PALAEOWORLD Editorial Office
State Key Laboratory of Palaeobiology and Stratigraphy
Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences
Beijingdonglu 39, 210008 Nanjing, PR China
e-mail: palaeoworld@nigpas.ac.cn

PALAEOWORLD online submission:
http://ees.elsevier.com/palwor/

PALAEOWORLD full-text (Volume 15 –) available at:
http://www.sciencedirect.com/science/journal/1871174X

Permian Stratigraphy, Environments and Resources, v. 2
***Palaeo*world**, *No. 9*, pp. 147-152
Jin *et al.* (Eds)

MICROSTRATIGRAPHY OF PERMO -TRIASSIC TRANSITIONAL SEQUENCE OF THE MEISHAN SECTION, ZHEJIANG , CHINA

Cao Changqun, Shang Qinghua
Nanjing Institute of Geology and Palaeontology, Nanjing 210008, China

Abstract: New observations confirm that the Permo-Triassic transitional sequence in Meishan is rather condensed and discontinuities occur within Bed 26 as early lithified surfaces. These discontinuity surfaces, the appearance of *Hindeodus parvus* and the rapid shift in $\delta^{13}C$ values within Bed 27 represent significant environmental changes during the Permo-Triassic transitional interval.

Keywords: Permo -Triassic, discontinuity, Meishan

INTRODUCTION

The Meishan Section is one of the most promising candidates for the global stratotype of the Permian-Triassic boundary. In view of the precise biostratigraphic constrains, a 28 cm thick sequence consisting of Beds 25, 26 and 27 at this section has been the subject of recent studies on defining the GSSP for the Erathem boundary and on the end-Permian Mass Extinction. Yin *et al.* (1996) formally proposed the first appearance of *Hindeodus parvus* between Bed 27c and Bed27b at Section D of Meishan as the "golden spike" of the Permian-Triassic boundary. Extensive studies of the stratigraphic ranges of fossils from the Meishan sections reveals the elimination of 280 of 329 species (85%) of marine invertebrates, that is, a rapid extinction of Permian faunas (Yin *et al.*, 1996). Carbon isotopic analysis documented a negative excursion of $\delta^{13}C$ value from +2 to -1 or less with a recovery to 0 by the first occurrence of *Hindeodus parvus* at the base of bed 27c (Xu *et al.*, 1993). And the isotopic age of the clay beds above and below the sequences were precisely dated as 251.4 Ma and 250.7 Ma respectively (Bowring *et al.*, 1998). These facts have served as a catalyst for geoscientists in developing various versions of the pattern and causes of the end-Permian Mass Extinction. However, this growing interesting in the boundary has not been matched by corresponding sedimentary studies. Knowledge of the sedimentary characters of this sequence are relatively few and thus many of proposed explanations have been made on the assumption that sedimentation within this sequence is fairly continuous and each bed is intraformationally uniform in deposition though the isotopic dating demonstrated it was not the case (Bowring *et al.*, 1998).

In order to update the sedimentary and isotopic geochemistry record of this sequence, we examined the outcrops in all quarries at Meishan. Particularly detailed work was done on Section A, B and the eponymous section of the Changhsing Limestone where the outcrops are fresh; exposures at the D Section of Meishan are rather weathered. To investigate trace fossils and sedimentary structures, as well as for pinpointing samples for isotopic analysis, a vertical column consisting of polished block samples from Bed 24 to 28 was prepared. By means of thin sections, microscopic examination was made on rock composition and sedimentary textures. Our new observations confirm that the Permo-Triassic transitional sequence in Meishan is rather condensed as previously suggested (Jin *et al.*, 1994a). Moreover, discontinuities occur not only beneath Bed 25 as a ferriferous crust upon a hardground but also within Bed 27 as early lithified surfaces. These discontinuity surfaces, the appearance of *Hindeodus parvus* and the rapid shift in $\delta^{13}C$ values between Bed 27b and 27c may provide insights into the environmental changes during the critical Permo-Triassic transitional interval.

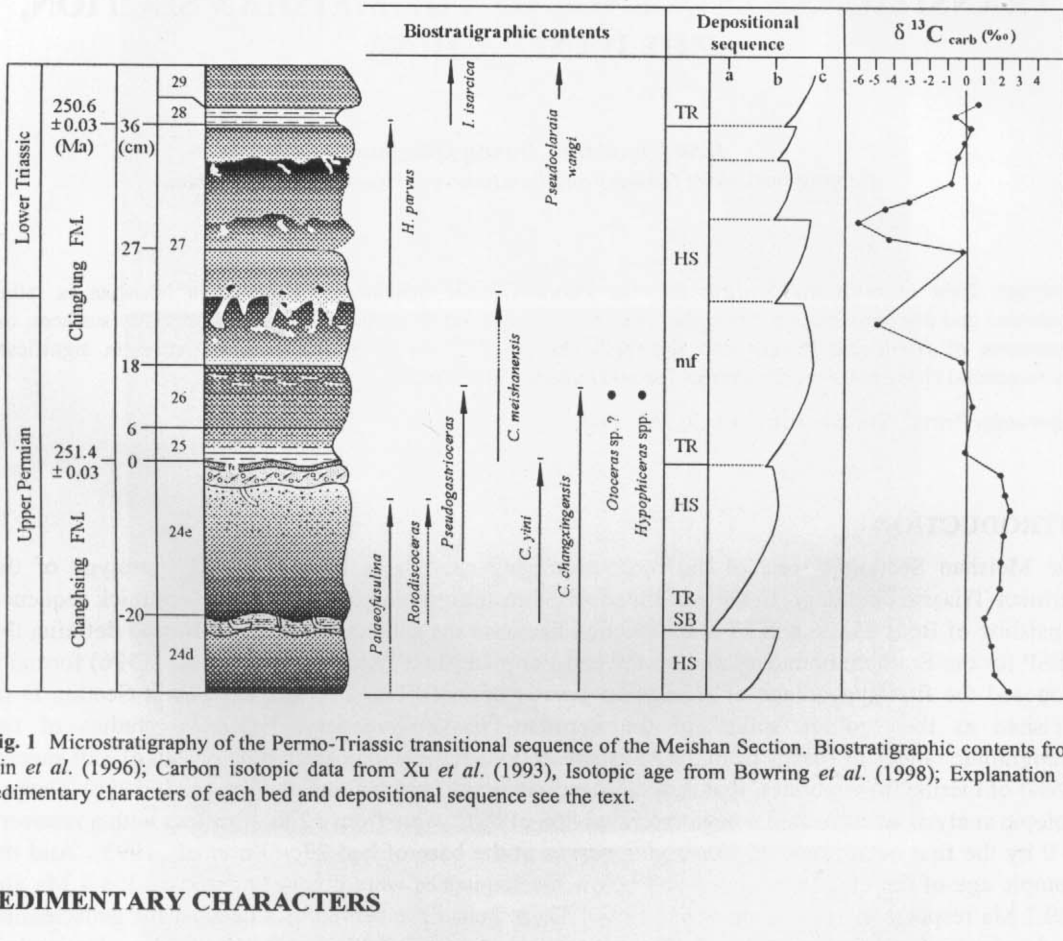

Fig. 1 Microstratigraphy of the Permo-Triassic transitional sequence of the Meishan Section. Biostratigraphic contents from Yin *et al.* (1996); Carbon isotopic data from Xu *et al.* (1993), Isotopic age from Bowring *et al.* (1998); Explanation of sedimentary characters of each bed and depositional sequence see the text.

SEDIMENTARY CHARACTERS

Towards the end of the Changhsingian, a regression - transgression change occurred in the shelf area in South China, and caused a widespread boundary surface of third order sequences. This surface becomes less distinct in slope ramp sequence such as the Meishan areas. Zhang *et al.* (1996) places the corresponding boundary surface between Bed 24d and 24 e of the Meishan Section, which is 20 cm below the top surface of the Changhsingian age limestone. Zhang bases this conclusion on the occurrence of a wavy bed surface with fillings of abraded bio-clastics in inter-wave depressions, and discontinuous microfacies. He suggested that short-term subareal exposure might have occurred. We found abundant trace fossils at the top surface of Bed 24d. They are mostly *Planolites, Skolithos* and a dry crack-like structure. This assemblage of trace fossils characterises the intertidal Permian argillaceous carbonate facies in South China and thus, may serve as evidence of a short-term exposure around the suggested sequences boundary. Appearance of the scours filled by muddy laminae and a small amount of terrigenous clastics that seldom in other parts of the Changhsing Formation, is consistent with the identification of a sequence boundary.

Bed 24 e The topmost 20 cm thick limestone of the Changhsing Formation usually consists of three natural beds, and the thickness of each bed is not consistent in all sections. It is composed of lime mudstone without terrigenous sediments and coarsens upward into the fine-grained calcarenite at the very top level. Pyrite crystals are rich in the top horizon. The uneven top surface is always capped by several muddy laminae. Cylindrical, straight, vertical burrows, ranging from 0.1 to 0.5 cm in diameter and from 3.0 to 1.0 cm in length occur in the lateral margin of the upper natural bed. Occurrence of borings and burrowings indicate that this bed was temporarily exposed on the sea floor. The conodonts from Bed 24e form the *Clarkina yini* Zone (Mei *et al.*, 1998), which is distinct from the underlying *Clarkina changxingensis* Zone.

Above the muddy laminae of Bed 24e is a sharp contact to the overlying flaggy bed of sponge spicules. This bed, about 1 cm in thickness, is laterally extensive. The dominance of monotonous siliceous sponge spicules suggests that these biogenic fragments were laid down in quiet but rather restricted environment and so, represent the final part of a regressive sequence. The spicular rock is usually encrusted by a thin ferriferous layer that may be up to 0.5 cm in thickness. It used to be regarded as weathered residues of pyrite bands, but is more likely a ferriferous precipitate layer resulting from fraction leaching during the diagenetic reorganization of volcanic ash. This surface, which might coincide with a regional subsidence, represents a basal boundary of a parasequence incorporating Beds 25, 26 and 27.

Bed 25 is the lower horizon of a non-laminated clay bed. It is usually pale in colour in weathered outcrops and consequently, is commonly called as "the White Clay Bed". Its thickness ranges from 2 cm to 7cm depending on the weathering intensity, the higher the intensity the thicker the bed. The bed grades upward into Bed 26 as a consequence of gradually increasing of organic and calcareous content. The total thickness of these two beds is around 12 cm. No fresh rock sample of Bed 25, usually dark in colour, has been obtained as it is often deeply weathered. This bed is composed of illite-montmorillonite, an alternated ash clay. Benthic carbonate skeletal fossils diminished dramatically at this point in the section. Fossils of conodonts, foraminifers, ostracods and tiny brachiopods have been found from this bed but are always sparse. Calcareous shells are often pyritized and attached with crystals and framboidal pyrite on surface (Rui *et al.*, 1988). In the Niu-tou-shan Section, 13 km to the east of Meishan, proximal lag deposits comprising pebbles of Changhsingian limestone are found from the corresponding boundary clay bed, overlying directly the Lungtan Formation of the Wuchiapingian in age. This implies that the boundary clay records the onset of a rapid, transgression during the Permo -Triassic transitional interval.

Microsphaerules and β-type quartz crystals are most abundant in this bed comparing to the other ash clay beds (He *et al.*, 1987). It was well documented the amount of microsphaerules or/and β-type quartz crystals are always 10^2 to 10^3 times to those from the other ash clay beds of the Permo-Triassic section in Huangshi of Hubei and Shangsi of Sichuan (Gao *et al.*, 1987; Wu *et al.*, 1990). This feature is confirmed in the Permo-Triassic sections in Taojiang, Dongling and Yangou of Jiangxi Province. In the Yangou Section, rich microsphaerules occur within the carbonate rocks at a level close to the base of the *Hindeodus parvus* Zone but lacking ash clay bed (Zhu Xiangshui, pers. comm., 1998). It suggest that the boundary clay is an instantaneous deposition of acidic volcanic ash, and the extraordinary abundance can be regarded as a finger-print feature in identifying this bed and its synchronic beds in South China.

Bed 26, the so-called "Black Clay Bed", is a laminated calcareous claystone ranging from 7 to 10 cm in thickness. The clay is composed mainly of montmorillonite - illite, black but dark brown in weathered outcrops. Bioclasts are rare, microsphaerules or/and β-type quartz crystals are rich in its lower part. Small-sized trace fossils of *Planolites* are abundant on the bedding plane. Skeletal fossils are rare but highly diverse, including fish teeth, ammonoids, brachiopods and bivalves, microgastropods, ostracodes and conodonts. This bed has been named as Mixed Bed 1 (Sheng *et al.*, 1984) or the Lower Transitional Bed (Yin, 1985). Co-occurence of the Triassic *Otoceras* and the Permian *Pseudogastroceras* and *Xinodiscus* is particularly interesting. Brachiopods are small in size, thin-shelled, and include species of *Crurithyris, Neowellerella, Cathaysia, Pygmochonetes, Waagenites, Spinomarginifers* etc. Bivalves are sparse and thin-shelled. These fossils represent a brief recolonization of epifauna on the barren soft substratum of ash deposits. Most of these shell fossils are complete and well preserved regardless of the delicacy of the skeleton. The slow deposition, quiet and anoxic environment and mixed fossils of pelagic and benthic faunas suggests that the transgression reached its maximum. Conodonts from Beds 25 and 26 are included in the *Clarkina meishanensis* Zone (Zhang *et al.*, 1996). The change from Bed 26 to Bed 27 is gradual and no boundary surface can be recognised. Crystal and framboidal pyrite are concentrated in discontinued dark laminae with rich organics.

Bed 27 was described previously as grey dolomitic marl (Sheng *et al.*, 1984) or grey medium-bedded silty limestone (Yin *et al.*, 1996). This bed has been also named as Mixed Bed 2 (Sheng *et al.*, 1984) or the Upper Transitional Bed (Yin, 1985). This bed contains hardground surfaces at several levels. Microscopic examination reveals that the dark, early lithified rock comprises a minor percent of clay, rich organic shreds and may be described as an argillaceous calcalutite. Bioclastics are fairly abundant and are mostly complete shells of ostracodes, foraminifers and thin-shelled brachiopods. The remaining void of brachiopod shell cavity is filled by sparry cement. Rich organic and muddy laminae parallel to the bedding plane decrease upward from its base. The overlying pale lime mudstone contains fewer bioclastics and organic material. The contact surface between the black calcalutite and pale mudstone are essentially sharp but is gradual in places when the hard ground was disturbed by repeated borrowing. A few of cycles beginning in pale lime mudstone and grading upwards into biocalcilutite are well displayed locally (Fig. 2). The lower one occurs at a level 5 cm above the base of this bed, and is consistent over all sections in Meishan. Intensively borrowing and probably also dissolution during a period of slow deposition to nondeposition resulted in a very strong relief of the hardground surface up to 3 cm high. The hardground is partly covered by a faintly laminar black calcilutite crust that seems more resistant to weathering. Angular fragments of different sizes and very thin shell fragments derived from the underlying calcilutites are resedimented within this relief. The sharp-edged and high irregular relief at the surface of the hardground demonstrate that a solid rock was affected deep subsolution (Zankl, 1969).

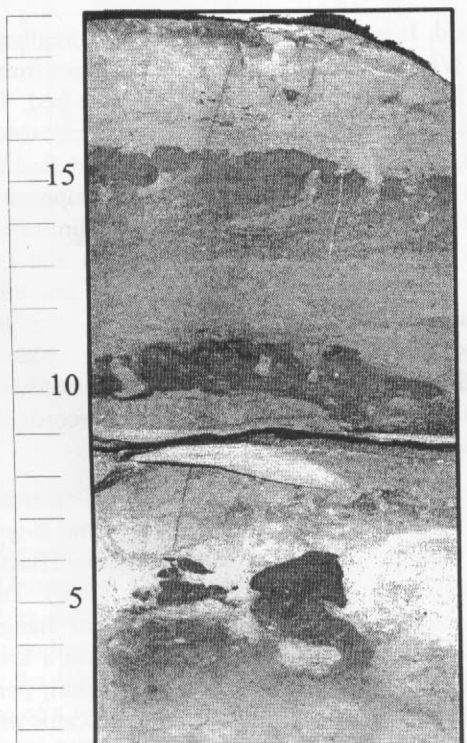

Fig. 2 Polished section of Bed 27 showing the transactions hardgrounds and bioturbation. Sample from the B Section in Meishan.

The hardgrounds occurring at the higher levels are not persistent throughout in all sections. They are composed of black calcilutite close to that forming hardground of the lower horizon. Their surface is borrowed thoroughly by *Thalassinoides*. In Bed 27, crystal or powder-crystal pyrite is disseminated in a calcilutite layer with rich organics.

It is perhaps significant that hardgrounds are mostly frequently encounted at the tops of regressive carbonate sequences but not emergence and unconformity. These hardground surfaces seem to separate regression calcilutites and transgressive mudstone phases of sedimentation. During a period of very slow carbonate sedimentation, an interruption of deposition occurred several times, followed by dissolution of an already lithified surface.

CONCLUSION

This study confirms the presence of two depositional cycles caused by repeated rapid transgressions during the Permo-Triassic interval: the initial phase represented by Bed 24e, and the second phase consisting of Bed 25, 26 and 27. Within the latter depositional cycle, Bed 27 characterizes the highstand system tract rather than the transgressive system tract (Yin and Tong, 1997), and the appearance of *Hindeodus parvus* coincides apparently with the onset of regression.

From a rapid transgression model during the Permo-Triassic interval, Jin *et al.* (1994b) predicted that this is a rather condensed sequence with nondeposition surface at the base. It was also suggested that there is a substantial time gap at the boundary based on geochronology (Roberts *et al.*, 1996) and carbon isotopes (Baud, *et al.*, 1989). Yin (1996) pointed out that the *Hindeodus parvus* Zone is limited to Bed 27c and Bed 27d, that is, an 8cm thick part of Bed 27. Compared to this zone in other sections, the stratigraphic thickness of this zone is thin and thus, indicates a slow rate of sedimentation. Repeated development of hardgrounds implies that the deposition had been rather slow, and thus had caused depositional gaps of short time-span. However, these discontinuities did not last long since all hardground surface are not coated with such authigenic minerals as phosphate and glauconite.

ACKNOWLEDGEMENTS

We acknowledge support from Chinese Academy of Science (Grant 49672092) and the National Nature Science Foundation of China (Grant K2951-B1-409). We especially wish to thank Prof. Jin Yugan for guidance and consistent encouragement, and Dr, Douglas H. Erwin for his thorough review of the manuscript.

REFERENCES

Baud A., Magaritz M. and Holser W.T., 1989. Permian-Triassic of the Tethys: Carbone isotope studies. Geologische Rundschau, **78**(2): 649-677.

Bowring S.A., Erwin D.H., Jin Yugan, Martin M.W., Davidek K. and Wang Wei., 1998. U/Pb Zircon Geochronology and Tempo of the End-Permian Mass Extinction. Science, **280**(5366): 1039 -1045.

Gao Zhenggang, Xu Daoyi, Zhang jinwen and Sun Yiyin, 1987. Discovery and study of of microsphaerules at the Permian-Triassic boundary of the Shangsi Sction, Guangyuan, Sichuan. Geological Review, **33**(30): 203-211.

He Jinwen, Run Lin and Chai Chifang, 1987. The latest Permian and earliest Triassic volcanic activities in the Meishan area of Changxing, Zhejiang. .Journal of Stratigraphy, **11**(3): 194-199.

Jin Yugan, Glenister B.R., Kotlyar C.K. and Sheng Jinzhang, 1994a. An operational scheme of Permian chronostratigraphy. Palaeoworld, **4**: 1-14 .

Jin Yugan, Zhang Jing and Shang Qinhua, 1994b. Two phases of the end-Permian Mass Extinction. Pangea: Global Environments and Resources. Canadian Society of Petroleum Geologists, Memoir, **17**: 813-821.

Mei Shilong, Zhang Kexin and Wardlaw B.R., 1998. A refined succession of Changhsingian and Griesbachian neogondolellid conodonts from the Meishan section, candidate of the global stratotype section and point of the Permian-Triassic boundary. The Permian-Triassic boundary and global Triassic correlations. Palaeogeography, Palaeoclimatology, Palaeoecology.

Renne P.R., Zhang Zichao, Richard M.A., Black M.T. and Basu A.R., 1995. Synchrony and causal relations between Permian -Triassic boundary crises and Siberian flood volcanism. Sciences, **269**: 1413-1416.

Roberts J., Claoue'-Long, Foster J.C. and Shrmp C.B., 1996. Zircon dating of the Permian System of eastern Australia. Australian J. Earth Sci., **43**: 401-421.

Rui Lin, He Jinwen; Chen Chuzhen and Wang Yigang, 1988. Discovery of fossil animals from the basal clay of the Permian-Triassic boundary in the Meishan area of Changxing, Zhejiang, and its significance. Journal of Stratigraphy, **12**(1): 48-52.

Sheng Jinzhang, Chen C.Z., Wang Y.G., Rui L., Liao Z.T., Bando Y., Ishii K., Nakazawa K. and Nakamura K., 1984. Permina-Triassic boundary in middle and eastern Tethys. Journal of the Faculty of Science, Hokkaido Univ., Ser.4, **21**(1):133-181.

Wu Shunbao, Ren Yingxin and Bi Xianmei, 1990. Volcanic material and origin of clay rock near Permo-Triassic boundary from Huangshi, Hubei and Meishan of Changxing County, Zhejiang. Earth Science, Journal of China University of Geoscience, **15**(6): 589-595.

Xu Daoyi and Yan Zhen, 1993. Carboneisotope and iridium event markers near the Permian-Triassic boundary section of Changxing, Zhejiang, southern China. Palaeogeography, Palaeoclimatology, Palaeoecology, **104**: 171-176.

Yin Hongfu, 1985. On the Transitional Bed and the Permian-Triassic boundary in South China. Newsletter on Stratigraphy, **15**(1): 13-27.

Yin Hongfu, Wu Shunbo and Ding Meihua, 1996. The Meishan Section, candidate of global stratotype section and point of Permian-Triassic boundary. In: Yin Hongfu (ed), The Palaeozoic - Mesozoic Boundary, candidates of the Global Stratotype Section and Point of the Permian-Triassic boundary, Geological Publishing House, Beijing. 127-137.

Zankl H., 1969. Structural and textural evidence of early lithification in fine grained carbonate rocks. Sedimentology, **12**(3-4): 241-256.

Zhang Kexin, Jinnan Tong, Yin Hongfu and Wu Shunbao, 1996. Sequence stratigraphy near the Permian-Triassic boundary section of Changxing, Zhejiang, southern China. In: Yin Hongfu (ed), The Palaeozoic - Mesozoic Boundary, candidates of the Global Stratotype Section and Point of the Permian-Triassic boundary, Geological Publishing House, Beijing. 72-83.