Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Asian Earth Sciences
ELSEVIER
Journal of Asian Earth Sciences 26 (2006) 575–583
www.elsevier.com/locate/jaes

The Wuchiapingian–Changhsingian boundary (Upper Permian) at Meishan of Changxing County, South China

Wang Yue[a,*], Shen Shuzhong[a], Cao Changqun[a], Wang Wei[a], Charles Henderson[b], Jin Yugan[a]

[a]*Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing, Jiangsu 210008, China*
[b]*Departments of Geology and Geophysics, University of Calgary, Calgary, Alta., Canada T2N 1N4*
Received 24 May 2004; revised 27 October 2004; accepted 6 December 2004

Abstract

Section D at Meishan, Changxing County in the Zhejiang Province, China, has been extensively studied in various aspects of the stratigraphy during the past 20 years. It was ratified by the International Union of Geological Sciences (IUGS) as the Global Standard Stratotype Section and Point (GSSP) for the Permian–Triassic boundary in 2000, and is also a potential stratotype for the Wuchiapingian–Changhsingian boundary. However, the contact relationship between the Longtan (Wuchiapingian) and Changxing (Chainghsingian) formations has been a controversial subject for years. Recent studies on Section C, about 300 m west of Section D, at Meishan confirm a complete depositional succession around the boundary and suggest that the proposed boundary level, the FAD of *Clarkina wangi* within the lineage from *C. longicuspidata* to *C. wangi,* is consistent with the first appearance of the index Changhsingian fusulinid *Palaeofusulina sinensis* and tapashanitid ammonoids.

Keywords: Changhsingian; Boundary; Meishan; Wuchiapingian

1. Introduction

The Changhsingian represents the second and last stage of the Upper Permian, which is also known as the Lopingian Series. It is officially referred to as an informal chronostratigraphic unit (Remane et al., 2000) since formal recognition of this stage boundary has not yet been presented to the International Union of Geological Sciences for ratification. Among the potential candidates for the GSSP of this boundary, Section D at Meishan appears very promising. It not only has historic priority, but is also represented by a fully developed marine sequence with highly diverse faunas and microflora.

Meishan is located between the cities of Nanjing and Shanghai in Changxing County, Zhejiang Province, SE China (Fig. 1). Stratigraphic successions of Late Paleozoic

* Corresponding author. Tel.: +86 25 83282164; fax: +86 25 83282131.
E-mail addresses: yuewang@nigpas.ac.cn (W. Yue), szshen@nigpas.ac.cn (S. Shuzhong), cqcao@public1.ptt.js.cn (C. Changqun), weiwang@

nigpas.ac.cn (W. Wei), charles.henderson@ucalgary.ca (C. Henderson), jinyugan@yahoo.com (J. Yugan).

1367-9120/$ - see front matter
doi:10.1016/j.jseaes.2004.12.003

and Early Triassic rocks are well exposed and have been extensively studied over the past 25 years. In 2000, the upper part of Section D was ratified by IUGS as the Global Standard Stratotype Section and Point for the Permian–Triassic boundary (Yin et al., 2001). The lower part of Section D has also been well studied in terms of many fossil groups (Sheng et al., 1984), magnetostratigraphy (Li and Wang, 1989), chemostratigraphy (Li, 1998), radiometric dating (Bowring et al., 1998; Mundil et al., 2001) and sequence stratigraphy (Zhang et al., 1997). In 1981, Zhao et al. (1981) proposed to formally define the base of the Changhsingian Stage at the horizon between the *Clarkina orientalis* Zone and the *C. subcarinata* Zone that is located at the base of Bed 2. They indicated that the base of this stage is also marked by the occurrence of *Palaeofusulina*, along with the tapashanitid and pseudotirolitid ammonoids. Since the well-defined faunal changes in major fossil groups such as conodonts, brachiopods, ammonoids, corals and fusulinaceans across the boundary (Jin et al., 1997) may be accentuated by the presence of a significant unconformity, effort have been made to look for a suitable boundary a little

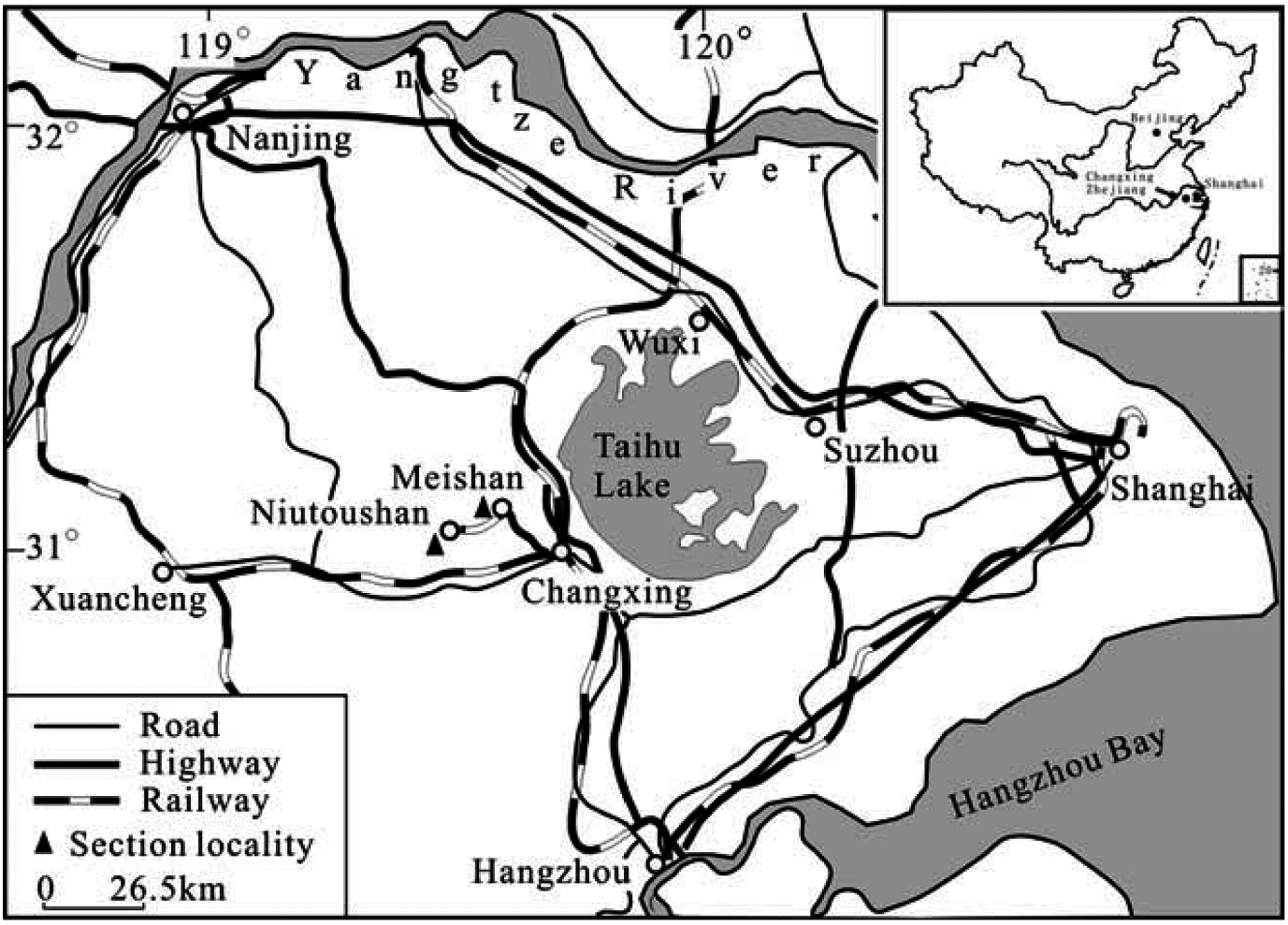


Fig. 1. Locality map of the Meishan Section in Changxing, South China.

higher in the section. Wardlaw and Mei (2000) suggested the First Appearance Datum (FAD) of *Clarkina subcarinata* as a marker for the base of the Changhsingian. Later, Mei et al. (2001a,b) found the *C. longicuspidata–C. wangi* lineage in Bed 4, and suggested the FAD of *C. wangi* in the lineage as the lower boundary of the Changhsingian, which is 88 cm above the base of the Changxing Limestone. However, this proposal was disputed by Wang et al. (2001), who believed that there is a depositional gap between the Longtan Formation and the Changxing Limestone as previously suggested by others (Zhu and Zhu, 1984).

Meishan Section C, about 300 m west of Section D, was recently excavated. Detailed studies on the lithology and palaeontology of the boundary strata provide strong evidence for a conformable succession from Wuchiapingian to Changhsingian. A complete evolutionary lineage from *Clarkina orientalis–C. longicuspidata* to *C. wangi* is confirmed at this section and the index fossils of the

Changhsingian, *Sinoceltites, Tapashanites* and *Palaeofusulina sinensis* are found around the proposed boundary level.

2. The Wuchiapingian–Changhsingian boundary succession at Section C

The outcrop of the Longtan Formation at Section D is small and obscured by faulting and poor exposures. The beds outcropping at Section C are stratigraphically lower than those at Section D. Section C is topographically low and thus, a-11 m-thick section of the Longtan Formation could be exposed (Figs. 2 and 3).

2.1. Upper Permian (Lopingian) Changxing Limestone

Bed 13 (depth, 1668–1797 cm) Grey, medium- to thick-bedded bioclastic, micritic limestone with abundant ostracods, small foraminifers and calcareous algae. Brachiopods: *Cathaysia chonetoides* Chao, *Orthothetina regularis* Huang (MSC8-3, indicating the sample number from Meishan Section C); Ammonoids: *Meekella* sp. (MSC8-3); Non-fusulinacean foraminifers: *Frondicularia*, *Geinitzina*, *Colaniella*, *Ammodiscus*, *Glomospira* (MSC8-1).

Bed 12 (depth, 1661–1668 cm) Greyish yellow, thin-bedded, silty phosphatic rock with shale bed 0.5 and 1.5 cm thick, respectively, at its top and base.

Bed 11 (depth, 1615–1661 cm) Grey, thin- to medium-bedded, siliceous sponge spicules-bearing, bioclastic micritic limestone with siliceous bandings, with muddy wavy bedding. Bioclasts contain small foraminifers, siliceous sponge spicules, gastropods and a few echinoderms. Conodonts: *Clarkina wangi* (Zhang), *C. wangi-subcarinata* transitional form (MSC6-4); Non-fusulinacean foraminifers: *Geinitzina, Colaniella, Frondicularia, Nodosaria* (MSC6-4).

Bed 10 (depth, 1594–1615 cm) White medium-bedded carbonized tuff.

Bed 9 (depth, 1540–1594 cm) Grey, thin- to medium-bedded, bioclastic, micritic limestone with horizontal laminae. It contains bioclasts of ostracods, small foraminifers, fish bones, siliceous sponge spicules, other spicules and intraclasts. Brachiopods: *Araxathyris* sp., *Meekella* sp., *Cathaysia chonetoides* Chao, *Neochonetes* sp. (MSC6-2); Conodonts: *Clarkina wangi* (Zhang) (MSC6-1, 2); Fusulinacean: *Reichilina* sp., *Nankinella* sp. (MSC6-1); Non-fusulinacean foraminifers: *Geinitzina, Colaniella, Ammodiscus* (MSC6-1, 2), *Glomospira, Frondicularia* (MSC6-2).

Bed 8 (depth, 1287–1540 cm) Alternative beds of dark, thin- to medium-bedded, bioclastic micritic limestone with laminated chert bands forming five cycles; horizontal bedding; bioclastics comprising fragments of foraminifers, brachiopods, ostracods, sponge spicules, calcareous algae, fish bones, gastropods and echinoderms, usually oriented. Brachiopods: *Cathaysia chonetoides* Chao (MSC5-4, 12, 13, 14); *Araxathyris* sp. (MSC5-14); Conodonts: *Clarkina wangi* (Zhang) (MSC5-9, 13, 14); Ammonoids: *Sinoceltites* sp., *Tapashanites* sp. (MSC5-4); Fusulinaceans: *Reichilina media, R. changhsingensis* (MSC5-4), *R. pulchra* MaClay, *R.* sp. (MSC5-4, 13), *Staffella* sp. (MSC5-4), *Palaeofusulina simplex* Sheng and Chang (MSC5-4, 13); Non-fusulinacean foraminifers: *Geinitzina* (MSC5-4, 14), *Ammodiscus*, *Glomospira*, *Colaniella* (MSC5-4, 13), *Hemigordius* (MSC5-13).

Bed 7 (depth, 1217–1287 cm) Dark grey, medium-bedded biomicritic limestone with muddy horizontal laminae. Bioclasts are mainly composed of sponge spicules in the upper part and abundant ostracods, small foraminifers and sponge spicules in the remaining parts. Brachiopods: *Araxathyris* sp., *Orthothetina* sp., *Neochonetes* sp. (MSC5-1); *Cathaysia chonetoides* (Chao) (MSC5-1,2);

Spinomarginifera lopingensis (Kayser) (MSC5-3); Ammonoids: *Sinoceltites* sp. (MSC5-1); *Pseudogastrioceras* sp. (MSC5-3); Conodonts: *Clarkina longicuspidata* Mei and Wardlaw, *C. longicuspidata-wangi* transitional form, *C. orientalis* Barskov and Koroleva (MSC5-1); *C. wangi* Zhang (MSC5-1, 3); Fusulinaceans: *Palaeofusulina* cf.

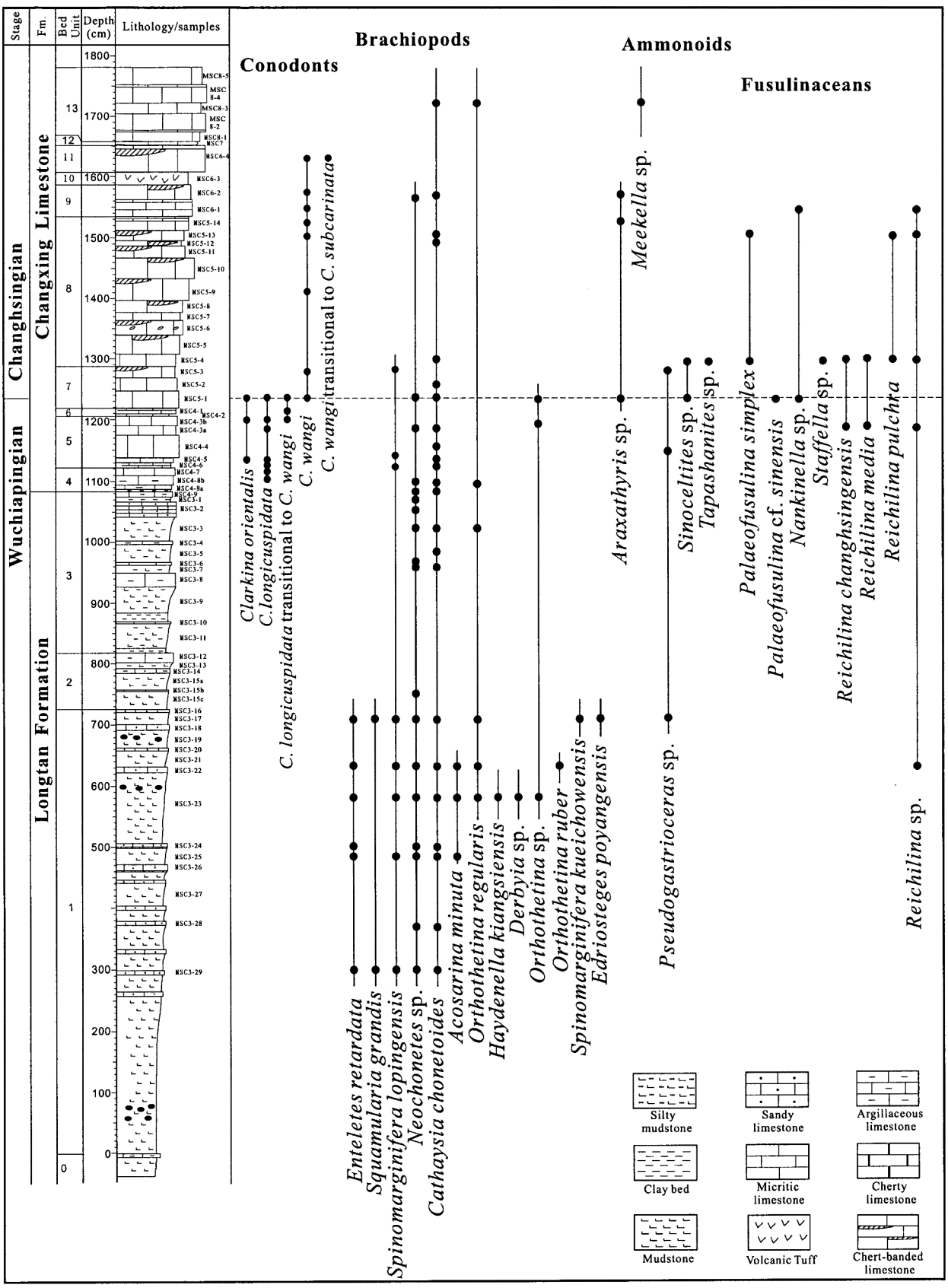


Fig. 2. Fossil occurrences at Section C in Meishan, Changxing, Zhejiang.

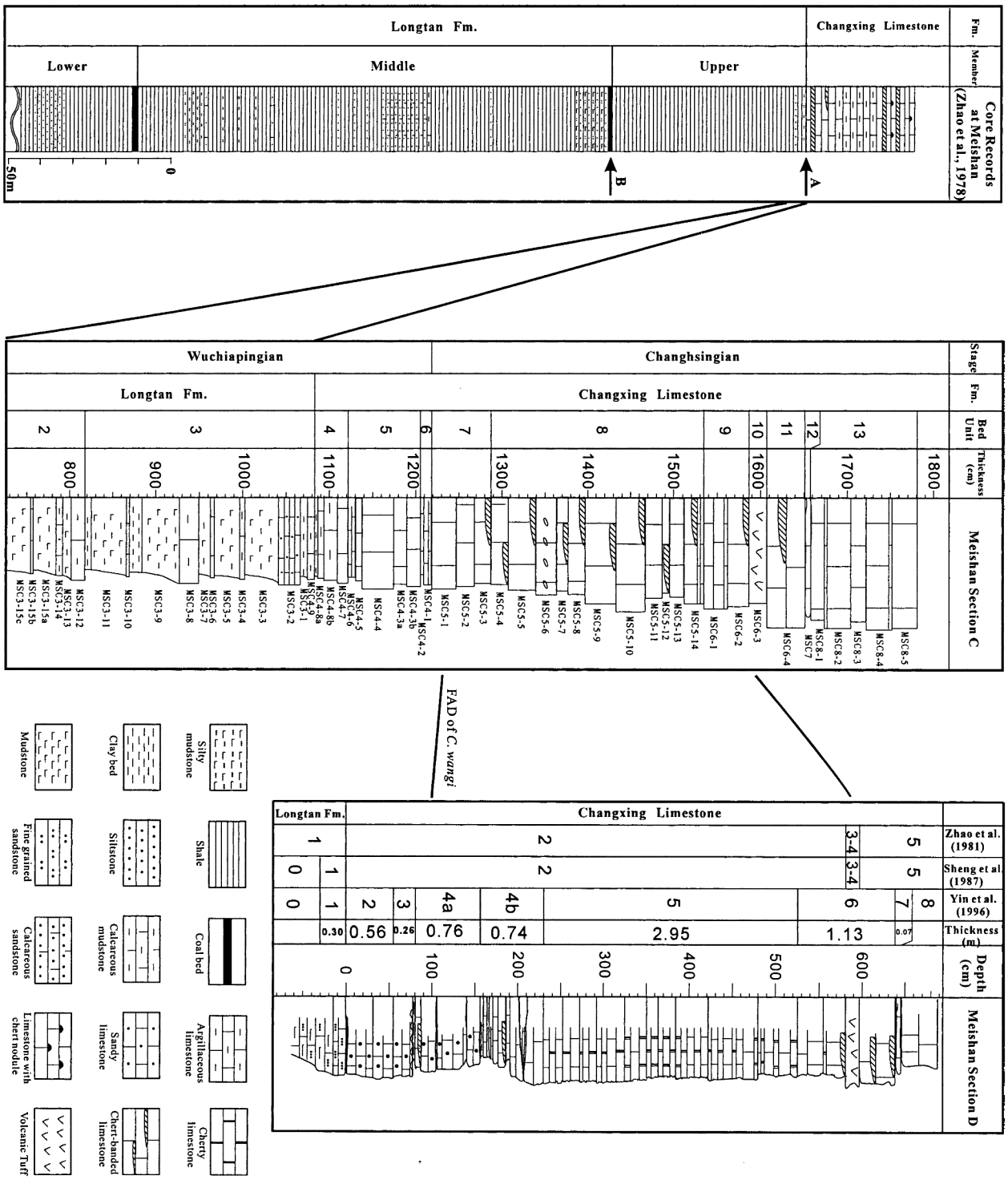


Fig. 3. Stratigraphic correlation of the Meishan sections. Arrow A indicates the sequence boundary defined by Zhang et al. (1997). Arrow B indicates the sequence boundary between the middle and upper parts of the Longtan Formation.

sinensis Sheng, *Nankinella* sp. (MSC5-1); Non-fusulinacean foraminifers: *Climmacommina* (MSC5-1), *Nodosaria*, *Glomospira*, *Frondicularia, Colaniella* (MSC5-1, 2), *Geinitzina* (MSC5-1, 2, 3).

Bed 6 (depth, 1203–1217 cm) Black cherty and rich organic shale, laminated, containing quartz silt, bioclastic, mica and chert grains, with 3 cm thick clay bed at the bottom. Conodonts: *Clarkina longicuspidata-wangi* transitional form (MSC 4-1).

Bed 5 (depth, 1118–1203 cm) Black, thin- to medium-bedded and laminated biomicritic limestone containing debris of foraminifers, ostracods, calcareous spicules,

brachiopods and enchinodermates. Partly dolomitized. Brachiopods: *Neochonetes* sp. (MSC4-3a); *Orthothetina* sp. (MSC4-3b), *Spinomarginifera lopingensis* (MSC4-5, 6), *Cathaysia chonetoides* (MSC4-3a, 4, 5, 6); Ammonoids: *Pseudogastrioceras* sp. (MSC 4-4); Conodonts: *Clarkina longicuspidata* Mei and Wardlaw (MSC4-3a, 3b, 5, 6); *C. orientalis* Barskov and Koroleva (MSC4-3b, 5);

C. longicuspidata-wangi transitional form (MSC4-3b); Fusulinaceans: *Reichilina changhsingensis* Sheng and Chang, *R. media* K.M. MaClay, *R.* sp. (MSC4-3b); Non-fusulinacean foraminifers: *Dagmarita, Hemigordius* (MSC4-3), *Colaniella*, (MSC4-3, 5) *Frondicularia*, *Nodosaria* (MSC4-3, 5, 6), *Glomospira, Geinitzina* (MSC4-3, 4, 5, 6).

Bed 4 (depth, 1079–1118 cm) Dark marl with horizontal laminae, containing intra-clasts, sand grains, and fragments of ostracods, sponge spicules, foraminifers, fish bones and other biogenic debris; thin clay bed ranging from 2 to 10 cm in thickness occurring between marl beds at the bottom of this bed. Brachiopods: *Cathaysia chonetoides* (Chao), *Neochonetes* sp. (MSC4-8a, b), *Orthothetina regularis* Huang (MSC 4–8a); Conodonts: *Clarkina longicuspidata* Mei and Wardlaw (MSC4–8b, 4–7).

2.2. Upper Permian (Lopingian) Longtan Formation

Bed 3 (depth, 824–1079 cm) Alternating beds of grey mudstone and earthy yellow, thin beds of calcareous siltstone or silty limestone consisting of six cycles. From the corresponding part of Bed 0 of Section D, Zhao et al. (1981) reported *Orbiculoidea minuta* Liao, *Orthotichia* sp., *Paryphella gouwaensis* Liao, *Spinomarginifera lopingensis* (Kayser), *S. kuichowensis alpha* Huang, *Streptorhynchus* sp. (ACT 32). New collections include brachiopods: *Neochonetes* sp. (MSC3-1, 2, 3, 6, 7, 4–9), *Cathaysia chonetoides* (MSC3-3, 5, 7), *Orthothetina regularis* (MSC3-3)

Bed 2 (depth, 730–824 cm) Grey mudstone intercalated with greenish grey, thin dolomitic sandstone or sandy dolomite forming three cycles.

Bed 1 (depth, 0–730 cm) Greenish-grey or earthy yellow mudstone intercalated with thin beds of siltstone that contain abundant brachiopods and a few ammonoids.

Ammonoid: *Pseudogastrioceras* sp. (MSC 3-17); Brachiopods: *Squamularia grandis* (MSC3-17, 29), *Enteletes retardate* (MSC3-17, 22, 23, 24, 25, 29), *Cathaysia chonetoides* (MSC3-17, 22, 23, 24, 25, 28, 29), *Orthothetina regularis* (MSC3-17, 22, 23), *Spinomarginifera lopingensis* (MSC3-17, 22, 23, 25, 29), *S. kueichowensis* Huang (MSC3-17), *Neochonetes* sp. (MSC3-17, 22, 23, 24, 25, 28, 29), *Edriosteges poyangensis* (MSC3-17), *Orthothetina rubber, Acosarina minuta,* (MSC3-22, 23, 25), *Derbyia* sp., *Haydenella kiangsiensis*, *Orthothetina* sp. (MSC3-23); Fusulinaceans: *Reichilina* sp. (MSC3-22); Non-fusulinacean foraminifers: *Glomospira*, *Ammodiscus*, *Geinitzina*, *Dagmarita*, *Colaniella*, *Nodosaria* (MSC3-22); *Colaniella* sp. (MSC3-22).

3. Correlation of Section C and D at Meishan

The stratigraphic succession around the Wuchiapingian–Changhsingian boundary of Section C and Section D can be precisely correlated based on the general trend of lithological changes, characteristic beds and fossil occurrences (Fig. 3). The lower part of the Changhsingian in both sections is made up of dark grey limestones intercalated with thin-bedded chert bands, and characterized by distinct laminations. The top part of the Longtan Formation is mainly composed of calcareous siltstone with abundant brachiopods. These provide a general control for lithological correlation between the two sections. Furthermore, Bed 10 of Section C is a distinct 19 cm thick layer of carbonized tuff. Its equivalent appears in the upper part of Bed 6 of Section D. At Section D, the FAD of *C. wangi* within the conodont lineage of *Clarkina longicuspidata–C. wangi* is at the base of Bed 4. At Section C, this lineage occurs from bed 4 to bed 7 with the FAD of *C. wangi* at the base of Bed 7.

4. Depositional sequence around the Wuchiapingian–

Changhsingian boundary

It has long been recognized that there is an apparent conformable contact between the Longtan Formation and its overlying Changxing Limestone (Sheng, 1962; Zhao et al., 1981). Wang (1965), however, reported an unconformity at the base of the Changxing Limestone at Dushan in southern Anhui Province, some 20 km to the southwest of Meishan (Fig. 1). The thickness of the Changxing Limestone decreased from 37.5 m at Meishan to 13.1 m at Dushan. In addition, the core record of the wells near Dushan shows a basal conglomerate about 10–25 cm thick at the base of the Changxing Limestone. A layer of limonite about 10–15 cm thick was also discovered between the Longtan sandstone and Changxing Limestone. Zhu and Zhu (1984) suggested the lack of Lower Changhsingian strata as the result of the 'Dongnan Movement' (Yan et al., 1964), which stands for a regional elevation. Later, Zhu (1986) reported the basal conglomerate and limonite layer at Meishan, and made further claims for an uncomformity between the Longtan and Changxing formations.

The generalized stratigraphic succession of the Longtan Formation from core records of all wells in Meishan (Zhao et al., 1978), as well as the core-records from the wells near Section D and C (CK 818 and CK658), shows that this formation, some 300 m thick, represents a transgressive sequence with a brief regression between the middle and upper parts (Fig. 3). The lower part is about 90 m thick, consists of coarse sandstone, siltstone and bauxitic clay beds with fossils of roots and stems, and includes mineable coal seams. Plant fossils from bauxitic clay beds include *Gigantopteris nicotianaefolia* Schenk, *Protoblechnum wongi* Halle, *Taeniopteris norinii* Halle, and *Pecopteris* sp. The middle part, 150 m thick, is composed of alternating

beds of fine grained sandstone and sandy siltstone. It contains three one-meter thick sandy limestone beds containing abundant brachiopods, corals and the fusulinid *Chenella* sp. This part is topped by coal-bearing deposits 12 m thick, which comprise alternating beds of fine grained sandstone with cross bedding and silty mudstone containing fragmental plant fossils. The upper part, 60 m in thickness, comprises mudstone intercalated with fine grained sandstone. Fossils of ammonoids Araxoceratidae gen. et sp. indet., *Pseudogastrioceras* sp.; bivalves *Palaeoneilo sunanensis* Liu, *P.* cf. *leiyangensis* Liu, *Pernopecten* sp., *Schizodous* cf. *dubiiformis* Waagen; brachiopods *Anidanthus* cf. *sinosus* (Huang), *Acosarina* sp., *Cathaysia chonetoides* (Chao), *Crurithyris* sp., *Prelissorhychia* sp. have been reported from the uppermost 4 m thick bed. Ammonoids *Pseudogastrioceras* sp., *Jinjiangoceras* and *Konglingites* sp. were recorded from this part. The sedimentary and fossil features indicate a gradually deepening trend from coastal swamp, through shallow and finally deeper shelf with brief swamp deposition between the middle and upper parts. The maximum regression during the Wuchiapingian Stage occurs within the middle part of the formation, which is represented by widespread limestone beds overlying the mineable coal seams.

Transgressive deposits (fine cherty siliciclastics) of the Talung, the basal Changxing Limestone, and upper Longtan Formation overlie this maximum regression surface within the Longtan Formation, presumably with an unconformable contact. However, the extent of this unconformity is uncertain. Regionally, the boundary between the Longtan Formation and the Changxing Limestone is regarded as a sequence boundary (Zhang et al., 1997). In Sections C and D at Meishan, however, this boundary is represented by a smooth transition from calcareous mudstone beds that increase in thickness upward to thick-bedded bioclastic

limestone. It seems more appropriate to place the sequence boundary at the top of the middle part of the Longtan Formation because the 12 m thick, fine-grained sandstone and sandy mudstone interval is characterized by coastal facies features such as cross bedding, coal seams and plant fossils. The exposure at the Meishan D section contains only the uppermost part of the Longtan Formation (Fig. 3). These beds include earthy yellow, calcareous siltstone and mudstone with horizontal beddings that contain ammonoids and brachiopods (Yin et al., 1996). This part in Section C extends downward for nearly 11 m and appears to be conformable with the overlying Changxing Limestone. It may represent the first transgressive cycle above the unconformity in the middle to upper Longtan Formation. The lowest bed of the Changxing Limestone at Section D and Section C, which is represented by dark grey, thick-bedded silty wackestone, appears to form the upper part of a cycle or parasequence.

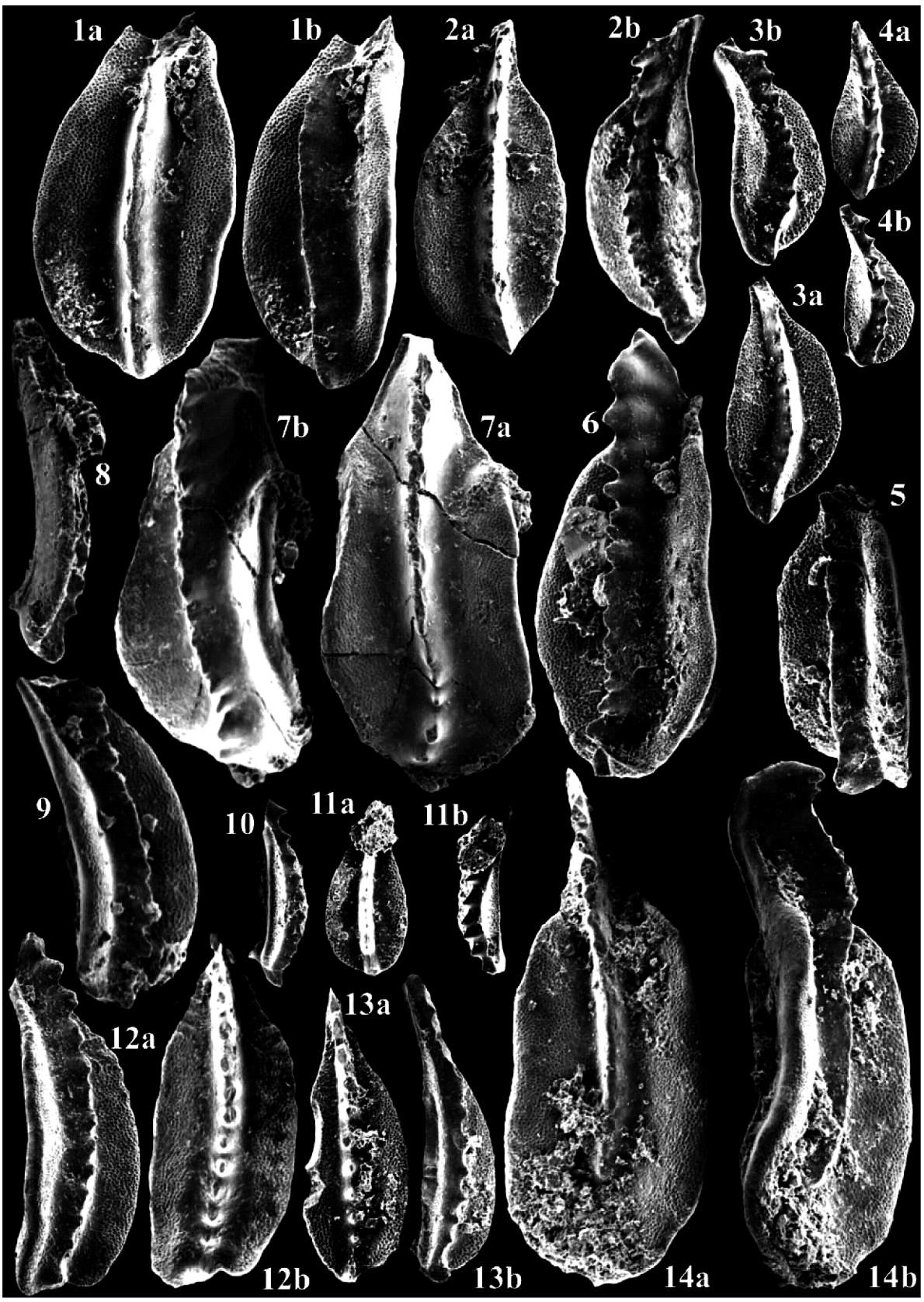
A close observation indicates that no basal conglomerate exists at the newly excavated Section C. There are only cm-scale lenses of clasts at the basal part of the Changxing Formation. The size of clasts is less than 5 cm. The clasts are brecciated, mostly lime mudstone with some brachiopod fragments, and commonly show normal grading. They were previously reported as conglomerate beds but are actually intra-clast deposits generated by storms. The montmorillonite clay beds can be seen from the topmost part of the Longtan Formation. However, these thin beds can not be referred to as clay of the eluvial facies because these beds always form the top part of the cycles from siltstone, mudstone to clay. A correlation between the Changxing Formation at Meishan and its neighboring sites shows that this lithostratigraphic unit represents a carbonate wedge of slope facies, which gradually overlapped the Longtan Formation of marginal facies southward (Yang et al.,

1993). The tectonically derived unconformity between the Changxing and Longtan formations that had been previously suggested can be rejected.

5. Fossil succession

The fossils from Section C are highly diverse and include brachiopods, ammonoids, conodonts, fusulinids, small foraminifers, fish remains, spores and pollen. Among them, brachiopods are the most abundant fossils around the boundary between the Changxing Formation and the Longtan Formation. More than 1300 brachiopod specimens were collected, including 15 species of 12 genera. As shown in Fig. 2, brachiopods are very abundant and diverse in the uppermost part of the Longtan Formation and are dominated by many common Lopingian species. *Spinomarginifera lopingensis, Edriosteges poyangensis, Orthothetina ruber* and *Squamularia grandis* are the most common species in the late Wuchiapingian in South China (Liao, 1979; Shen and Shi, 1996). *Cathaysia chonetoides, Haydenella kiangsiensis* and *Orthothetina regularis* are very abundant in the entire Lopingian in South China. Above Bed 1 at Section C, brachiopods remain very abundant, but are less diverse. Some species with relatively large shells such as *Squamularia grandis, Edriosteges poyangensis, Enteletes retardata* disappeared at the top of Bed 1. Only a few small brachiopods, including the tiny *Neochonetes* sp. and *Cathaysia chonetoides,* remain present in the topmost bed (Bed 2) of the Longtan Formation and in the lowest part of the Changxing Formation (Sample MSC3-8). According to Liao (1980), two lithofacies can be largely recognized from the Lopingian sequences in South China. The silciclastic facies usually contains small, thin-shelled brachiopods which suggest a relatively deep-water environment. On the other hand, the carbonate- and clastic facies usually

contains large, thick-shelled, diverse brachiopods which roughly indicate a shallow environment. Therefore, this change in brachiopod composition in view of the brachiopod size may indicate upward deepening from the upper part of the Longtan Formation to the lower part of the Changxing Formation.



The base of the Changhsingian Stage is suggested to be defined by the FAD of *Clarkina wangi* within the lineage

from *C. longicuspidata* to *C. wangi* at the base of Bed 4a-2 at Meishan Section D (Mei et al., 2001b). The transition from *Clarkina longicuspidata* to *Clarkina wangi* was clearly present at Meishan C (Fig. 4). As shown in Fig. 2, *Clarkina longicuspidata* is recognized from Bed 4 to Bed 7, specimens of *C. longicuspidata* transitional to *C. wangi* occur from Bed 5 to Bed 7, and *C. wangi* occurs from Bed 7 to Bed 11 in the section. The FAD of *Clarkina wangi* occurs 1.35 m above the base of the Changxing Limestone at Section C and 0.88 m above the base at Section D. The difference in thickness may reflect differential weathering as much as any lateral facies changes, given that the exposure at section C is so fresh.

The appearance of the tapashanitid and pseudotirolitid forms marks a turning point of phylogenetic development of Lopingian ammonoid faunas. The lowest occurrence of the tapashanitid *Sinoceltites* in Section C coincides with the FAD of *Clarkina wangi*, the indicative conodont species of the Changhsingian basal boundary. The other tapashanitid *Tapashanites* first appear 42 cm above the proposed boundary.

The Changhsingian fusulinid fauna is characterized by a dominance of *Palaeofusulina*. The Wuchiapingian–Changhsingian boundary in the carbonate successions of South China was previously defined by the appearance of Changhsingian fusulinid *Paleofusulina* and *Gallowayinella* (Rui and Sheng, 1981). The genus *Gallowayinella* may extend downward into the uppermost Wuchiapingian because it has been reported in association with *Clarkina orientalis* (Wang et al., 1997). In Section D, the primitive form such as *Palaeofusulina minima* Sheng occurs immediately above the boundary. More advanced forms such as *P. sinensis* do not appear until the Late Changhsingian. In Section C, the advanced form *P.* cf. *sinensis* occurs in the same level with the first tapashanitid ammonoid genus

Sinoceltites and the first *Clarkina wangi*. Among the others, *Reichelina changhsingensis* Sheng and Chang and *R. pulchra* Maclay, which occur at first in Bed 4a in Section D, are both characteristic forms of the Changhsingian fusulinid fauna in South China.

No indicative forms for the base of the Changhsingian Stage can be identified from non-fusulinacean foraminifers, though they are rather abundant and diverse. *Colaniella* is usually referred to as a distinct foraminifer genus of the Changhsingian in South China. This genus is particularly rich in the Changhsingian of northern peri-Gondwana regions, but primitive forms might appear in the Late Wuchiapingian. In Section C of Meishan, the genus *Colaniella* firstly appeared from Bed 1 of the Longtan Formation, and became very common in Changhsingian. Other genera include *Climmacommina*, *Nodosaria, Glomospira, Frondicularia, Geinitzina, Dagmarita, Hemigordius,* and *Ammodiscus*.

6. Conclusions

Study of the lithological succession around the Wuchiapingian and Changhsingian boundary at Section C shows that the sequence boundary coincides with the boundary between the middle and upper parts of the Longtan Formation. The upper part of the Longtan formation and the basal part of the Changhsiang Limestone represent a transgressive system tract. This observation implies that the boundary between the Changxing and Longtan formations appears within a transgressive system tract and is conformable. The continual depositional succession around this lithostratigraphic boundary is represented by a smooth transition from calcareous mudstone beds upward to thick-bedded bioclastic limestone.

The evolutionary lineage from *Clarkina longicuspidata*

to *Clarkina wangi* is clearly present at Meishan Section C. The FAD of *C. wangi* occurs at the same level with the advanced form of the genus *Palaeofusulina*, *P.* cf. *sinensis* and the first tapashanitid ammonoid *Sinoceltes*. This supplementary information proves that Section D at Meishan can meet the requirements for the GSSP of the Wuchiapingian–Changhsingian boundary.

Acknowledgements

We acknowledge the financial support by Chinese Academy of Sciences (KZCX2-SW-129), the National Nature Science Foundation of China, the Major Basic Research Projects of the Ministry of Science and Technology, China (G2000077700). We also desire to express our grateful thanks for valuable advice in the field to Prof. Liao Zhuoting; for lithological analysis to Prof. Xue Yaosong; for assistance in identifying ammonoids to Prof. Yang Fengqing; for field assistance to Li Wenzhong, Zhang Hua, Wang Xiaojuan, Zhen Quanfeng, Chen Jie, Mu Lin and Qu Lijun; and for the kind and constructive suggestions to Prof. Shi Guangrong from Deakin University, Australia and Prof. Douglas Erwin from Smithsonian Institution, USA.

Fig. 4. The fossil conodonts near the Wuchiapingian–Changhsingian boundary at Meishan Section C. All specimens are SEM photos magnified X70. They are kept in nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. The specimen numbers are from 139730 to 139743. Letters a and b are used with the same number when both upper (a) and oblique lateral (b) views of the same specimen are illustrated. Specimens 1–5 and 10 are *Clarkina wangi* (Zhang). All are Pa elements showing intra-population and ontogenetic variation; 1, 3, 4 are from sample MSC6-2; 2 is from sample MSC5-14; 5, 10 are from sample MSC5-1. Note fused carinal denticles even in juveniles (specimens 4, 10). Specimen 6–9 show *Clarkina longicuspidata* transitional with *C. wangi*. All are Pa elements. Specimens 6 and 8 are from sample MSC4-1; 7 is from sample MSC4-3b; 9 is from sample MSC5-1. These transitional specimens have high middle denticles, some of which are laterally compressed or mostly fused, but still a minor gap between the cusp and second last denticle. Specimen 11–13 are

References

Bowring, S.A., Erwin, D.H., Jin, Y.G., Martin, K.D., Wang, W., 1998. U/Pb zircon geochronology and tempo of the end-Permian mass extinction. Science V (280), 1039–1045.

Jin, Y.G., Wardlaw, B.R., Glenister, B.F., Kotlyar, G.V., 1997. Permian

chronostratigraphic subdivisions. Episodes 20 (1), 10–15.
Li, Y.C., 1998. Carbon and oxygen isotope stratigraphy of the Upper Permian Changxingian limestone in Meishan Section D, Changxing, Zhejiang. Journal of Stratigraphy 22 (1), 26–34 (in Chinese with English abstract).
Li, H.M., Wang, J.D., 1989. Magnetostratigraphy of Permo-Triassic boundary section of Meishan of Changxing. Zhejiang. Scientia Sinica, Series B 32 (11), 1401–1408.
Liao, Z.T., 1979. Brachiopod assemblage zone of Changhsing stage and brachiopods from Permo-Triassic boundary beds in China. Journal of Stratigraphy 3 (3), 200–207 (in Chinese).
Liao, Z.T., 1980. Brachiopods from the Upper Permian in western Guizhou, in: Nanjing Institute of Geology and Palaeontology (Ed.), Late Permian Coal-Bearing Strata and Biota in Western Guizhou and Eastern Yunnan (in Chinese).
Mei, S.L., Henderson, C.M., Cao C.Q., 2001a. Conodont definition for the base of the Changhsingian Stage, Lopingian Series, Permian. Proceedings of the International Conference on the Global Stratotype of the Permian–Triassic boundary and the Paleozoic-Mesozoic Events, Changxing, Zhejiang, China, pp. 65–67.
Mei, S.L., Henderson, C.M., Wardlaw, B.R., 2001b. Progress on the definition for the base of the Changhsingian. Permophiles 38, 36–37.
Mundil, R., Ian Metcalfe, Ludwig, K.R., Renne, P.R., Oberli, F., Nicoll, R.S., 2001. Timing of the Permian–Triassic biotic crisis: implications from new zircon U/Pb age data (and their limitations). Earth and Planetary Science Letters 187 (1–2), 131–145.
Remane, J., Faure-Muret, A., Odin, G.S., 2000. The International Stratigraphic Chart: the division of earth sciences. UNESCO 5, 1–14.
Rui, L., Sheng, J.Z., 1981. On the genus Palaeofusulina. Geological Society of American Bulletin, Special Paper 187, 33–37.
Shen, S.Z., Shi, G.R., 1996. Diversity and extinction patterns of Permian Brachiopoda of South China. Historical Biology 12, 93–110.
Sheng, J.Z., 1962. The Permian system in China. Science Press, Beijing pp. 1–93 (in Chinese).
Sheng, J.Z., Chen, C.Z., Wang, Y.G., Rui, L., Liao, Z.T., Bando, Y., Ishii, K., Nakazawa, K., Nakamura, K., 1984. Permian–Triassic boundary in middle and eastern Tethys. Journal of the Faculty of Science, Hokkaido University, Series IV XXI (1), 133–181.
Wang, A.D., 1965. The discovery of the *Pseudotirolites asiaticus* (Jack) in the Changxing Limestone at Dushan, Daxiaowang county, southeast Anhui. Geological Review 23 (3), 236–237 (in Chinese).

Wang, C.Y., Qin, Z.S., Sun, Y.K., Zhu, X.S., Xu, D.Y., Chen, G.Y., 1997. Age of *Gallowayinella* and the lower limit of the Changhsingian Stage based on conodonts. Journal of Stratigraphy 21 (2), 100–108 (in Chinese with English abstract).

Wang, C.Y., Chen, L.D., Tian, S.G., 2001. A recommendation: a desirable area and sections for the GSSP of the Changhsingian lower boundary. Permophiles 39, 9–11.

Wardlaw, B.R., Mei, S.L., 2000. Conodont definition for the basal boundary of the Changhsingian stage, in: Jin, Y.G. (Ed.), Conodont Definition on the Basal Boundary of Lopingian Stages: A Report from the International Working Group on the Lopingian Series, vol. 36. Permophiles, , pp. 39–40.

Yan, J.F., Shang, G.X., Wang, Z.Y., 1964. Primary study of the Middle-Upper Permian stratigraphy in Jiangxi Province. Geological Review 22 (3), 165–176 (in Chinese).

Yang, Z.Y., Wu, S.B., Yin, H.F., Xu, G.R., Zhang, K.X., Bi, X.M., 1993. Permo-Triassic Events of South China. Geological Publishing House, Beijing.

Yin, H.F., Wu, S.B., Ding, M.H., Zhang, K.X., Tong, J.N., Yang, F.Q., Lai, X.L., 1996. The Meishan section, candidate of the global stratotype section and point of Permian–Triassic boundary, in: Yin, H.F. (Ed.), The Palaeozoic-Mesozoic Boundary. China University of Geosciences Press, , pp. 31–48.

Yin, H.F., Zhang, K.X., Tong, J.N., Yang, Z.Y., Wu, S.B., 2001. The global stratotype section and point (GSSP) of the Permian–Triassic boundary. Episodes 24 (2), 102–114.

Zhang, K.X., Tong, J.N., Yin, H.F., Wu, S.B., 1997. Sequence stratigraphy of the Permian–Triassic boundary section of Changxing, Zhejiang. Acta Geologica Sinica 71 (1), 90–103.

Zhao, J.K., Liang, X.L., Zheng, Z.G., 1978. Late Permian cephalopods of South China. Palaeontologica. Sinica, New Series B 12 (1–194), 1–34 (in Chinese with English abstract).

Zhao, J.K., Sheng, J.Z., Yao, Z.Q., Liang, X.L., Chen, C.Z., Rui, L., Liao, A.T., 1981. The Changhsingian and Permian–Triassic boundary of South China. Bulletin of the Nanjing Institute of Geology and Palaeontology, Academia Sinica 2, 1–112 (in Chinese).

Zhu, G.P., 1986. Viewpoints on the 'Southeast Movement' at the boundary of Jiangsu, Zhejiang and Anhui provinces. Geology of the coalfield in Zhejiang 1, 27–34 (in Chinese).

Zhu, D.S., Zhu, G.P., 1984. It is not the transitional belt of the Changxing Formation and Dalong Formation of the Daxiaowang County. Geology of the coalfield in Zhejiang 2, 42–44 (in Chinese).