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The Global Boundary Stratotype Section and Point (GSSP) for the base of Changhsingian Stage (Upper Permian)

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The Global Stratotype Section and Point (GSSP) for the base-Changhsingian Stage is defined at the First Appearance Datum (FAD) of the conodont Clarkina wangi *within the lineage from* C. longicuspidata *to* C. wangi *at a point 88 cm above the base of the Changxing Limestone in the lower part of Bed 4 (base of 4a-2) at Meishan D section, Changxing County, Zhejiang Province, South China. This level is consistent with the first appearance of Changhsingian index fusulinid* Palaeofusulina sinensis *and tapashanitid ammonoids. The speciation event from* Clarkina longicuspidata *to* C. wangi *occurs just above the flooding surface of the second parasequence in the Changxing Limestone. In addition, the boundary interval is clearly recognizable by the depletion of isotopic carbon ratios and the normal polarity zone appearing above the Late Wuchiapingian reversed polarity zone. Section C, about 300 m to the west of Section D, exposes more of the upper Longtan Formation. It clearly shows the transitional nature of deposition across the Longtan/Changxing formational boundary, and thus is described as a supplementary reference section.*

Introduction

The Changhsingian represents the second and last stage of the Upper Permian, which is also known as the Lopingian Series. Previously it was officially referred to as an informal chronostratigraphic unit (Remane et al., 2000).

Grabau (1923) recognized the *Oldhamina* fauna from Changxing as the youngest one of the Permian faunal succession and first named the Changxing Limestone (Grabau, 1931). Huang (1932) referred the Changxing Limestone as the Latest Permian standard unit of South China. Sheng (1955, 1962) and Chao (Zhao in present spelling, 1965; Zhao et al., 1978) subsequently documented the correlation potential of the Changxing Limestone as a standard for the uppermost Permian on the basis of ammonoids and fusulinaceans. Furnish and Glenister (1970) and Furnish (1973) suggested the Changhsingian as a chronostratigraphic unit. Zhao et al. (1981) formally proposed the Changhsingian as an international standard for the last stage of the Permian with the D Section in Meishan as the stratotype. The base of the Changhsingian Stage was recommended to be defined at the horizon between the *Clarkina orientalis* Zone and the *C. subcarinata* Zone that is located at the base of bed 2 (sensu Zhao et al. 1981), which is the base of the Changxing Limestone in Section D at Meishan, Changxing County, Zhejiang Province, China (Figure 1A). The basal part of this stage is also marked by the occurrence of advanced forms of *Palaeofusulina*, and the tapashanitid and pseudotirolitid ammonoids.

The basal-Changhsingian boundary defined by Zhao et al. (1981) has been widely used since it was defined, as it reflects the well-defined faunal changes in major fossil groups such as conodonts, brachiopods, ammonoids, corals and fusulinaceans (Jin et al. 1997). These faunal changes may, however, be accentuated by the presence of a significant unconformity a short distance below the base of the Changxing Limestone. Proximity to this unconformity has led others to look for a suitable boundary a little higher in the section. Wardlaw and Mei (2000) suggested that the FAD of *Clarkina subcarinata sensu stricto* would be a suitable boundary at 13.71 m above the base of the Changxing Limestone, based on a significant change in the denticulation of gondolellid conodonts. Later, Mei and Henderson (2001) and Mei et al. (2001) suggested that the base of the Changhsingian Stage could be defined within the *C. longicuspidata – C. wangi* lineage in Bed 4 based on revised taxonomic definitions. The latter definition is only about 88 cm higher than the traditional boundary suggested by Zhao et al. (1981); thus it is in close proximity to the historical boundary position. This boundary occurs near the flooding surface in the second parasequence of the Changxing Limestone, and is therefore a very suitable position with respect to continuity of deposition. In addition, the first occurrences of the tapashanitid ammonoid *Sinoceltites* and the fusulinacean *Palaeofusulina* aff. *sinensis* coincide with the FAD of *Clarkina wangi* and the tapashanitid ammonoid *Tapashanites* first appears only 42 cm higher at Section C. Section C is a new exposure about 300 metres from Section D. The value of Section C is that it exposes more of the upper Longtan Formation and that it clearly shows the transitional nature of deposition across the Longtan/Changxing formational boundary. This removes one objection to the proposed stratotype that not enough of the underlying beds were present even though it doesn't have any bearing on the definition, which occurs higher in the lower Changxing Limestone.

The Global Stratotype Section and Point (GSSP) for the basal boundary of the Changhsingian Stage was then defined at the FAD of the conodont *Clarkina wangi* within the lineage from *C. longicuspidata* to *C. wangi* in the lower part of Bed 4 (base of 4a-2) at Meishan D section (Figure 2). Section C is described as a supplementary reference section.

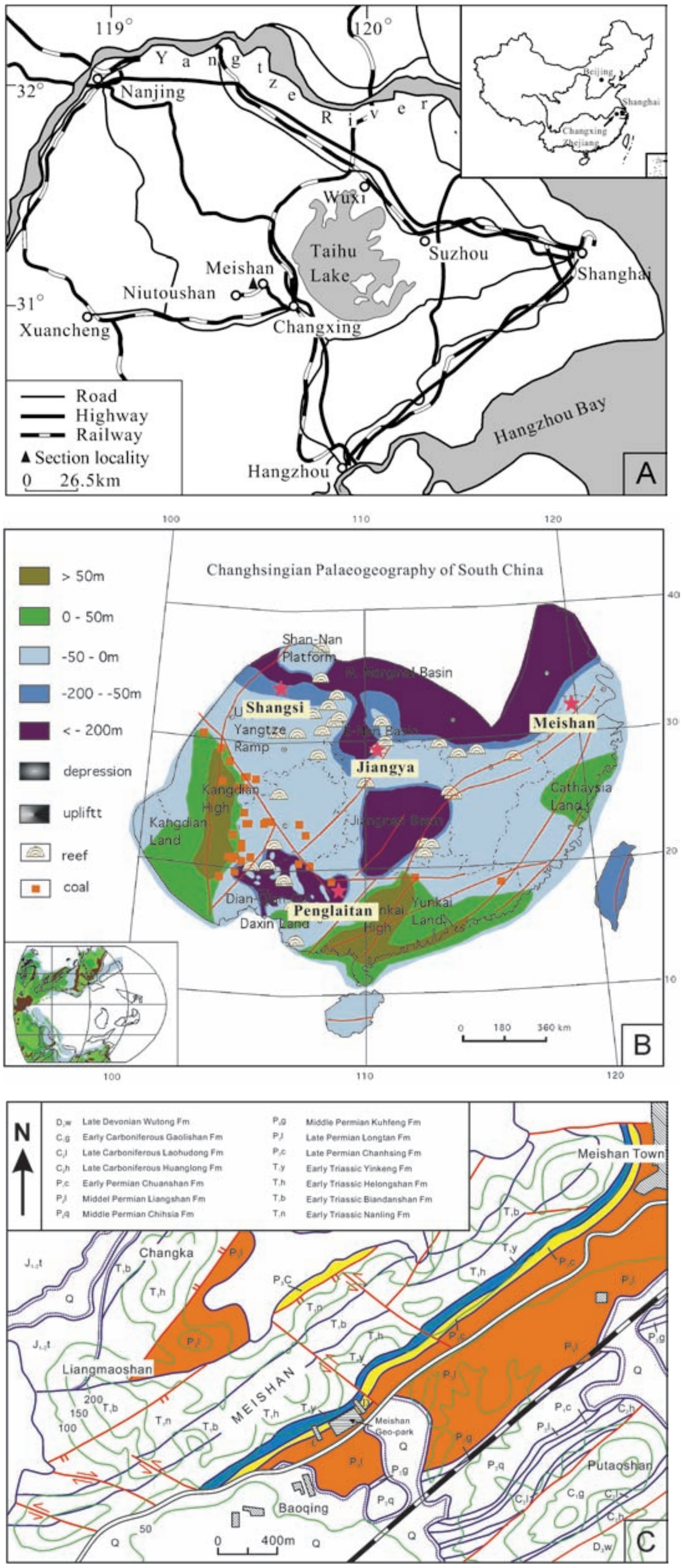

Figure 1 Maps showing the position in Meishan, Changxing County of Zhejiang Province of the GSSP for the Wuchiapingian-Changhsingian Boundary at Section D and the supplemental Section C. Map A shows the proximity of the section between Shanghai and Nanjing. Map B shows the position with respect to palaeogeographic setting (after Wang and Jin, 2000). Map C shows the position with respect to the geology in the region of Sections C and D as well as the Geopark constructed for the Permian-Triassic boundary GSSP.

Figure 2 Picture showing the proposed Wuchiapingian-Changhsingian Boundary interval at Section D, Meishan.

Figure 3 Picture showing the unit stratotype for the Changxing Limestone prior to construction of the Geopark.

Description of the Type Section

The Meishan D section is located between the cities of Nanjing and Hangzhou in Changxing County, Zhejiang Province, SE China (Figure 1A, B, C). The exact location of the Meishan D section is 31° 4' 55" N and 119° 42' 22.9" E. This section has been well protected and freely accessible to scientific researchers since it was ratified by IUGS as the GSSP for the Permian-Triassic boundary in 2001. The establishment of the GSSP for the lower boundary of the Changhsingian makes it a unit stratotype for the stage (Figure 3). Geologically this section is located along the western slope of the Meishan Anticline consisting of Upper Paleozoic and Lower Triassic rocks. The stratigraphic succession is well exposed and has not been disturbed structurally very much.

The Meishan sections have been described separately by Zhao et al. (1981), Sheng et al. (1984) and Yin et al. (1996). Conodont samples were collected continuously from the boundary interval between the Longtan Formation and the Changxing Limestone in Section D. This interval includes Beds 1, 2, 3, 4a, 4b and 5 of Yin et al. (1996). The boundary between Beds 1 and 2 is the lithologic boundary between the underlying Longtan Formation and the overlying Changxing Limestone. The descriptions and identified fossils from each unit at Section D follow below. The boundary succession at Section C has already been described in detail by Wang et al. (2006).

Upper Permian (Lopingian) Changxing Limestone

Bed 5 (depth, 211–370 cm). Dark grey thin- to medium-bedded bioclastic micritic limestone with siliceous bandings, with normal graded beddings and small sandy wavy beddings. Nonfusulinacean foraminifers (330–370 cm, ACT 109): *Glomospira* sp.; (290–330 cm, ACT 109): *Frondicularia ovata* K. M. Maclay, *Dagmarita* sp., *Nodosaria krotovi* Tcherd; (250–290 cm, ACT 108): *Geinitzina uralica* K. M. Maclay, *Globivalvulina distensa* Wang, *Nodosarina longissima* Sue, *Dagmarita* sp., *Pseudonodosarlina* sp.; (210–250 cm, ACT 107): *Dagmarita* sp., *Frondicularia* sp., *Geinitzina splandli* Tcherd.; fish (210–370 cm): Palaeomiscoidei gen. et sp. indet., *Sinohelicoprion changxingensis* Liu and Chang, *Sinoplatysomus meishanensis* Wei; ostracods (210–370 cm): *Bairdiacypris fornicata* Shi, *Bairdia wrodeloformis* Chen, *Basslerella firma* Kellett, *Eumiraculum changxingensis* Chen, *Petasobairdia bicornuta* Chen, *Silenmites sockakwaformis* Shi. Conodonts (215–230 cm, 5-1): *Clarkina wangi* (Zhang).

Bed 4b (depth, 158–211 cm). Grey thin- to medium-bedded bioclastic micritic limestone, intercalating light grey thin-bedded calcareous mudrock in the upper part, with slightly wavy beddings. Nonfusulinacean foraminifers (158-211 cm, ACT 106): *Geinitzina splandli* Tcherd., *Pseudoglandulina conicula* K. M. Maclay; fusulinaceans (158–211 cm): *Palaeofusulina minima* Sheng and Chang; fish (158–211 cm): Amblypteridae? Coelacanthidae gen. et sp. indet., Palaeoniscoidei gen. et sp. indet., *Sinonelicoprion changxingensis* Liu and Chang, *Sinoptatysomus meishanensis* Wei; ostracods (158–211 cm): *Basslerella obesa* Kellett, *Petasobairdia bicornuta* Chen. Conodonts (185–205 cm, 4b-3): *Clarkina orientalis* (Barskov and Koroleva), *C. wangi* (Zhang); (174–180cm, 4b-2): *Clarkina orientalis* (Barskov and Koroleva), *C. wangi* (Zhang); (160–167 cm, 4b-1): *Clarkina orientalis* (Barskov and Koroleva), *C. longicuspidata* transitional to *C. wangi, C. wangi* (Zhang).

Bed 4a (depth, 80.5 - 158 cm). Grey thick-bedded bioclastic micritic limestone. Fusulinaceans (85–125 cm, ACT 104): *Palaeofusulina minima* Shang and Chang, *Reichelina changhsingensis* Sheng and Chang; non-fusulinacean foraminifers (125–158 cm, ACT 105): *Frondicularia palmate* K. M. Maclay, *Geinitzina splandli* Tcherd, *Globivalvulina* sp., *Nodosaria longissma* Sue; (85 – 125 cm, ACT 104): *Nodosaria delicate* Wang, *Dagmarita* sp.; brachiopods (85– 158 cm): *Cathaysia chonetoides* (Chao), *C. parvalia* Chang. Conodonts (141–157 cm, 4a-4): *Clarkina longicuspidata* transitional to *Clarkina wangi, Clarkina wangi* (Zhang); (107–130 cm, 4a-3): *C. longicuspidata* Mei and Wardlaw, *C. longicuspidata* transitional to *C. wangi, C. wangi* (Zhang); (88–107 cm, 4a-2): *Clarkina longicuspidata* Mei and Wardlaw, *C. longicuspidata* transitional to *C. wangi, C. wangi* (Zhang).

Bed 3 (depth, 56–80.5 cm). Greyish yellow illite-montmorillonite clay, U-Pb age: 257 Ma (Mundil et al. 2001). (56–82 cm) Greyish black silty and calcareous mudrock intercalating argillaceous mudrock, with horizontal bedding. Conodonts (70–80 cm, 3-2): *Clarkina longicuspidata* Mei and Wardlaw, *C. longicuspidata* transitional to *C. wangi*; (56–70 cm, 3-1): *Clarkina longicuspida*ta Mei and Wardlaw.

Bed 2 (depth, 0–56 cm). Dark grey thick-bedded silt-bearing micritic limestone. Non-fusulinacean foraminifers (0–55 cm, ACT 103): *Colaniella* sp., *Eacristellaria* sp., *Geinitzina postcarbonica* Spandel, *Pseudoglandulina conica* K. M. M'Clay. Conodonts (47–56 cm, 2-4): *Clarkina longicuspidata* Mei and Wardlaw; (32–47 cm, 2-3): *Clarkina longicuspidata* Mei and Wardlaw, *C. orientalis* (Barskov and Koroleva); (20–30 cm, 2-2): *Clarkina longicuspidata* Mei and Wardlaw; (0–20 cm, 2-1): *Clarkina longicuspidata* Mei and Wardlaw, *C. orientalis* (Barskov and Koroleva).

— Conformable Contact —

Upper Permian (Lopingian) Longtan Formation

Bed 1 (depth of upper part, 0 – -30 cm). Dark dolomitized calcirudite with fragments of limestone, siltstone and phosphate. Nonfusulinacean foraminifers (0 – -30 cm, ACT 102): *Geinitzina uralica* K. M. M'Clay, *Hemigordius* sp., brachiopods (0 – -30 cm, ACT 102): *Orbiculoidea* sp., *Cathaysia chonetoides* (Chao), *Paryphella gouwaensis* Liao, *Spinomarginifera* sp. Conodonts (-4 to -12 cm, 1-2): *Clarkina longicuspidata* Mei and Wardlaw. (depth of lower part, -30 – -70 cm). Dark medium-bedded calcareous siltstone with horizontal bedding surfaces. Conodonts (-30 to -40 cm, 1-1): *Clarkina longicuspidata* Mei and Wardlaw.

Depositional Succession at the Wuchiapingian–Changhsingian boundary

Regionally, the Longtan Formation is a coal-bearing, marginal marine unit. The generalized stratigraphic succession of this formation from core records of all wells in Meishan (Zhao et al., 1978) as well as core records from wells near Section D and C (CK 818 and CK658) shows that this formation, some 300m in thickness, represents a transgressive sequence with a brief regression between the middle and upper parts. The lower part is about 90 m thick, consists of coarse sandstone, siltstone and bauxitic clay beds with fossils of roots and stems, and bears mineable coal beds. Plant fossils from bauxitic clay beds include *Gigantopteris nicotianaefolia* Schenk, *Protoblechnum wongi* Halle, *Taeniopteris norinii* Halle, and *Pecopteris* sp. The middle part, 80 m in thickness, is composed of alternating beds of fine-grained sandstone and sandy siltstone. It contains three one-metre thick sandy limestone beds containing abundant brachiopods, corals and the fusulinacean *Chenella* sp. This part is capped by a 12 m thick coal-bearing unit, which comprises alternating beds of cross bedded, fine grained sandstone 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., *Prelissorhynchia* sp. have been reported from the uppermost 4m thick unit. Ammonoids, including *Pseudogastrioceras* sp., *Jinjiangoceras* and *Konglingites* sp. were recorded from this part. The sedimentary and fossil features are indicative of a gradually deepening trend from the coastal swamp, shallow and deeper shelf with a brief interval of 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 the widespread limestone beds overlying the mineable coal beds.

Transgressive deposits (fine cherty siliciclastics) of the Talung, the basal Changxing Limestone, and upper Longtan Formation overlie this maximum regression within the Longtan Formation, presumably in an unconformable contact; however, the extent of this unconformity is uncertain. Regionally, the boundary between the Longtan Formation and the Changxing Limestone was regarded as a sequence boundary (Zhang et al. 1997). However, in sections C and D at Meishan, this boundary is represented by a smooth transition from calcareous mudstone beds that increase in thickness upward to thick-bedded bioclastic limestone (Wang et al., 2006), indicating that the sequence boundary is lower within the upper Longtan Formation. 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 unit is characterized by cross bedding, coal seams and plant fossils indicating a coastal facies. The exposure at the Meishan D section contains only the uppermost part of the Longtan Formation. These beds include earthy yellow, calcareous siltstone and mudstone with horizontal beds of increasing thickness that contain ammonoids and brachiopods (Zhao et al. 1981). This bed appears to be conformable with the overlying Baoqing Member of the Changxing Limestone and may represent the first transgressive cycle above the unconformity in the middle to upper Longtan Formation; the bed is not assigned to the Talung Formation because of the lack of chert.

The lowest bed (Bed 2) of the Changxing Limestone at section D, which is represented by dark grey, thick-bedded silty wackestone, appears to form the upper part of a cycle or parasequence. Bed 3 contains greyish black calcareous mudstone and thin-bedded argillaceous mudstone, the base of which represents the flooding surface of a second parasequence in the section. Beds 4 and 5 include thin to medium bedded wackestone and represent the regressive portion of this second parasequence. The speciation event from *Clarkina longicuspidata* to *C. wangi* occurs just above the flooding surface of the second parasequence. Yin et al. (1996) and Zhang et al. (1997) illustrate numerous high-frequency cycles throughout the Changxing Limestone.

Fossil Succession

Conodonts

The descriptions and identifications of gondolellid conodont taxa around this boundary have gone through a number of changes over the past several years during a search for a reliable high resolution biostratigraphy for the Lopingian. Mei et al. (2004) described a population approach for gondolellid taxa that involves analysis of the entire sample-population from juvenile to adult specimens and recognized that for this interval, the carinal denticulation pattern is the most important morphologic feature, although all other morphologic characters are considered and described. The key to this approach is that rare morphotypes within sample populations that resemble closely related taxa are not recognized as separate taxa unless a distinct ontogenetic series for that morphotype can be demonstrated. Rare specimens within a population may exhibit one or several characters that are thought to be diagnostic of other species; this problem is overcome by examining as many specimens as possible from the sample-population. The separate identification of rare morphotypes including gerontic or pathogenic morphotypes (usually the largest specimens in size) may result in apparent long ranges of pre-existing species and high apparent taxonomic diversities. The evolution of *Clarkina* species during much of the Lopingian involves a series of small gradational evolutionary events within an anagenetic series of species. The speciation events are recognizable and correlatable because the changes in the proportion of new characters occur over a relatively narrow interval. During this interval there are forms that are transitional in character. The basal-Changhsingian is 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 D. The detailed distribution of this lineage is also shown at both Meishan Section C and Meishan Section D. At section C (Figure 4), *Clarkina longicuspidata* is recognized from 10.95 to 12.45 metres, specimens transitional between *C. longicuspidata* and *C. wangi* occur from 11.9 to 12.45 metres, and *C. wangi* occurs from 12.2 to 16.4 metres in the section (higher samples have not been processed). At section D, *Clarkina longicuspidata* occurs from –0.4 to 1.3 metres, specimens transitional between *C. longicuspidata* and *C. wangi* occur from 0.7 to 1.67 metres, and *C. wangi* occurs from 0.88 to 2.3 metres in the section (higher ranges of *C. wangi* are not included here). Thus high-resolution stratigraphy shows that the interval with transitional specimens ranges from only 0.55 metres at Section C to 0.97 metres at section D. The FAD of *Clarkina wangi* occurs 1.35 metre above the base of the Changxing Limestone at Section C and 0.88 metre above the base at Section D, but this difference may reflect differential weathering given that the exposure at section C is fresher as well as lateral facies changes. Above the interval with transitional specimens the occurrence of *C. wangi* is confirmed and in general its abundance seems to increase upwards; abundant *Clarkina wangi* in section D first occur at 1.74 metres (0.86 m above the FAD).

Ammonoids

The occurrence of *Pseudogastrioceras* sp., *Jinjiangoceras* and *Konglingites* sp. in the upper part of the Longtan Formation suggests the upper part of the Longtan Formation is Latest Wuchiapingian. Based on fossil data from northern Jiangxi Province, Zhao et al. (1978) suggested two latest Wuchiapingian ammonoid zones, the *Konglingites* Zone in the lower and the *Sanyangites* Zone in the upper part. In the meantime, they pointed out that these two zones share all other ammonoid genera except the named genera *Sanyangites* or *Konglingites*. Vertical occurrences of *Sanyangites* are limited and *Konglingites* could extend into higher level or occurs in the top portion of the section. Therefore, the lack of *Sanyangites* does not necessarily mean any depositional gap in Sections C and D.

The appearance of the tapashanitid and pseudotirolitid forms marks a turning point of phylogenetic development of Lopingian

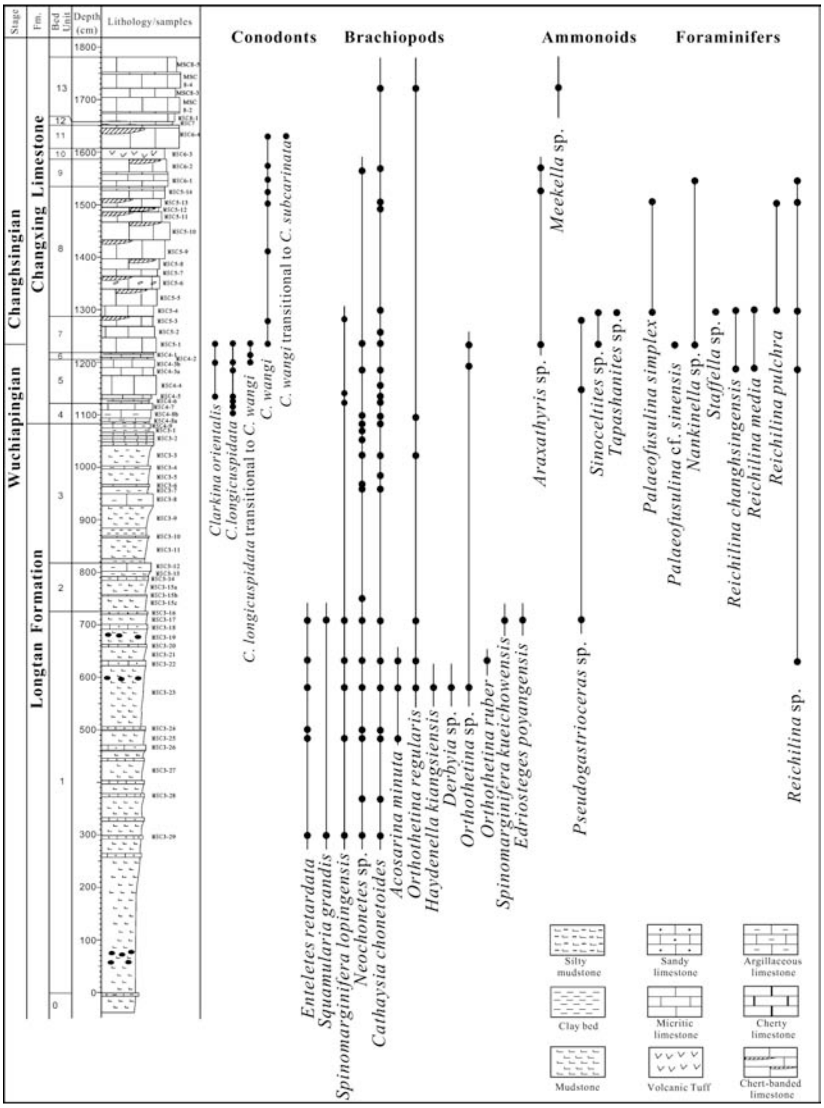

***Figure 4** Stratigraphic occurrences of fossils around the Wuchiapingian-Changhsingian interval at Section C, Meishan (after Wang et al., 2006).*

ammonoid faunas. The lowest occurrence of the tapashanitid genus *Sinoceltites* in Section C coincides with the FAD of *Clarkina wangi,* the index conodont species of the Changhsingian basal boundary. The other tapashanitid genus *Tapashanites* appears firstly 42 cm above the proposed boundary. A fully diversified Early Changhsingian ammonoid fauna occurs in a bed about 4 m above the boundary at Section D.

Brachiopods

Liao (1979) studied brachiopods around the boundary between the Changxing Formation and the Longtan Formation at Section C. Such species as *Orbiculoidea minuta* Liao, *Acosarina* sp., *Streptorhynchus* sp., *Paryphella gouwaensis* Liao, *Anidanthus* cf. *sinosus* (Huang), *Cathaysia chonetoides* (Chao), *Prelissorhynchia* sp. and *Spinomarginifera lopingensis* (Kayser) were recorded from the topmost bed of the Longtan Formation. New collections were studied, including more than 1300 brachiopod specimens from the Changhsingian/Wuchiapingian boundary beds of Section C. The collection includes 15 species in 12 genera. As shown in Figure 4, brachiopods are very abundant and diverse in the uppermost part of 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, 1980; Shen and Shi, 1996). *Cathaysia chonetoides, Haydenella kiangsiensis* and *Orthothetina regularis* are very abundant in the whole Lopingian in South China. Above Bed 1 at Section C, brachiopods remain very abundant, but apparently become less diverse. Some species with relatively large shells such as *Squamularia grandis*, *Edriosteges poyangensis, Enteletes retardata* disappear at the top of Bed 1. Only a few small brachiopods including the tiny *Neochonetes* sp. and *Cathaysia chonetoides* continue to be present in the topmost bed (Bed 2) of the Longtan Formation and in the lowest part of the Changxing Formation (Beds 3-8). This change in brachiopod composition may indicate a continuous transgression from the upper part of the Longtan Formation to the lower part of the Changxing Formation.

Fusulinaceans

The Changhsingian fusulinacean fauna is characterized by the dominance of the genus *Palaeofusulina* in the Tethys. The Wuchiapingian-Changhsingian boundary in the carbonate successions of South China used to be indicated by the appearance of the Changhsingian fusulinacean genera *Palaeofusulina* 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 lowest occurrence of the genus *Palaeofusulina* is right above the boundary. In addition to the primitive form such as *P. simplex* Sheng and Chang, an advanced form close to *P. sinensis* Sheng also occurs in the same level with the first tapashanitid ammonoid genus and the first *Clarkina wangi* at Section C (sample number MSC 5-1). More advanced forms, such as *Palaeofusulina sinensis,* do not appear until the Late Changhsingian (Bed 17 of Section D). Among the others, *Reichelina changhsingensis* Sheng and Chang and *R. pulchra* K.-M. Maclay, which first occur in Bed 4a, are both characteristic forms of the Changhsingian fusulinacean faunas of South China.

Palynology

Changhsingian palynomorphs, identified within the *Leiosphaeridia changxingensis- Micrhystridium stellatum* Assemblage Zone, are less diversified and mainly include acritarchs. In addition to the named species, this zone contains *Veryhachium* cf. *hyaloderlatum, Reduviasporonites stoschiana* and *Baltisphaeridium?* sp. (Ouyang and Utting, 1990). All of these species occur first about 50 cm above the base of the Changxing Limestone, that is Bed 3, except for *Micrhystridium stellatum*, which does not appear until 4m above the base. From Bed 1 to Bed 11 of Section C, palynomorphs were obtained from 16 levels. Those from the base of Bed 1 to the lower part of Bed 4 are characterized by a dominance of fossil spores and pollen with scarce acritarchs. Among them, percentage of spores and pollen reach 85% and 15% respectively. Spores such as *Crassispora orientalis, Triquitrites sinensis, Calamospora* sp., *Macrotorispora gigantean* and *Anticapipollis elongate*, and pollen of *Florinites florini* occur in all 10 levels. Characteristic forms for the Wuchiapingian palynological assemblages found only from one or two levels include *Bactrosporites shaoshanensis* (MSC3-24), *Patellisporites meishanensis* (MSC 4-8a, 4-9), and *Tumulispora triangulates* (MSC 3-2, 4-9). The acritarch *Micrhystridium stellatum* occurs in the basal part of Bed 1 and Bed 4 (MSC 4-8a). Composition of the palynological assemblages underwent a dramatic change near the boundary level. Those from Bed 6 to the lower part of Bed 11 are mostly acritarchs, which contain all component species of Leiosphaeridia changxingensis – Mychystridium stellatum Assemblage Zone.

Other fossils

No index forms for the base of the Changhsingian Stage can be identified from non-fusulinacean foraminifers and ostracods, although both groups are rather abundant and diverse. *Colaniella* is usually referred to as a distinct foraminifer genus of the Changhsingian in South China. Fossils of this genus are particularly rich in the Changhsingian of northern peri-Gondwana regions, but the primitive forms might appear in the Late Wuchiapingian. In Section D of Meishan, The genus *Colaniella* first appears in Bed 2. The ostracods from the lower part of Bed 2 to Bed 7 of Sheng et al. (1984), that is the lower 10 metres of the Changxing Limestone, are grouped into a single ostracod assemblage. It is named as *Bairdia urodeloformis - Acratia subfusiformis - Eumiraculum changxingensis* Assemblage and is characterized by the dominance of small and smooth forms. However, it is noteworthy that all three leading species of the assemblage occur first in Bed 4 at Section D (Shi and Chen, 1987). It is equally interesting to note that various fossil fishes appear in Bed 4a and 4b at Section D, including *Sinohelicoprion changxingensis* Wei and *Sinoplatysomus meishanensis* Wei and others (Wei, 1977).

Chemostratigraphy

Chemostratigraphic investigations have been undertaken for carbon isotopes and trace elements. Studies on stable isotope ratios of carbon were based on bulk sediment samples. The profile of carbon isotope values from all previous studies on the Longtan and Changxing Formations at Section D (Figure 5) exhibits a lower value around the boundary between these two formations (Li, 1998). It ranges from -3.4 to -0.2 per mil in Bed 1, 2 and 3, from -1 to 2.9 per mil in Bed 4a, 4b and 5. The average carbon isotopic value for the topmost Wuchiapingian beds is -0.21 per mil while that for the Early Changhsingian beds is about 2.5 per mil. A depletion of carbon isotopic values has been detected at two localities around the Wuchiapingian-Changhsingian boundary. In the Shangsi Section, Sichuan Province, a decrease of carbon isotopic values occurs at the boundary between the Wuchiaping and Talung Formations as well as at the Wuchiapingian-Changhsingian boundary (Li et al., 1989). The negative excursion reaches -1 per mil from an average value 3 per mil at the base of the Changhsingian Stage. Shao et al. (2000) reported a depletion of isotope carbon ratios around the Wuchiapingian-Changhsingian boundary at the Matan Section in the Heshan area, Guangxi. The decrease of carbon isotopic values around the Wuchiapingian-Changhsingian boundary in three distant localities of South China demonstrates a substantial marine chemical shift that corresponds with biotic evolutionary changes.

Magnetostratigraphy

Li et al. (1989) and Li and Wang (1989) divided polarity zones of the Changxing Limestone at Section D into four polarity zones. The basal part is 5 metres thick and is dominated by normal polarity and thus, is regarded as the basal normal zone, which may range from the *Clarkina orientalis* Zone to the *C. wangi* Zone. This implies that the proposed boundary is within a normal polarity zone (Figure 5) and a reversal occurs within the *C. wangi* Zone. Among these zones, the basal normal polarity zone appears at the same level as that in the upper part of the *C. liangshanensis* and the *C. orientalis* Zones of the Shangsi Section and the Lungtan Formation of the Hechuan Section. Although the nature of remnant magnetization of the Permian section in South China is often rather weak and scattered (Dobson et al., 1993), the Changhsingian polarity patterns in various sections are essentially consistent (Liu et al., 1999; Jin et al., 2000). This magnetostratigraphic sequence can be correlated well with that of the Meishan Section. Bed 11 of the Shangsi Section coincides with the conodont *Clarkina liangshanensis* Zone and represents the topmost level of the Wuchiapingian reversed polarity zone. Normal polarity is revealed from Bed 12 to Bed 16, which corresponds to the upper part of the *C. liangshanensis* and the *C. orientalis* Zones. Definitely, the uppermost Wuchiapingian possesses a broad normal polarity.

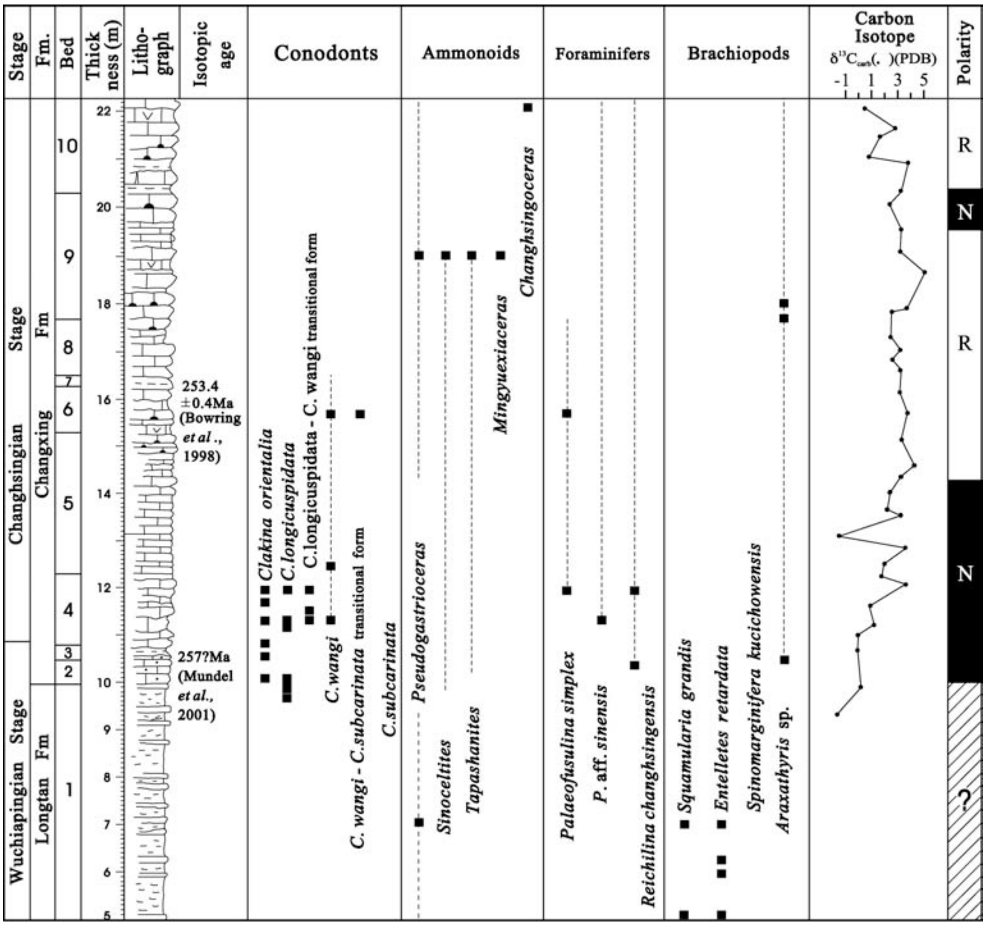

Figure 5 Integrated stratigraphic sequences around the Wuchiapingian-Changhsingian boundary in Meishan and the distribution of various fossil groups, carbon isotopes, geochronologic ages, and magnetic reversals. Note that the lithologic succession is subdivided into both beds and units. The beds are based on historical usage and are depicted to allow comparison with the literature. It is recognized that these beds are actually bedsets or parasequences except in the case of the ash beds, which represent true beds. The units are based on distinctive lithologic changes that reflect interpreted changes in depositional environment.

Geochronology

Using the IDTIMs U-Pb method on zircon, two sets of isotopic ages on the ash clay beds from Section D have been calculated (Figure 5). Bowring et al. (1998) provided an age of 253.4 ± 0.2 Ma to Bed 7 through the analysis of multi-zircon grains from the ash beds of the Baoqing Member. Mundil et al. (2001) prefer analyses on a single zircon grain and suggested an age of 257 ± 0.7 Ma or "257 Ma?" to an ash bed between Bed 3 and Bed 4, which is about 70 cm above the base of the formation (not 7 m above the *Clarkina orientalis* Zone as stated by Mundil et al.). They later interpolated the age of the Wuchiapingian-Changxingian boundary at 256Ma (Mundil et al., 2004). On the other hand, the estimated duration of the Changhsingian based on both sets of isotopic ages tend to be around 2 to 3 million years, that is from +253.4 Ma to 251.2 Ma of Bowring et al. (1998) and from 256 Ma to 252.4 Ma of Mundil et al. (2004). Currently there is a general consensus of 252 Ma for the Permian-Triassic boundary (Gradstein et al., 2004; Mundil et al. (2004)) and we herein assign the Changhsingian Stage base to about 254 Ma.

Correlation of the Wuchiapingian-Changhsingian GSSP

The regional correlation of the boundary level, the FAD of *Clarkina wangi,* was discussed in detail during the Workshop of Lopingian Stratigraphy and Events on Oct. 16, 2003 in Nanjing. The defining point is clearly indicated at Section C in Meishan by the FAD of *C. wangi* at 120 cm above the base of the Changxing Limestone following an interval of 20cm thickness with the transitional forms from *Clarkina longicuspidata* to *Clarkina wangi*. Having studied four Guadalupian – Lopingian sections in northwestern Hubei, Tian (1993) suggested an evolutionary lineage from *Clarkina parallela* Tian to *C. wangi* Dai and Zheng. Among them, the Lopingian conodont succession from the Jiangya Section is relatively complete. Based on the samples collected extensively around the Wuchiaping and Talung Formations, the evolutionary lineage from *Clarkina longicuspidata* to *C. wangi* can also be traced. The FAD of *Clarkina wangi* within this lineage occurs at or near bed JY70. In the Shangsi Section, the FAD of *Clarkina wangi* has been delineated precisely. The Wuchiapingian- Changhsingian boundary interval is clearly recognizable by the depletion of isotopic carbon ratios and the normal polarity zone appearing above the Late Wuchiapingian reversed polarity zone. In the western Tethys, the Dorashamian Stage (Rostovtsev and Azaryan, 1973) is correlatable with the Changhsingian Stage. Conodont zones of the Dorashamian Stage in northern Iran can be correlated one by one with those of the Changhsingian in South China (Sweet and Mei, 1999). *Clark-*

ina wangi co-occurs with *Clarkina subcarinata* in the basal assemblage zone of the Ali Bashi Formation in northern Iran. However, the precise level of the FAD of *Clarkina wangi* there needs to be defined in the future. In the Hambast Formation of the Abedeh Section in Iran, Kozur (2005) has defined a new zone on the basis of a new species referred to *Clarkina hambastensis*. Kozur indicates that the correlation of the base Dorashamian using *C. hambastensis* with the base of the Changhsingian of South China is rather good. This new species represents the round posterior morphotype of *Clarkina wangi* as defined by Mei et al. (2004) and used in this GSSP discussion. Zhao et al. (1981) indicated that the ammonoid *Paratirolites - Shevyreites* Zone from the Ali Bashi Formation might be correlated with the *Tapashanites- Pseudostephanites* Zone since index genera such as *Paratirolites* and *Shevyreites* also occur in the Lower Changhsingian beds in Guizhou Province of South China. They suspected that the Ali Bashi Formation lacked three ammonoid zones that occur in the upper part of Changhsingian strata in South China. In the Salt Range of Pakistan, the upper part of the Wargal Formation above the Larkrik Member contains conodont zones from the *Clarkina dukouensis* to *C. longicuspidata* Zone (Wardlaw and Mei, 1999), and therefore, represents nearly the whole Wuchiapingian Stage. Instead of *Clarkina wangi, Vjalovognathus* sp. B follows the occurrence of *Clarkina longicuspidata* in the Kalabagh Member and the basal part of the Chhidru Formation. The diagnostic fusulinacean genus *Palaeofusulina* is scarce in shelf deposits of northern Gondwana, while instead the foraminifer genus *Colaniella* is common. Advanced forms like *Colaniella minima* and *C. nana,* which occur first in the basal Changhsingian in Section D of Meishan, first appear in the topmost Wargal Formation (Unit 5) and the basal beds of the Chhidru Formation (Unit 2). Magnetostratigraphic data indicate that the upper part of the Wargal Formation is characterized by an extensive reversed polarity zone that may be correlated with the reversed polarity zone of the Wuchiapingian in South China. The upper part of the Wargal Formation and the Chhidru Formation can be correlated with the normal polarity zone of the Changhsingian because these strata contain a broad normal polarity (Jin et al., 2000). In the pelagic Tethys, radiolarians of the *Neoalbaillella optima* and *N. ornithoformis* zones are correlated respectively with the *Nanlingella simplex* and *Palaeofusulina sinensis* zones (Ishiga, 1990). This correlation indicates that these two zones belong to the Wuchiapingian and the Changhsingian respectively. The GSSP for the Wuchiapingian-Changhsingian boundary raises a challenge for the correlation of the boundary level outside Tethyan regions as well as for continental sequences. Major provincialism controls have resulted in the lack of a directly applicable worldwide biostratigraphic zonation for much of the Late Permian, indicating that it is necessary to resort to other means of correlation, such as major sequence boundaries and maximum flooding surfaces, significant reversals of polarity, remarkable isotopic fluctuations and isotopic ages, to establish a reliable correlation. For example, in North China, Embleton et al. (1996) reported the upper part of the upper Shihhotse Formation is dominated by reversed polarity, and thus can be correlated with the Wuchiapingian reversed polarity zone. Uppermost Wuchiapingian and Changhsingian marine sequences are dominated by normal polarity (Menning and Jin, 1998), as is the top of the Shihhotse Formation and the overlying Sunjiagou Formation.

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