plant fossils occurring at Chahe, Zhejue and Jiucaichong. The census number is referring to positions indicated on each sedimentological logs (Figs. 2–4).

			Cordaites sp.	Compsopteris sp.	Pecopteris sp.	Fascipteris sp.	Neuropteris sp.	Annularia	T.	Gigantonoclea	Lobatannularia	Gigantopteris	Taeniopteris sp.	Lepidodendron	Paracalamites	Fertile pinnule	Ginkgoites	Stigmaria	
	Census		rda	duu	cop	scip	nro	nun	Tingia	gan	bat	gan	eni	pid	rac	ıŢ.	nkg	gm	Roots
Section	number	Bed			Pe	Fa	ž	Ar	Ţ	ij	Го	ij	Та	Le	Pa	Fe	ij	Sti	Rc
Chahe	1	1	40	25	2	4													
	2	1		1														3	
	3	2	26	13				1	1	1									
	4	3	10	10							1								
	5	3	2	20															
	6	4	13	8	2														
	7	4		6	2						6	1				1			
	8	6	8	1	3						2	1						1	
	9	7	14	19	9	1	4			1			3						
	10	14	3		1							1							
	11	16	15								_	3						1	
	12	17	8	4	1						3	4							+
	13	18	4		1														
	14	18	3	1.7							1			4				1	
	15	19	15	17	1						1	1			1				
	16	20	18								3	2			1			4	
	17	26																4	
	18	27	12	1						4								1	
	19	28	12 9	1						4									
	20	29	4		1					1 2								2	+
	21 22	29 30	4		1					2								3 5	
	23																	3	
	23 24	30 32	9		2						1						1	3	
	25	34	5		2						1	1	1				1		
	25 26	34			2							1	1					4	
	27	35	1															4	
	28	38	4									1						1	_
	29	40	4		1							1						1	Τ
	30	41	4		1														_
Total: 475	30	41	227	125	28	5	4	1	1	9	18	15	4	4	1	1	1	31	
Jiucaichong	g 1	1	221	123	20	5		1	1	,	10	13	4	7	1	1	1	2	+
Juculenon	2	2																_	+
	3	3													1			2	Ċ
	4	4	3		1										1			-	
	5	7	3		•										•				
	6	8	3	2	1		1				2								
	7	11	3	-	1		•			2	1	3	1						
	8	17	-							-	-							1	+
	9	17																3	+
	10	17		2	4	1						2						4	+
Total: 50			12	4	7	1	1			2	3	5	1		2			12	
Zhejue	1	34																4	+
-	2	35	6								1	2							
	3	36	3		3							2							
	4	37																6	+
	5	38	1	3	3							1							+
	6	39																6	+
	7	40	1	1	1								1					1	
	8	41																10	
	9	50	1	11	1							4							+
	10	53																4	
Total: 77			12	15	8						1	9	1					31	
Grand total: 602			251	144	43	6	5	1	1	11	22	29	6	4	3	1	1	74	

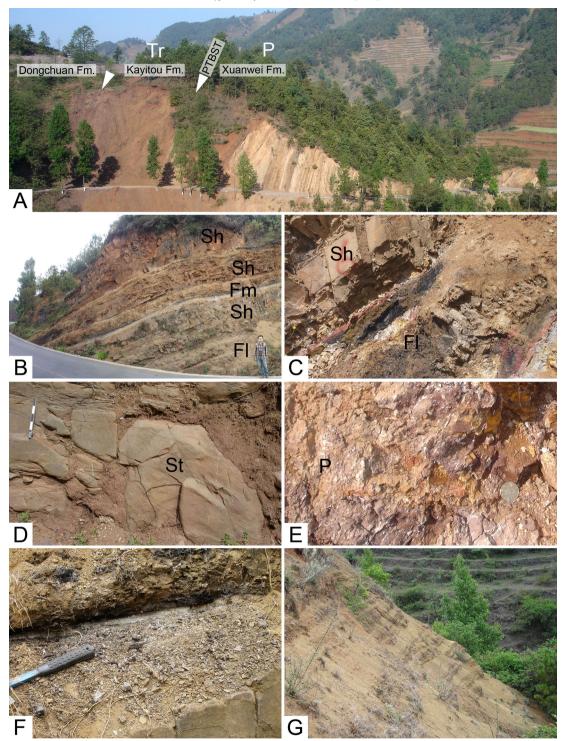


Fig. 6. (A) Exposure of the terrestrial PTB transition at Chahe, western Guizhou. (B) Beds 33–46 within the Xuanwei Formation at the Zhejue section. The sediments of the Xuanwei Formation consist of massive planar bedded sandstone units intercalated with grey silty mudstone units. (C) Dark, organic rich, silty mudstone at the top of Bed 5, Xuanwei Formation, Chahe section. (D) Cross-bedded sandstone unit within the Xuanwei Formation at the base of Bed 1, Jiucaichong section. (E) Occurrence of paleosol (entisol) within Bed 5, Xuanwei Formation, Chahe section. (F) The top of the Xuanwei Formation and PTBST at Jiucaichong, showing a thin light green bentonite unit (Bed 21a). (G) Typical Kayitou Formation facies of homogeneous silty sandstone at the Jiucaichong section.

relative abundance is close to 100% in samples in which they occur. At the Zhejue section, multicellular spores occur within sample 11Z026 (Bed 49a), from the claystone bed representing the uppermost layer of the PTBST. A similar pattern is seen at the Jiucaichong section where the fungal spores occur in samples 11J009 (Bed 21a) within the PTBST upper claystone bed (Fig. 6F) and 11J010 (Bed 21b). At the coastal Mide section, fungal spores occur within the two organic-rich units at the base of the section, within samples 11M002 (Bed 2) and 11M004 (Bed 4). Here, a significant diversity

of fungal spores is apparent, including numerous ascospores (Fig. 9 and 39–42). At Chahe, fungi are evidenced, only by the presence of a few hyphae in sample 11C041 (Bed 59), or about 10 m below the PTBST. Several spores can be attributed to *Reduviasporonites* (Fig. 9 and 49–51).

4.1.4. Palynofacies analysis

All four sections (66 samples) were investigated for palynofacies characterization (Supplement Table 1). Black and brown phyt-

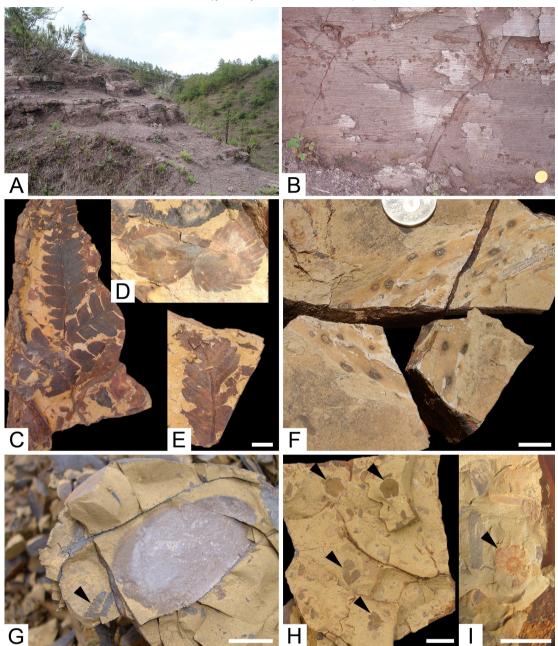


Fig. 7. All scale bars = 1 cm. (A) Red sediments of the Dongchuan Formation showing intercalation of cross-bedded sandstone units with massive siltstone units at the top of the Jiucaichong section. (B) Details of the sandstone facies of the Dongchuan Formation at Chahe. (D) Lobatannularia ensifolia (Halle, 1927) Halle, 1928, from the Xuanwei Formation at Chahe. (E) Gigantopteris dictyophylloides Gu and Zhi, 1974, from the Xuanwei Formation at Chahe. (F) Stigmaria ficoides (Sternberg, 1820) Brongniart, 1822 from the Xuanwei Formation at Chahe. (C) Pecopteris sp. from the Xuanwei Formation at Chahe. (G) Preservation facies of plants within the Kayitou Formation at Jiucaichong Bed 25, arrows point at Lepidopteris cf. martinsii (Harris, 1932) Poort and Kerp, 1990. (H) Arrows pointing at Annalepis spp. from the Kayitou Formation at Mide Bed 23. (I) Arrow pointing at a Peltaspermum sp. ovuliferous disk found in sediments from the Kayitou Formation at Mide Bed 23.

oclasts are the dominant components in all studied assemblages. Specific signatures of the studied successions include the dearth of amorphous organic matter, high abundance of charcoal and specifically charcoalified wood shards, and fairly high relative abundance of fungal spores at some stratigraphical levels. The recovery of miospores is very low with the exception of four samples (Fig. 10).

The organic matter within the basal parts of all sections (Xuanwei Formation) is dominated by charcoal. Rounded charcoal particles reach a maximum relative abundance of 89% in the Chahe section, and 97% in the Zhejue section. Higher in the successions, the organic matter in the Xuanwei Formation is dominated by brown and black phytoclasts. Interestingly, miospores are concentrated in samples within the topmost part of the formation, close to

the PTB, reaching up to 18% of the organic components. Fungal spores generally occur in samples adjacent to the PTB at the top of the Xuanwei Formation.

4.2. The Kayitou Formation

The Kayitou Formation is exposed as distinctive mustard yellow silty sandstone units (Fig. 6G) resting conformably on the underlying Xuanwei Formation with a gradational contact spanning 1–3 m. Weathering makes bedding visible on the outcrop surface, but a freshly excavated face shows homogeneous grain size with no obvious variations. The Kayitou Formation is 34-meter-thick at Chahe and 35-meter-thick at Jiucaichong (Figs. 2 and 4). At the coastal Mide section, the Kayitou Formation is much thicker, pos-

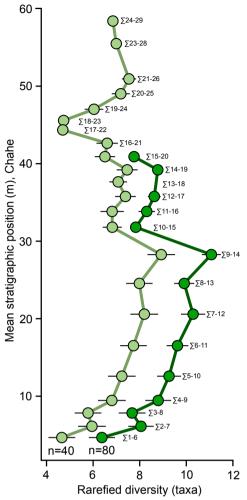


Fig. 8. Diversity variation within macrofloral assemblages in the sampled sections within the Xuanwei Formation sampled at the lower part of the Chahe section. Data from Table 2 was combined using sliding window binning of six consecutive census intervals. The resulting data was rarefied at 40 and 80 specimens to remove sample size variation related bias. Error bars are 95% confidence intervals.

sibly reaching $60\ m$ but only the basal $36\ m$ was measured for this study.

4.2.1. Sedimentological analysis

The sediments of the Kayitou Formation are homogeneous and only the Fl and Fm facies (Table 1, Fig. 6G) are represented. The succession comprises 0.1-1-meter-thick siltstone to silty-sandstone units. The basal part of the formation is dominated by the homogeneous and massive to crudely laminated Fm facies (Table 1). The Fl facies is finely laminated with very well defined sub-centimeter-scale heterolithic sets, and its occurrence increases towards the top of the formation. In association, the upper onethird of the Kayitou Formation is characterized by the occurrence of small-scale current ripples at the base of most Fl units. Both Fl and Fm facies are extremely friable, breaking into small blocks and shards when excavated. The mustard yellow color grades upward into yellowish-green, and the upper third of the formation is generally finely variegated with yellowish-green and purple-red bands increasing in dominance towards the top. The mustard yellow color is especially evident on powdered rocks.

4.2.2. Paleobotany

In the Kayitou Formation, plant fossils are found in the lowermost few meters at the Jiucaichong and Mide sections, but they are much more scarce than in the Xuanwei Formation. The preservation is also different, as plant fossils consists of scattered, small (≤1 cm) comminuted debris (Fig. 7G). New plant taxa appear in the Kayitou Formation, the most significant being *Annalepis* (Fig. 7H), peltaspermalean foliage (*Lepidopteris* cf. *martinsii*, Fig. 7G) and fertile organs (*Peltaspermum* sp., Fig. 7I). These collectively constitute a distinctive *Annalepis*–*Peltaspermum* assemblage. *Annalepis* is a Triassic lycopsid that relates to Isoetes, with similar growth habit as *Pleuromeia* (*Grauvogel-Stamm* and *Duringer*, 1983; Naugolnykh, 2013). The genus is based on isolated sporophylls that articulate in cones (Meng, 1998; Grauvogel-Stamm and Lugardon, 2001), which closely resemble those of *Tomiostrobus* (Naugolnykh, 2012).

4.2.3. Ostracod assemblage

At the Mide section, marine ostracods have been previously mentioned from the Kayitou Formation in Beds 21 to 26 (e.g. Yu et al., 2010). Recent fieldwork did not recover any ostracods outside Bed 25, which yielded abundant specimens on the surface of cracked siltstones/fine sandstones. Preliminary observations indicate that the recovered assemblage is nearly monogeneric and dominated by *Hollinella* specimens. Two species were previously reported: *Langdaia suboblonga* and *Hollinella tingi* (sic). No *Langdaia* was observed in our study. Altered and corroded specimens of *Hollinella* originally characterized by their lobes and frill, are abundant and might have been mistakenly identified as *Langdaia* in past studies. *Hollinella tingi* (Patte) has been demonstrated to be restricted to the Early Permian (e.g. Crasquin-Soleau et al., 2004) and its specific characters are not evident from Mide specimens.

4.3. The Dongchuan Formation

The Dongchuan Formation is exposed as alternating purple-red siltstone and sandstone units (Fig. 7A) resting conformably on the underlying Kayitou Formation with a gradational contact spanning \sim 5 m. The Dongchuan Formation is at least 50+ meter-thick in the study area, the top has not been identified. In the purple-red Dongchuan Formation, no fossil plants were found owing to the oxidizing conditions that destroyed all traces of organic matter.

4.3.1. Sedimentological analysis

Two main facies are represented within the Dongchuan Formation, the most common feature being the Sh facies (Table 1, Fig. 7A). The Sh facies occurs as 0.2–1-meter-thick units of fine-to medium-grained sandstone, with horizontal laminations, and common current ripples. Boundaries are usually not erosive. Deposition of the Sh facies corresponds to tractive current or repeated sediment discharges within aqueous environments. The St facies is composed of fine- to medium-grained sandstones with trough cross bedding (Fig. 7B). Increasing occurrence of the St facies is observed towards the top of the formation, as seen from stacked sequences found in an unmeasured part of the Dongchuan Formation at Chahe (Fig. 7B). Deposition of the St facies corresponds to fluvial channel bedforms.

4.4. X-ray fluorescence

Results of the XRF analysis of a series of samples from the Xuanwei and Kayitou formations, across the four studied sections show that the chemical composition of the rocks is consistent and that all samples are devoid of CaCO₃ (Supplement Table 2). No data clustering appear based on geographical location of sections (Fig. 11), not even for the coastal Mide section at a distance of 170 km from Chahe, Zhejue and Jiucaichong (Fig. 1), showing that the chemical composition is laterally consistent and not related to geographical location but rather to time of deposition. Three major composition clusters are evident from the principal component



Fig. 9. 1–56; Extended depth of field light micrographs of selected representative palynomorphs from the Xuanwei Formation of Chahe, Zhejue, Jiucaichong and Mide, scale bar – 50 µm. 1: Cyclogranisporites?/Convolutispora sp. (11J004) – 2: Iraquispora sp. (11Z006) – 3: Microbaculatisporites sp. (11J003) – 4: Aratrisporites sp. (11J004) – 5: Convertucosisporites cameronii (de Jersey, 1962) Playford and Dettmann, 1965 (11C023) – 6: Lundbladispora sp. (11C023) – 7 and 8: Convertucosisporites sp. (11C023) – 10: Leiotriletes concavus (Kosanke, 1950) Potonié and Kremp, 1955 (11C023) – 11: Waltzispora strictura Ouyang and Li, 1980 (11Z006) – 13: Maltzispora strictura Ouyang and Li, 1980 (11Z006) – 13: And 14: Densoisporites nejburgii (Schulz, 1964) Balme, 1970 (11C045) – 15: Granulatisporites sp. (11C023) – 16: Granulatisporites sp. (11Z005) – 20: and 21: Calamospora microrugosa (Ibrahim, 1932) Schopf et al., 1944 (11C023) – 22: Punctatosporites sp. A (11J003) – 23: Punctatosporites sp. B (11C023) – 24: Punctatosporites sp. C (11C023) – 25: Laevigatosporites sp. (11Z006) – 26 and 27: Laevigatosporites sp. (11C023) – 28: Torispora zhejuensis Peng et al., 2006 (11Z006) – 20: Torispora zhejuensis Peng et al., 2006 (11Z006) – 30: Vitreisporites pallidus (Reissinger) Nilsson, 1958 (11C023) – 31: Klausipollenites sp. (11J012) – 32: Vesicaspora sp. (11C023) – 33 and 34: Chomotriletes sp. (11C023) – 35 and 36: Acritarch (11M002) – 37: Foraminiferal test lining (11M003) – 48: Multicellate fungal spore (11M004) – 44: Multicellate fungal spore (11M004) – 46 and 47: Multicellate fungal spore (11M004) – 49 and 50: Reduviasporonites sp. (11J009) – 51: Reduviasporonites sp. (11J000) – 53: Multicellate fungal spore (11M004) – 49 and 50: Reduviasporonites sp. (11J009) – 51: Reduviasporonites sp. (11J000) – 53: Multicellate fungal spore (11J000) – 52: Fungal hyphae (11J009) – 53: Multicellate fungal spore (11J000) – 52: Fungal hyphae (11J009) – 53: Multicellate fungal spore (11J000) – 49 and 50: Reduviasporonites sp. (11J009)

analysis of the XRF data (Fig. 11), two within the Xuanwei Formation and one within the Kayitou Formation. The Xuanwei Formation includes two clusters, the first grouping siliciclastic

sediments and the second grouping organic-rich sediments enriched in elements such as S, P, W, Se, Cu, Ca, As. Additionally, the results from the "coal beds" and the other organic-rich samples

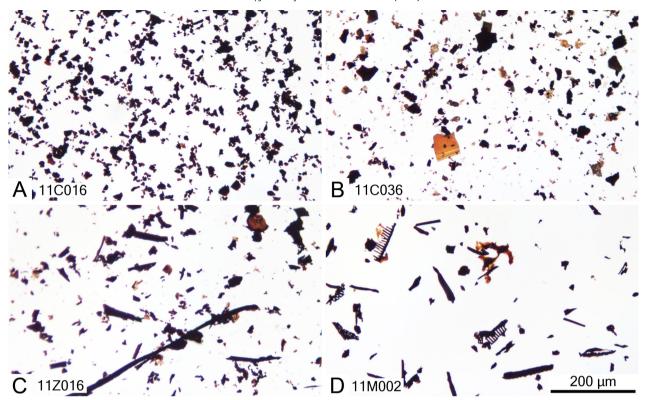


Fig. 10. Micrographs of representative palynofacies assemblages present in the Xuanwei Formation. A: the most common type of palynofacies with dominant black phytoclasts. B: Palynofacies similar to A with dominant brown phytoclasts. C: Palynofacies dominated by black and brown phytoclasts, also showing occurrence of long black charcoal shards and miospores (notice trilere spore on the top right hand corner). D: Typical palynofacies of the upper part of the Xuanwei Formation at Mide, showing abundant phytoclasts and black charcoal shards (notice the two fern tracheids with scalariform pitting).

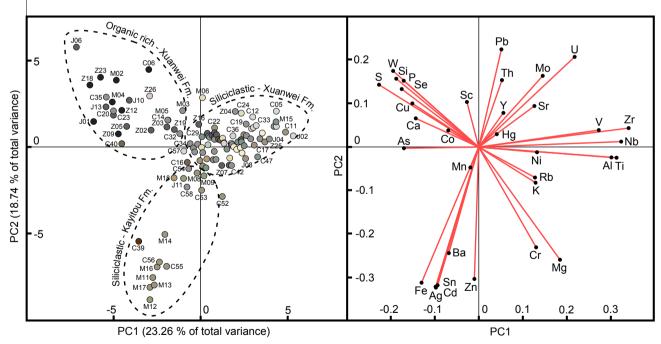


Fig. 11. The XRF data presented as Principal component analysis with standardized variables. PC1 vs. PC2 plot for each sample is presented on the left and PC loadings on the right. Sample names have been shortened e.g. "11C001" corresponds to "C01" in the diagram.

show that they contains a significant proportion of terrigenous silica (from 13% to 37% Si, Supplement Table 2). These two groups of sediments alternate through the succession. The third cluster encompasses sediments from the Kayitou Formation with enriched proportions of Fe, Ba, Sn, Ag and Cd. All sediments analyzed were devoid of carbonate, as indicated by the small amount of calcium (Supplement Table 2).

5. Paleoenvironmental interpretation

The general evolution of the PTB successions in Guizhou and Yunnan shows a transition from deposits representing terrestrial, nearshore fluvio-lacustrine environments with wetlands to brackish lagoonal and coastal marine environments. Across the four sections, Jiucaichong is the most proximal relative to Chahe and

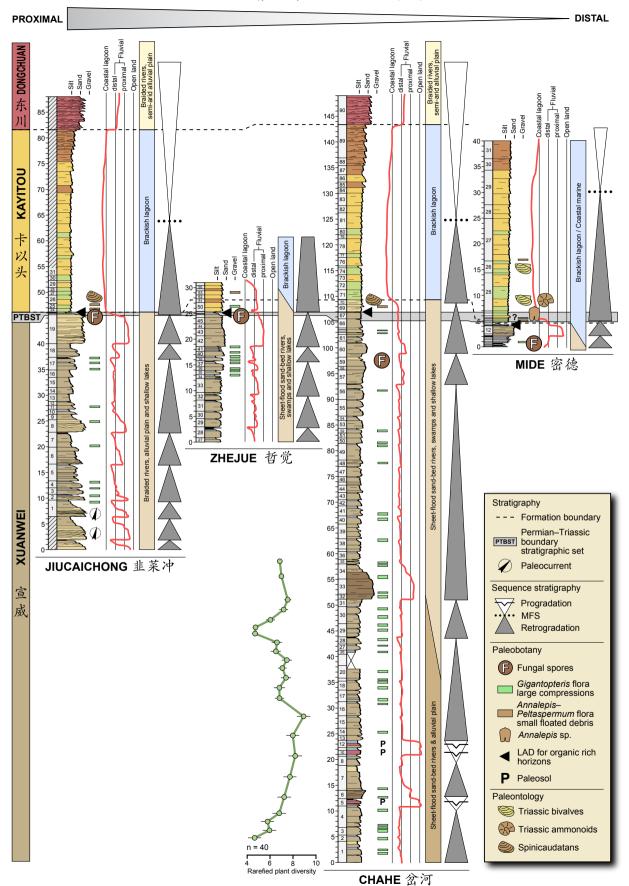


Fig. 12. Correlation of the studied sections, depositional environments and stratigraphical synthesis.

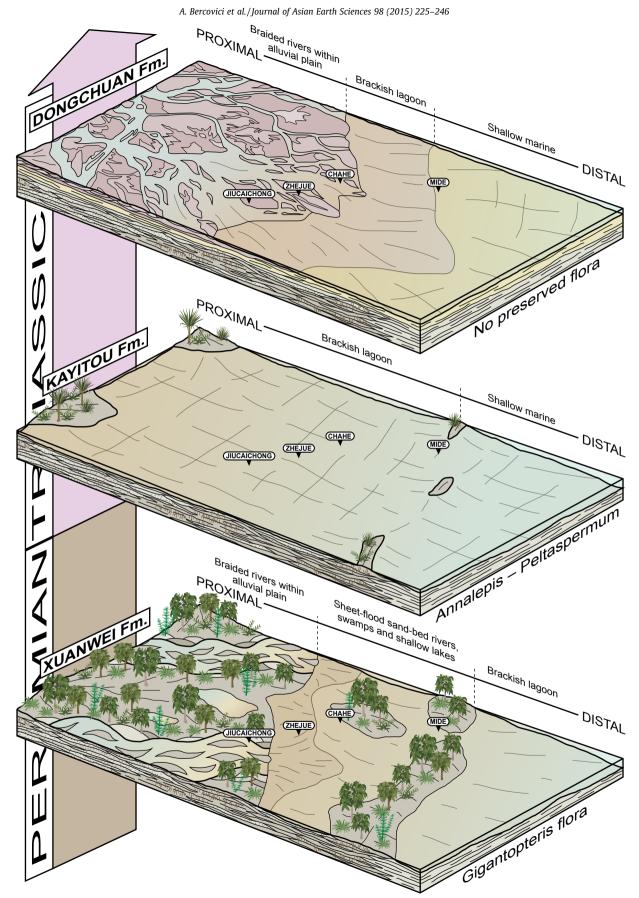


Fig. 13. Block diagrams showing the reconstruction of the depositional environment of the Xuanwei, Kayitou and Dongchuan formations. Position of the four studied sections is indicated relative to the proximal/distal transect.

Zhejue, showing more fluvial influence and less deposition of fine organic rich sediments (Fig. 6). The occurrence of freshwater algal cysts in these organic-rich facies indicates deposition in a lacustrine environment. Our results show that variations in plant diversity occur within the lowermost 60 m of the Xuanwei Formation at Chahe, albeit the average diversity is fairly consistent with around six taxa represented amongst 40 specimens (Fig. 9). A drop in diversity is evident around Chahe Bed 29, correlated with a local environmental transition from dry floodplains to wetlands (Fig. 12).

Our sedimentological and paleontological observations contrast with previous interpretations of depositional environments (Zhao, 2003; Yu et al., 2007). The Xuanwei Formation does not represent meandering river systems because no point bar deposits were identified. Rather, it represents wetlands consisting of swamps and shallow lacustrine environments with sheet-flood sand-bed rivers. At the liucaichong section, more proximal settings correspond to the occurrence of braided river systems within alluvial plain and shallow lakes (Figs. 12 and 13). The Kayitou Formation does not correspond to lacustrine deposits (Yu et al., 2007), but rather to terrigenous sedimentation from suspension in coastal lagoon environments, as attested by the presence of marine fossils at the Mide section. The occurrence of plant fossils with a marine fauna, as in the Permian of Laos (Bercovici et al., 2012a; Blanchard et al., 2013) and Saudi-Arabia (Berthelin et al., 2004), nevertheless indicates close proximity to the coastline and terrigenous input in the basin. In more proximal settings, such as represented in the Chahe and Zhejue sections, marine influence is not evidenced by any fossils, and the occurrence of spinicaudatans (i.e. conchostracans) at the Jiucaichong and Chahe section would indicate a mainly coastal influence such as a brackish lagoon. The transition between the Xuanwei Formation and the Kayitou Formation is marked by the sharp disappearance of organic matter in the sediments.

5.1. Xuanwei Formation

The successions within the Xuanwei Formation were deposited chiefly in a non-marine environment at all sections except Mide, which displays marine influence at the very top of the Xuanwei Formation. A vertical transition from alluvial plain facies to fluvial and lacustrine facies towards the top of the formation is evidenced. Two major depositional environments are represented:

- The first, expressed in the lower part of the Xuanwei Formation (0–40 m at Chahe), is composed of stacked sequences of Sh and St facies fining upwards to the generally organic-rich Fl and Fm facies, sometime associated with paleosol development (facies P or occurrence of Stigmaria sp.). The repeated occurrence of these paleosols is indicative of an alluvial floodplain. These stacked genetic sequences range from 0.5 to 4-meter-thick and are interpreted as flash discharges leading to the deposition of sand-sheets within shallow lakes or alluvial plain settings. We interpret the coarser deposits as formed by sheet-flood sand-bed rivers sensu Miall (1996).
- The second type of depositional environment is represented by thick sequences of Sh facies (at Chahe, Bed 32–34, Fig. 2, and Zhejue, Bed 42–46, Fig. 3) or St facies (at Jiucaichong, Bed 6,7, 8–10, and 19, Fig. 4), fining upward to Fl facies. The top of the sand bars are generally represented by the Sh facies with some current ripples attesting to decreasing flow rates. These genetic sequences are thicker (5–7 m) compared to those in the lower part of the succession. These are interpreted to represent increased flash discharges (Sh facies at Chahe and Zhejue) within swamps and shallow lake deposits. At Jiucaichong these are instead interpreted to represent low sinuosity braided river

deposits (St facies) within shallow lake or alluvial plain deposits. Increasing lacustrine influence is further indicated by the occurrence of freshwater algal cysts in palynological samples within the upper part of the Xuanwei Formation. The transition from the more terrestrially influenced lower part and the more lacustrine/riparian-influenced upper part is marked by a drop in plant diversity around Bed 29 at Chahe, associated with the onset of a thick sandstone unit representing a flash discharge event (Beds 32–34).

The Gigantopteris flora recovered from the Xuanwei Formation at all four sections is indicative of a warm and humid climate. The taxa present are typical climate-sensitive, hygrophilous wetland plants (DiMichele and Philips, 2002; DiMichele et al., 2005a, 2006a). This interpretation is further supported by the occurrence of organic-rich horizons throughout the Xuanwei Formation. Additionally, the palynological assemblages from the four studied sections show relative abundance of nearly 100% spores. Conifer pollen (monosaccate and taeniate bisaccate pollen grains) are absent from the palynological assemblages, with the vast dominance of spores indicating hygrophilous affinity. Interestingly, an important proportion of fossil plants recorded in the Xuanwei Formation are pollen producers (Cordaitales, pteridosperms and ginkgoales). There is therefore a mismatch between the composition of macroflora and palynological assemblages, which could be related to preservational or taphonomic bias.

Occurrence of Stigmaria was reported in several plant-producing units (Table 2). Stigmaria is a form-genus for the rootlet-bearing rhizome of the lycopsid *Lepidodendron*. The rhizophores develop horizontally and shallow within the soil horizon, and usually get preserved as in-situ three-dimensional casts in Pennsylvanian and Early Permian coal swamp environments (Martín-Closas and Galtier, 2005; Wagner and Diez, 2007). In the Xuanwei Formation, Stigmaria are preserved as organic compressions without any connected rootlets, within laminated silty sandstone (Sh facies), often associated with plant debris. This contrasts with the usual ecological interpretation of Stigmaria representative of gleyed paleosols (Rosenau et al., 2013), Gleved soil activity is characterized by structureless claystones units with slickensides, obliterating sedimentary features as well as potential fossil plant compressions. We therefore propose that Stigmaria rhizophores were transported together with the subaerial plant remains, rather than being preserved in-situ, although this scenario would not be usual in a typical Pennsylvanian coal swamp environment (Ferguson, 1970).

5.2. Kayitou Formation

The monotonous succession of massive silty mudstone facies (Fm facies) with intercalation of very fine planar lamination (Fl facies) indicates deposition in calm, ever-flooded aqueous environments. Deposition of the Kayitou Formation corresponds to a shallow coastal terrestrial lagoon evolving towards marine deposition at the Mide section. The general facies progradation observed at all sections may be associated with a regional marine transgression recorded at the beginning of the Triassic (Lehrmann et al., 2007; Yin et al., 2014).

At the Mide section, the occurrence of marine bivalves, brachiopods, ammonoids and ostracods (Yu et al., 2010) clearly indicates a marine depositional setting. We found several 3–5 mm spinicaudatan valves at Jiucaichong, possibly indicating freshwater environments (Kozur and Weems, 2010), albeit precise taxonomical identification of the specimens was not yet established. These interpretations are strengthened by the presence of typical marine Hollinellid ostracods. The monogeneric assemblage further indicate unstable conditions that can relate to the modification of one or more paleoecological parameters, such as temperature, salinity, oxygenation and amount of suspended matter. *Hollinella*

is an important environmental proxy since its size has been correlated with proximity to the paleoshoreline and detrital input: small species tend to be relatively offshore inhabitants whereas larger ones occur closer to shore and can handle strong terrestrial influx (Melnyk and Maddocks, 1988). All the specimens found here are large (around 1 mm long), denoting conditions close to the shoreline under relatively strong detrital input.

The warm and humid climate evidenced from the Xuanwei Formation also prevail across the PTB and in the lowermost Kayitou Formation. The *Annalepis–Peltaspermum* assemblage is mainly composed of hygrophilous, climate-sensitive plants (Martín-Closas, 2003). Much like the *Gigantopteris* flora of the Xuanwei Formation, the lycopsids and pteridosperms of the lowermost Kayitou Formation indicates a warm and humid climate.

5.3. Dongchuan Formation

The Dongchuan Formation is composed of redbeds, occurring in stacked fining-upward sequences of Sh and St facies with each stack comprising 0.5–2 m. The increasing occurrence of the St facies with stacked trough cross-bedding, characteristic of braided rivers (Best and Bristow, 1993; Miall, 1996) indicates a progressive change in depositional environment to braided rivers within semi-arid alluvial floodplains.

Evidence of pedogenesis is not found across the Dongchuan Formation and organic matter is absent. The Dongchuan Formation represents the first evidence of redbeds in South China with depositional environment similar to what is known from the Late Permian of North China (Shu and Norris, 1999; Yang et al., 2010; Thomas et al., 2011; Stevens et al., 2011), South Africa (Ward et al., 2000; Gastaldo et al., 2005; Coney et al., 2007), Russia (Benton et al., 2004), Europe (Körner et al., 2003; Schneider et al., 2006; Bourquin et al., 2006, 2007; Bercovici et al., 2009b), and the Early to Middle Permian of North America (DiMichele et al., 2004, 2005b, 2007), with climate change to drier conditions (Sheldon, 2005). During the end of the Paleozoic, plants had been tracking the effects of global climate change (Rees et al., 2002), and South China represents the ultimate place where wetland floras still thrived close to the PTB (DiMichele et al., 2001, 2006b; Hilton and Cleal, 2007). This climate change to drier conditions is gradual, with onset marked by the occurrence of variegated deposits in the top of the Kayitou Formation.

6. Placement of the PTB

6.1. Radiometric ages

Traditionally, correlation of the PTB successions across the Yangtze platform has been performed using the PTBST as a marker (Peng and Shi, 2009), based on an array of stratigraphic methods not necessarily including biostratigraphy (Peng et al., 2001; Peng et al., 2002; Wang and Yin, 2001; Peng et al., 2005; Peng et al., 2006; Yu et al., 2007). The PTBST "eventostratigraphic clay" correspond to Bed 68 at Chahe, Bed 21 at Jiucaichong and Bed 49 Zhejue (Figs. 2-4 and 12) whereas Mide does not host any noticeable clay bed (Fig. 5). This so called "eventostratigraphic clay" has been identified as a bentonite in Bed 68 at Chahe (Shen et al., 2011a). Lithostratigraphic correlations are demonstrably insufficient on their own, but recent high-resolution radiometric dating (Shen et al., 2011a) has greatly supported the correlation of the PTBST between Meishan and Chahe (Fig. 12). Bed 25 at Meishan was dated at $252.28 \pm 0.08 \,\text{Ma}$, very close to the age of $252.30 \pm 0.07 \,\text{Ma}$ recorded for of Bed 68 at Chahe (Shen et al., 2011a). Our results on the new Jiucaichong exposure shows that this bentonite bed is also present at the top of the Xuanwei Formation (Bed 21a, Fig. 6F). Based on the stratigraphic position of this bentonite bed and the geographic proximity of the Chahe, Zhejue and Jiucaichong sections (Fig. 1), Bed 68 at Chahe, Bed 21 at Jiucaichong and Bed 49 at Zhejue can tentatively be correlated (Fig. 12). This working hypothesis needs to be confirmed by performing high-resolution radiometric dating of Jiucaichong Bed 21 and Zhejue Bed 49.

6.2. Paleobotany

The Annalepis-Peltaspermum assemblage evidenced in the lowermost part of the Kayitou Formation contrasts significantly with the composition of the Gigantopteris flora recovered from the underlying Xuanwei Formation. The presence of Annalepis from the Mide and Tucheng sections (Yu et al., 2010), represents the first occurrence of a typical Triassic element. Annalepis is common in the Middle Triassic of Europe and South China, but at Mide and Tusheng this flora is encountered in the lowermost part of the Kayitou Formation, consequently assigned to the lowermost Triassic (Yu et al., 2010). Peltasperms are common elements of the late-Paleozoic floras, and are mostly represented in our assemblages from South China by the gigantopterids in the Xuanwei Formation. They are also known from the Triassic (Retallack, 2002; Wachtler, 2011), and we reported the occurrence of *Peltaspermum* sp. (Fig. 7I) and Lepidopteris cf. martinsii (Fig. 7G) in the basal Kayitou Formation. In South China, Annalepis and Peltaspermum represents the pioneer species in the restructuring of the Early Triassic plant ecosystems.

Interestingly, fragments of gigantopterids were also encountered within the Annalepis-Peltaspermum macrofloral assemblage at the Tusheng section (Yu et al., 2010). Three specimens are shown in Yu (2008), representing two <1 cm fragments of Gigantopteris sp. and one of Gigantonoclea sp. Two interpretations for the presence of these persisting relicts of the Late Permian Gigantopteris flora in the early Triassic are possible: either as survivor of the EPE, or as reworked elements. Short-term survivorship of the Gigantopteris flora is a likely possibility, because plant compressions are not prone to reworking. Gigantopterids clearly lost dominance as they are represented in very low numbers within the Annalepis-Peltaspermum assemblage of the Tusheng section. Similar short-term survival of organism was evidenced at the PTB in the marine realm (Payne et al., 2013), and also in the earliest Paleogene, immediately after the end-Cretaceous mass extinction event (Bercovici et al., 2009c, 2012b; Landman et al., 2012). Pteridosperms were also components of Mesozoic ecosystems, and persisted till the beginning of the Cenozoic (McLoughlin et al., 2008). However, considering the fragmentary nature of the plant debris recovered from the Kayitou Formation and the transport involved for depositing terrestrial plant debris in near-shore marine environments, the Annalepis-Peltaspermum assemblage might also constitute an allochthonous assemblage of transported elements.

6.3. Palynostratigraphy

The relative abundance of spores and pollen recorded here differs greatly from those presented by Peng et al. (2006), who recorded significant quantities of pollen within the Xuanwei Formation (18.3% at Chahe and 17.5% at Zhejue). Peng et al. (2006) noted a relative increase of pollen grains towards the top of the Xuanwei Formation, especially above the PTBST where the assemblages were described as dominated by pollen grains (66.6% at Chahe and 59.6% at Zhejue). More recently, Shen et al. (2011a) also provided a figure of 5% gymnosperm in samples stratigraphically below the end-Permian carbon isotope negative shift at Longmendong, Chuanyang and Chahe sections and those results are more compatible with our observations. Unfortunately, the low numbers

of pollen and spores recovered from the sediments of the four studied sections makes them unsuitable markers of the PTB and EPE.

6.4. The PTB "fungal spike" event

An "anomalously high abundance" of fungal spores at the top of the Xuanwei Formation was noted by Peng and Shi (2009) in agreement with our results of relative fungal abundance close to 100% in some samples (Supplement Table 1). At least seven taxa of fungal spores were identified in our palynological samples, among which Reduviasporonites characterizes the end-Permian fungal spike worldwide (Visscher et al., 1996). Recent debate has questioned the significance of this fungal event, and more specifically the affinity of these organic-walled microfossils due to their close morphological resemblance to the zygnematalean green algae Tympanicysta (Afonin et al., 2001; Foster et al., 2002). However, Visscher et al. (2011) argued that Tympanicysta occurs mostly in very recent sediments because of the low preservational potential of this fragile and thin-walled algal cyst. Moreover, organic geochemical analysis of *Reduviasporonites* that exclude the sedimentary matrix shows a signature not related to algal cysts but rather to fungal spores (Sephton et al., 2008; Visscher et al., 2011). The occurrence of Reduviasporonites immediately before the end-Permian mass extinction would still indicate the onset of terrestrial environmental collapse and organic matter decomposition. Similarly, a fungal spike was also evidenced in association to the devastation of terrestrial plant ecosystems at the Cretaceous-Paleogene boundary (Vajda and McLoughlin, 2004, 2007; Vajda and Bercovici, 2014). In all four studied sections, fungal spores and Reduviasporonites only occur within a restricted stratigraphic interval at the very top of the Xuanwei Formation, corresponding to latest Permian deposits.

6.5. Invertebrate biostratigraphy

Evidence of marine fossils has been reported in the lowermost part of the Kayitou Formation at Mide and Tusheng sections (Yu et al., 2010). Among these fossils, occurrence of the ammonoid Ophiceras sp. in Mide Bed 25 (Fig. 12, Tian et al., 2008; Yu et al., 2010) clearly indicates Early Triassic (Griesbachian) age (Brühwiler et al., 2008). The bivalve assemblage is diverse and includes Unionites fassaensis, U. canalensis, U. sp., Towapteria schythica, T. sp., Leviconcha orbicularis, L. prazorbicularis, Pteria ussurica, P. ussurica variabilis, P. murchisoni leshanensis, P. sp., Bakevellia exporrecta linearis, Eumorphotis sp., Neoschizodus laevigata, Promayalina cf. minuta and Gervillia pannonica (Yu et al., 2010). Collectively, this assemblage represents a Lower Triassic range (Rong and Fang, 2004; Posenato et al., 2005). The monogeneric Hollinella ostracod assemblage recovered from the lowermost part of the Kayitou Formation at Mide is however not age diagnostic, as it is typically encountered in the Permian at large and is known to persist shortly during the Early Triassic. The spinicaudatans recovered from Chahe Bed 70 and Jiucaichong Bed 24–26 (Fig. 12) were attributed to the genera Euestheria and Palaeolimnadia by Chu et al. (2013), and could potentially be indicative of Triassic age (Tash and Jones, 1979; Kozur and Weems, 2010; Chu et al., 2013).

7. Conclusions

Four exposures spanning the PTB, located in Western Guizhou and Eastern Yunnan, China were studied for sedimentology, pale-ontology and geochemistry. The studied interval spans parts of the Xuanwei, Kayitou and Dongchuan formations where three major types of depositional environments were identified based mainly on the sedimentological results. The vertical successions show an evolution from alluvial and lacustrine deposits with few

channel deposits (sheet-flood sand-bed and braided rivers) to coastal marine deposits, and finally to braided rivers within semi-arid alluvial plains. The sediments exposed at the new Jiucaichong section have a stronger fluvial influence in the upper part of the Xuanwei Formation compared to the two adjacent Chahe and Zhejue sections (which are more lake-influenced), revealing a transition from proximal (onshore sediments) at Jiucaichong, to distal (paralic/marine) successions at the Mide section.

There is still an ongoing discussion regarding the ages of these successions. Shen et al. (2011a) placed the PTB at the Chahe section within the Dongchuan Formation, \sim 14 m above the bentonite Bed 68. The position was based on three criteria including a negative carbon isotope anomaly, the presence of charcoal interpreted to signify wildfires associated with the PTB, and a color change of the sediments to red/purple (Shen et al., 2011a,b). We argue that the PTB should be in proximity to the bentonite bed at Chahe. dated at 252.30 ± 0.07 Ma (Shen et al., 2011a), which closely coeval to the PTB at the Meishan GSSP. The FADs of typical Triassic (Induan) bivalves, spinicaudatans, and ammonites reported from the basal part of the Kayitou Formation, associated with the Triassic plant genus Annalepis in the coastal Mide and Tusheng sections (Yu et al., 2010), support this interpretation. Moreover, we identified a single zone enriched in fungal spores including Reduviasporonites, close to the formation contact between the Xuanwei and Kayitou formations at all four sections, including Chahe close to Bed 68 (Fig. 12).

The disappearance of plants and palynomorphs in the basal Kayitou Formation from these successions has previously been attributed to the EPE. However, we show a major regional facies change occur between the Xuanwei and Kayitou formations that likely account for preservational differences. It is however clear that two distinct plant assemblages occur across the formation contact between the Xuanwei and Kayitou formations in Western Guizhou and Eastern Yunnan: The Gigantopteris flora of the Upper Xuanwei Formation, and the Annalepis-Peltaspermum assemblage in the basal part of the Kayitou Formation (Fig. 12). The Gigantopteris flora (Gigantonoclea guizhouensis-Annularia pingloensis assemblage) has previously been attributed to the Late Permian (Changhsingian) whilst the Annalepis-Peltaspermum assemblage has been attributed to the Early Triassic (Induan; Yu et al., 2010). Similar floral turnover associated to the EPE has been evidenced globally (Wang, 1996; Looy et al., 1999, 2001; Rees, 2002; Lindström and McLoughlin, 2007; Krassilov and Karasev, 2009; Hochuli et al., 2010; McLoughlin, 2011), with lycopsids involved in the recovery phase during the Early Triassic (Retallack, 1997; Wang and Chen, 2001; Grauvogel-Stamm and Lugardon, 2001; Naugolnykh, 2013). Importantly, the typical Permian gigantopterids persist as relicts within the Triassic Annalepis-Peltaspermum Assemblage. It could imply that gigantopterids cannot be used as a reliable Permian marker in South China if their occurrence represent short-term survival.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jseaes.2014.11. 016. These data include Google maps of the most important areas described in this article.

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Appendix Table 1: Palynological preparation report and raw palynofacies count data. Samples showing no organic matter recovery were discarded.

Appendix Table 2: Raw XRF data showing the elemental composition of each sample in ppm. For each samples, four separate analysis were performed and averaged (lines with orange background), with anomalous readings removed from analysis. Calibration of the device was checked regularly using a standard sample of known composition. The calibration results and associated offset is reported at the end of the spreadsheet.

Sample	Locality	Formation	Bed	Strat position (cm)	Rock color	Process qty.	HCI reaction	HF residue color	Observations	Black phytoclas ts (%)			Charcoal rounded (%)		_	Fungal in the state of the stat	miospore s (%) (Total (specime ns)
11C001	盆河 Chahe	宣威 Xuanwei	1	275	Light grey	10 g	None	Pinkish white + gel	Discarded			(%)						
11C002	盆河 Chahe	宣威 Xuanwei	1	365	Tan	10 g	None	Tan white	Discarded									
11C003 11C004	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	2	390 520	Tan Yellow tan	10 g 10 g	None None	Tan pink Brownish grey	Discarded No palynomorphs	0	97,0	0	0	2,3	0	0	0	300
11C005 11C006	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	4 5	1080 1230	Light grey Dark	10 g 10 g	None None	Grey + gel Dark	No palynomorphs, little organic matter No palynomorphs	0	14,7	0	77,3	8,0	0	0	0	300
11C007	盆河 Chahe	宣威 Xuanwei	7	1780	Tan	10 g	None	Tan pink	Discarded		,,		77,0	0,0				
11C008 11C009	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	9	2010 2080	Grey Yellow tan	10 g 10 g	None None	Grey Light grey	Discarded Discarded									
11C010	盆河 Chahe	宣威 Xuanwei	11	2220	Grey	10 g	None	Grey	No palynomorphs	0	10,7	0	79,0	10,3	0	0	0	300
11C011 11C012	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	12 13	2355 2460	Grey tan Light grey	10 g 10 g	None None	Grey + gel Brownish grey + gel	Discarded Discarded									
11C013 11C014	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	15 17	2845 3345	Light grey Grey	10 g 10 g	None None	Tan pink Dark brown	Discarded No palynomorphs	75,0	24,0	0	0	0	0,7	Ω	0	150
11C015	盆河 Chahe	宣威 Xuanwei	18	3445	Light grey	10 g	None	Tan grey	Discarded		·				0,1	O .		
11C016 11C017	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	18 26	3520 4110	Brownish grey Grey tan	10 g 10 g	None None	Dark brown Brown	No palynomorphs Discarded	69,3	30,7	0	0	0	0	0	0	300
11C018	盆河 Chahe	宣威 Xuanwei	27	4230	Grey	10 g	None	Dark	No palynomorphs	77,0	23,0	0	0	0	0	0	0	300
11C019 11C020	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	28 28	4360 4380	Grey Grey	10 g 10 g	None None	Dark Dark brown	No palynomorphs No palynomorphs	64,7	25,0	0	0	10,0	0	0,3	0	300
11C021 11C022	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	30 30	4820 4955	Grey tan	10 g 10 g	None None	Dark grey Brownish red	No palynomorphs Discarded	0	89,7	8,3	0	2,0	0	0	0	300
11C022	盆河 Chahe	宣威 Xuanwei	35	5845	Dark grey	10 g	None	Dark brown	Some spores and algae	0	86,0	0	0	0	0	0	14,0	300
11C024 11C025	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	35 36	5880 6025	Yellow tan Grey	10 g 10 g	None None	Tan Grey + gel	Discarded Discarded									
11C026	盆河 Chahe	宣威 Xuanwei	39	6410	Greenish grey	10 g	None	Grey	No palynomorphs	0	100,0		0	0	0	0	0	300
11C027 11C028	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	39 40	6485 6720	Dark grey Grey	10 g 10 g	None None	Dark Grey + gel	No palynomorphs Discarded	82,0	18,0	0	0	0	0	0	0	300
11C029	盆河 Chahe	宣威 Xuanwei	41	6895	Greenish grey	10 g	None	Dark grey	Very few spores	38,7	59,7	0	0	0	0	0	2,0	300
11C030 11C031	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	42 46	7030 7485	Tan Light grey	10 g 10 g	None None	Light grey Brownish grey	Discarded Few spores	0	87,7	0	0	0	0	0	12,0	300
11C032	盆河 Chahe	宣威 Xuanwei	47	7680	Grey	10 g	None	Dark brown	No palynomorphs, little organic matter		·							0
11C033 11C034	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	49 52	8120 8410	Light grey Grey	10 g 10 g	None None	Tan Grey + gel	Discarded Discarded									
11C035 11C036	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	54 55	8650 8820	Grey	10 g	None None	Dark Grey	No palynomorphs	91,0 35,0	0 65,0	0	9,0	0	0	0	0	300 300
11C037	盆河 Chane 盆河 Chahe	宣威 Xuanwei	55 55	8970	Light grey Grey	10 g 10 g	None	Dark brown	No palynomorphs No palynomorphs	12,0	80,0		3,0	0	0	0	0	300
11C038 11C039	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	56 56	9175 9195	Greenish grey Dark brown	10 g	None	Grey	Discarded No palynomorphs	15,0	85,0		0	0	0	^	0	300
11C040	盆河 Chahe	宣威 Xuanwei	56	9280	Brownish grey	10 g 10 g	None None	Dark Dark brown	No palynomorphs No palynomorphs	15,0 75,7	18,0	0		3,3	0	0	0	300
11C041 11C042	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	59 60	9745 10080	Grey	10 g 10 g	None None	Grey Grey + gel	Some fungal hyphes Very few spores	0	98,0 97,0		0	2,0	0	0	0	300 300
11C042	盆河 Chahe	宣威 Xuanwei	60	10115	Grey	10 g	None	Dark grey	No palynomorphs	88,3	9,3		0	0	0	0	0	300
11C044 11C045	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	61 62	10200 10280	Light greenish grey Grey	10 g 10 g	None None	Tan white Dark grey	Discarded Some spores and possible fungal spores	61,7	11,7	8,0	0	0	18,7	0	0	300
11C046	盆河 Chahe	宣威 Xuanwei	63	10300	Grey tan	10 g	None	Grey	Discarded	01,7	11,7	0,0	Ü	Ü	10,7	O .	Ü	000
11C047 11C048	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	64 65	10330 10350	Greenish grey Grey	10 g 10 g	None None	Grey Dark grey	No palynomorphs Very few palynomorphs	62,3 24,0	37,7 70,0		2,0	0	0	0	0 4,0	300 50
11C049	盆河 Chahe	宣威 Xuanwei	65	10370	Grey	10 g	None	Grey	Discarded	24,0	70,0	J	2,0	Ü	· ·	O .	4,0	00
11C050 11C051	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	66 66	10530 10550	Light grey Grey	10 g 10 g	None None	Brownish grey Dark grey	Discarded No palynomorphs	7,7	90,3	0	0	0	2,0	0	0	300
11C052	盆河 Chahe	宣威 Xuanwei	67	10630	Grey tan	10 g	None	Grey	No palynomorphs	21,0	79,0		0	0	0	0	0	300
11C053 11C054	盆河 Chahe 盆河 Chahe		67 68	10655 10675	Grey tan Grey	10 g 10 g	None None	Grey + gel Pinkish white	Discarded Discarded									
11C055	盆河 Chahe	宣威 Xuanwei	69	10710	Grey tan	10 g	None	Brownish red	Discarded									
11C056 11C057	盆河 Chahe 盆河 Chahe	宣威 Xuanwei 宣威 Xuanwei	69 70	10750 10855	Grey tan Light grey	10 g 10 g	None None	Grey Grey	Discarded Few palynomorphs	68,9	13,3	0	0	0	0	0	18,0	45
11C058	盆河 Chahe	卡以头 Kayitou		11560	Grey	10 g	None	Light grey + gel	Discarded									
11J001 11J002	韭菜冲 Jiucaichong 韭菜冲 Jiucaichong		0	180 1055	Dark Light grey	10 g 10 g	None None	Very dark Light grey	No palynomorphs Discarded	88,0	8,0	0	0	4,0	0	0	0	300
11J003	韭菜冲 Jiucaichong		2	1065	Dark grey	10 g	None	Dark brown	Very few spores	86,0	14,0		0	0	0	0	0	300
11J004 11J005	韭菜冲 Jiucaichong 韭菜冲 Jiucaichong		5	1330 1650	Grey Grey	10 g 10 g	None None	Dark grey Grey	One spore Discarded	87,0	13,0	0	0	0	0	0	0	300
11J006	韭菜冲 Jiucaichong		7 11	2270	Dark grey	10 g	None	Dark brown	No palynomorphs	0	10,0		46,0	26,3	0	0	0	300
11J007 11J008	韭菜冲 Jiucaichong 韭菜冲 Jiucaichong		17	2795 3720	Greenish grey Grey tan	10 g 10 g	None None	Dark Dark brown	No palynomorphs No palynomorphs	87,0 55,7	13,0 44,3		0	0	0	0	0	100 300
11J009 11J010	韭菜冲 Jiucaichong 韭菜冲 Jiucaichong		21a 21b	4595 4600	Greenish grey	10 g 10 g	None None	Brown + gel Dark	Some fungal hyphes	93,0 74,3	7,0		0 2,7	0 4,0	0	0	0	300 300
11J010 11J011	韭菜冲 Jiucaichong		22	4602	Dark grey Yellow green	10 g	None	Grey + gel	Some fungal hyphes Discarded	74,3	19,0	U	2,1	4,0	U	U	U	300
11J012 11J013	韭菜冲 Jiucaichong 韭菜冲 Jiucaichong		22 23	4605 4615	Grey tan	10 g 10 g	None None	Dark brown	Some spores No palynomorphs	72,0 91,0	25,0	0	9,0	0	0	0	3,0	300 300
11Z001	哲觉 Zhejue	宣威 Xuanwei	-	-	Dark grey Dark grey	10 g	None	Dark Grey	Discarded	91,0	0	0	9,0	0	0	0	U	300
11Z002 11Z003	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	-	-	Dark grey	10 g 10 g	None None	Dark Dark brown	No palynomorphs	79,0 0	18,0 3,0		97,0	3,0	0	0	0	300 300
11Z004	哲觉 Zhejue	宣威 Xuanwei	-	-	Dark grey Grey	10 g	None	Dark grey	No palynomorphs No palynomorphs	62,0	38,0	0	0	0	0	0	0	300
11Z005 11Z006	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	-	-	Dark grey Greenish grey	10 g 10 g	None None	Dark Dark	No palynomorphs Few spores	24,0 43,7	72,0 48,3		0 2,7	0 0,7	0	0	0 4,7	300 300
11Z007	哲觉 Zhejue	宣威 Xuanwei	-	-	Dark grey	10 g	None	Dark	Few palynomorphs	50,0	36,0	0	0	0	0	0	14,0	300
11Z008 11Z009	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	27 28	70 230	Dark grey Dark	10 g 10 g	None None	Dark Dark	No palynomorphs No palynomorphs	89,3 54,0	5,7 11,0		0	0 27,3	0	0	0,3	300 300
11Z010	哲觉 Zhejue	宣威 Xuanwei	28	255	Dark grey	10 g	None	Dark	No palynomorphs	64,3	4,0	5,7	0	26,0	0	0	0	300
11Z011 11Z012	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	28 29	285 450	Dark grey Dark	10 g 10 g	None None	Dark brown Dark	Very few spores No palynomorphs	64,7 13,0	32,7 82,0		0	0	0	0	2,7	300 300
11Z013	哲觉 Zhejue	宣威 Xuanwei	30	580	Dark grey	10 g	None	Dark	No palynomorphs	55,7	43,7	0	0	0	0	0	0,7	300
11Z014 11Z015	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	30 31	590 795	Greenish grey Dark grey	10 g 10 g	None None	Dark Dark	No palynomorphs Very few spores	19,0 6,0	81,0 92,7		0	0	0	0	0 1,3	300 300
11Z016	哲觉 Zhejue	宣威 Xuanwei	31	805	Dark grey	10 g	None	Dark	Very few spores	57,0	24,7	7,0	0	11,0	0	0	0,3	300
11Z017 11Z018	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	32 32	900 920	Dark grey Dark	10 g 10 g	None None	Dark Dark	Very few spores No palynomorphs	43,7 6,3	54,7 84,7			0	0	0	1,7 0	300 300
11Z019	哲觉 Zhejue	宣威 Xuanwei	32	960	Dark grey	10 g	None	Dark	No palynomorphs	4,3	95,7			0	0	0	0	300
11Z020 11Z021	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	33 34	1230 1300	Grey Greenish grey	10 g 10 g	None None	Grey + gel Grey + gel	Discarded No palynomorphs	49,0	51,0	0	0	0	0	0	0	300
11Z022	哲觉 Zhejue	宣威 Xuanwei	37	1550	Grey	10 g	None	Grey	No palynomorphs	25,7	74,3	0	0	0	0	0	0	300
11Z023 11Z024	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	37 39	1565 1655	Dark Grey tan	10 g 10 g	None None	Dark Brownish grey	No palynomorphs No palynomorphs	34,0 67,3	57,0 32,7		0	9,0	0	0	0	300 300
11Z025	哲觉 Zhejue	宣威 Xuanwei	47	2480	Grey tan	10 g	None	Brownish grey	Very few spores	4,3	86,7	7,3	1,7	0	0	0	0	300
11Z026 11Z027	哲觉 Zhejue 哲觉 Zhejue	宣威 Xuanwei 宣威 Xuanwei	49a 49b	2505 2520	Pinkish grey Tan	10 g 10 g	None None	Dark brownish red Tan pink	Some fungal spores Discarded	7,3	92,3	0	0	0	0	0	0	300
11M001	密德 Mide	宣威 Xuanwei	0	5	Grey	10 g	None	Light grey	Discarded									
11M002 11M003	密德 Mide 密德 Mide	宣威 Xuanwei 宣威 Xuanwei	1 2	20 45	Dark Grey	10 g 10 g	None None	Dark brown Dark brown	Fungal spores and acritarchs No palynomorphs, possible foram	14,1 90,7	43,6 3,3		21,8	17,9 6,0	3,0	0	0	300 300
11M004	密德 Mide	宣威 Xuanwei	3	60	Dark	10 g	None	Dark	Fungal spores	13,0	7,0		0	0	0	0	0	300
11M005 11M006	密德 Mide 密德 Mide	宣威 Xuanwei 宣威 Xuanwei	5 6	130 160	Yellow green Yellow tan	10 g 10 g	None None	Grey Tan	Discarded Discarded									
11M007	密德 Mide	宣威 Xuanwei	7	180	Yellow tan	10 g	None	Tan	Discarded									
11M008 11M009	密德 Mide 密德 Mide	宣威 Xuanwei 卡以头 Kayitou	13 18	410 485	Grey tan Yellow green	10 g 10 g	None None	Light brown Grey	Discarded Discarded									
11M010	密德 Mide	卡以头 Kayitou	19	505	Light brown	10 g	None	Brown	No palynomorphs	85,0	9,7		0	0	0	0	0	300
11M011	密德 Mide 密德 Mide	卡以头 Kayitou 卡以头 Kayitou		670 805	Grey tan Yellow green		None None	Grey + gel Grey + gel	No palynomorphs Discarded	94,7	5,3	0	0	0	0	0	0	300
11M012	H ING TITLIGE					_	None	Light brown + gel	Discarded									
11M013	密德 Mide	卡以头 Kayitou		1100	Grey tan	_	N.I.		Discount									
		卡以头 Kayitou 卡以头 Kayitou 卡以头 Kayitou	25	1380 1600	Yellow green Greenish grey	10 g	None None	Grey + gel Grey + gel	Discarded Discarded									
11M013 11M014	密德 Mide 密德 Mide	卡以头 Kayitou	25 26 27	1380	Yellow green	10 g 10 g 10 g												

