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Foraminifers in the Global Stratotype (GSSP) of the Permian–Triassic Boundary (Bed 27, Meishan, South China)

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Abstract—The paper documents the results of a detailed study of the taxonomic composition and stratigraphic distribution of foraminifers in the Permian–Triassic transition bed (Bed 27) in the P–T GSSP (Bed 27, Meishan, South China). The earliest foraminiferal assemblage that followed the largest biotic crisis at the end of the Permian includes 15 genera of four orders, of which lagenids were the most abundant and diverse. The order Lagenida includes the following families: Pachyphloiidae (*Pachyphloia*), Geinitzinidae (*Lunucammina* s.l. (= *Geinitzina* = *Neogeinitzina*) and Robuloididae (*Robuloides*). In addition, the assemblage includes numerous members of the family Ichthyolariidae, the generic assignment of which needs confirmation: *Frondinodosaria, Nodosinelloides, Protonodosaria, Tauridia*, and *Eocristellaria*. Most recorded taxa occur in both Permian and Lower–Middle Triassic beds in the Tethyan Region and outside it, mainly in the middle, less commonly in the higher latitudes of the Northern and Southern Hemispheres. Apart from lagenids, a small proportion in the assemblages is represented by taxa of wide stratigraphic and geographical ranges (cosmopolitans) of the order Ammodiscida (*Ammodiscus, Glomospiranella*), and the order Globivalvulida (*Globivalvulina*), order Cornuspirida, family Neodiscidae (*Neodiscus*), family Hemigordiidae (*Hemigordius, Hemigordiella*) and a genus of uncertain affinity (*Abriolina*), typical of the Permian in the Tethyan Realm. The new results confirm previous records of foraminifers of the genera *Lunucammina* s.l., *Pachyphloia, Robuloides, Nodosinelloides, Cryptoseptida, Globivalvulina, Hemigordius*, and *Ammodiscus* in the P–T boundary bed in the Meishan section, and supplement the list of recorded taxa by *Neodiscus, Abriolina, Eocristellaria, Tauridia*, and *Hemigordiellina*. New results update the data on the diversity and abundance of foraminiferal shells in the sections as well as reveal some problems of their identifications. No significant biological innovations, changes in variability, or appearance of new taxa are registered immediately above the critical level at the P–T boundary, while the extinction of some survivors continued after the crisis.

Keywords: foraminifers, biotic crisis, Permian–Triassic, mass extinctions.

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INTRODUCTION

Studying geological, cosmic, and climatic events responsible for mass biosphere changes in the Earth's history and recorded in the complete and well dated standard stratigraphic successions is an important field in modern fundamental geological science. This includes the extinction at the Permian–Triassic (P–T) boundary, one of the largest in the Phanerozoic. Detailed studies of this catastrophe are now conducted in the region containing the most complete stratigraphic sequence of the P–T boundary beds where the P–T boundary GSSP is chosen Meishan (Changxing County of Zhejiang Province) in southeastern China (Yin, 1996; Yin et al., 2001).

In accordance with the decision of International Stratigraphic Commission (ICS), the GSSP of the P–T boundary is chosen in the Meshan section within a bed of dolomitized limestone 16 cm thick (Bed 27) based on the appearance of the conodont species *Hindeodus parvus* (Yin et al., 2001). The transitional Bed 27 is subdivided into four smaller beds 27a, 27b, 27c, 27d, whereas the boundary between the systems is drawn at the base of Bed 27c (Yin et al., 2001).

The Meishan section has recently been extensively studied, which included geochemical, isotopic, and mineralogical studies of the P–T boundary beds. These studies aimed to reveal traces of global change in the biota and establishing the sources of land volcanism that led to the formation of ash beds at this level (Zhou et al., 2002). The distribution of iridium and other platinoids was analyzed as these elements are considered to be cosmic effect indicators (Xu Dao-yi et al., 1989; Xu Dao-yi, Zheng, 1993; Lin Xu et al., 2007); determined isotopic parameters δ^{18}O and δ^{13}C, which indicate changes in atmosphere, temperature, and salinity of marine basins (Xu Dao-yi et al., 1989; Yin, 1996; Yin et al., 2001; Xie et al., 2007). Molecular compounds studied are indicators of changes in marine and terrestrial ecosystems (Xie et al., 2007;

Wang, 2007; Wang and Visscher, 2007; Chen et al., 2007), whereas the minerals (pyrite framboids) studied indicate redox conditions (Wenjie Shen et al., 2007). Absolute datings of events near the P–T boundary are refined based on ashes (Mundil et al., 2001). Clay of Bed 25 of the Meishan section was found to contain spherical molecule of carbon ^{60}C (fullerenes), which as suggested are of cosmic origin and have a unique ability to conserve organic matter, the influx of which from space could significantly change the organic world on the Earth (Becker et al., 2001). However finds of fullerenes in Bed 25 have been questioned, and accordingly so have conclusions based on fullerenes (Farley and Mukhopadhyay, 2001). The boundary bed 27 of the Meishan section contained many metallic microsphere and particles of cosmic origin considered to be products of intense impulse influx to the Earth of cosmic matter (PTB Cosmic Dust Event), but after the "mass biotic extinction" in Bed 24 (Korchagin et al., 2010).

Along with studies of traces of geological, cosmic, paleogeographic, and climatic events at the P–T boundary in the Meishan section, changes in the taxonomic composition of various faunal groups are also studied, to provide interpretations of so-called mass extinctions. Foraminifers and conodonts are key groups in these studies, as very important indicators of changes in the environment of shelf and tools for composing zonal biostratigraphic scales.

Previous analysis of the changes in the foraminiferal diversity in various regions of the Tethys in the Permian and Triassic, including data from the Meishan Section, showed that there were two episodes of extinction of foraminifers: (1) at the end of the Midian (Guadalupian–Lopingian) when main fusulinid groups and some "small foraminifers" became extinct and (2) at the end of the Changhsingian, when fusulinids and many groups of "small foraminifers" that survived the Midian crisis became extinct. It was also shown that at the end of Changhsingian the diversity and abundance of foraminifers decreased sharply. For instance, in the Meishan Section according to Zhao et al. (1981) a sharp decrease in the specific diversity of foraminifers is observed in Bed 24. This observation is fully supported by our modern studies. It is worth noting that in the overlying beds 25 and 26 no foraminifers were found, whereas Song et al. (2006) mentioned the presence of isolated specimens. It is noteworthy that a significant decrease in the species diversity and abundance of foraminifers at the boundary between beds 24 and 25 in the Meishan section is connected with the lithological change in the rock. Therefore, it is possible that some of the geological record in the Meishan Section escaped study in accordance with the "Signor-Lipps effect". Nevertheless, there is evidence supporting the view that events leading to the biotic crisis happened at the level between beds 24 and 25, and during accumulation of beds 25, 26, 27, and 28.

Previous studied also showed that in different regions of Tethys, the lower Triassic horizons contain a stratigraphic interval referred to as the "dead zone", where foraminiferal assemblages are either very impoverished or absent (Leven and Korchagin, 2001). It is noteworthy that the revision of the taxonomic composition of conodont assemblages in the P–T boundary beds of the Meishan section allowed the refinement of the distribution of this group in the section and served as the basis for new zonal subdivision of the P–T boundary beds although it did not result in a revision of the previous results (Jiang et al., 2007; Zhang et al., 2007).

Foraminifers from the Meishan Section were also examined (Zhao et al., 1981; Song et al., 2006). Detailed data on taxonomic composition and distribution of this fossil group were received from 8 samples from four beds (27a, 27b, 27c, 27d) (Song et al., 2007). Bed 27 contained species of *Hemigordius, Cryptoseptida, Frondina, Ichthyofrondina, Geinitzina, Nodosinelloides, "Nodosaria" Robuloides, Neoendothyra* (considered to be a junior synonym of *Robuloides*), *Rectostipulina, Globivalvulina, Tuberitina, Ammodiscus*, and taxa of uncertain taxonomic status: transitional genera A, B, C, D, and E (Song et al., 2007). In addition, it was shown that the most diverse species associations are contained in beds 27b and 27c (Song et al., 2007). Other sources give a different picture of changes in foraminiferal diversity in this bed: foraminifers are almost entirely absent in Bed 27b. Their number is reasonably high in Bed 27a and reaches its maximum near the boundary between beds 27c and 27d (Kaiho et al., 2006).

It should be noted that taxonomic views on foraminiferal genera and species vary in different papers (Zhao et al., 1981; Song et al., 2006, 2007). These differences are partly due to poor preservation of shells, insufficient level of knowledge of morphology and shell walls of Permian and Triassic foraminifers, and also with the different views on their classification.

Thus the above listed association of foraminifers from Bed 27, in accordance with the views on the position of the P–T boundary is a transitional association, but it should also be considered as either earliest post-crisis or crisis association formed after a sharp change in the species diversity and abundance of foraminifers in Bed 24.

This paper presents new study of the taxonomic composition and distribution of foraminifers obtained by the author after a considerably more detailed sampling of Bed 27 of the Meishan section, which was subdivided into 21 subdivisions, rather than usual 4 or 8 units (Fig. 1). The foraminifers recorded are figured, the dynamics of their abundance is studied, and intervals containing no foraminifers are also documented.

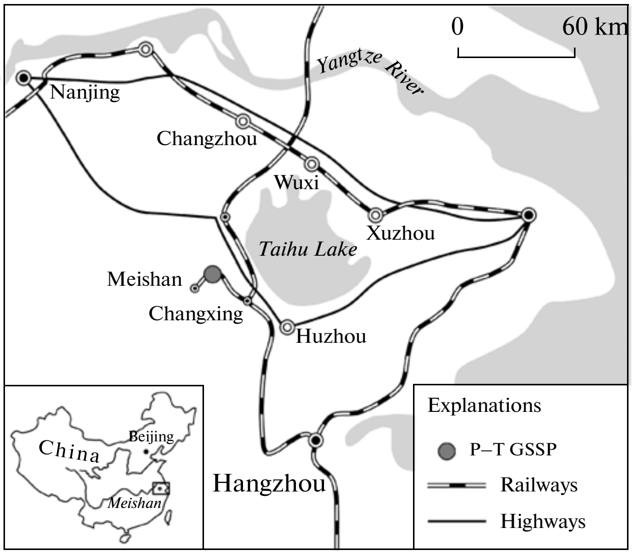

Fig. 1. Location of the Meishan section and P–T GSSP.

MATERIAL

The paper is base on material collected and studied by the present author during joint Russian-Chinese field work in 2006 together with I.I. Pospelov (Geological Institute, Russian Academy of Sciences) and Bian Qintao (Institute of Geology and Geophysics of the Academy of Science of the People's Republic of China) (Fig. 1). Studied were conducted using the mm-per-mm method, previously used for the Cretaceous–Tertiary boundary beds in Gams (eastern Alps) (Grachev et al., 2005).Continuous successions were sampled in the Meishan section (sector D) in 2 m below and above the P–T boundary (sometimes the successions were cut out). The samples were comprehensively examined (and are still being examined) in the lab (Fig. 2a).

Bed 27 was subdivided into 21 portions of equal thickness (0.5–0.7 cm) without taking into account the lithology of the rock (Fig. 2b). It is noteworthy, that our observations show that Bed 27 should be, based on lithology, divided into five layers, rather than four (Yin et al., 2001), as these layers are separated by horizons of sharp-edged fragments of dark gray clayey limestones formed either as a result of a break in sedimentation or a result of bioturbation. The uppermost of the five layers is composed of yellowish-gray clayey limestones and can be absent in some outcrops and even within the same block of the bed. However, before more comprehensive analysis of lithology, Bed 27 will be conventionally divided into four parts.

Foraminifers were studied using traditional methods in non-orientated thin sections.

TAXONOMIC NOTES

There are several classifications of Permian Triassic foraminifers, including higher taxa and genera, with no universally accepted interpretation. I used the classification by Loeblich and Tappan (1987), some interpretations of the classification of Paleozoic foraminifers (excluding endothyrids and lagenids) (*Spravochnik...,* 1993, 1996), additions to classification of lagenids by Groves et al. (2004), and in part some updated classifications (Gaillot and Vachard, 2007; BauDagher-Fadel, 2008).

In this paper, a group of highly specialized "large" foraminifers – fusulinids – after (*Spravochnik...*, 1996) is considered as a superorder and is not united with Paleotextulariacea, Parathuramminacea, Earlandiacea, Nodosinellacea, which are considerably different in many respects (Loeblich and Tappan, 1987) or Biseriaminnoidea (Gaillot and Vachard, 2007). All "small" foraminifers, assigned by some authors (Loeblich and Tappan, 1987; Gaillot and Vachard, 2007; BauDagher-Fadel, 2008) to the suborder Fusulinina (order Fusulinida in other classifications), are assigned to different orders (including the order Globivalvulinida). Following Groves et al. (2004), I accept priority of the order Lagenida, rather than Nodosariida, as a higher taxon to which I also assign the families Pachyphloidiidae and Geinitzinidae (Groves et al., 2004). In this paper I also use—*Neodiscus,* Neodisciscidae*, Hemigordiella, Tauridia, Langella, Pachyphloides*, resurrected after revision, and also new taxa, such as Langellinae, Frondinidae (Gaillot and Vachard, 2007). Previously abandoned genera, such as *Frondinodosaria* (possibly a synonym of *Vervellina*) and *Neogeinitzina*, are considered as valid in this paper. Species assigned in various papers to "*Nodosaria*", "*Dentalina*", "*Astacolus*", do not, in my opinion, belong to these genera and are assigned to the Permian and Triassic "lagenids".

Because of the existing differences in the identification of foraminifers I list below some possible synonyms previously identified from this bed (Zhao et al., 1981; Song et al., 2007) and add my interpretation of their possible assignment.

Nodosaria decorosa Wang (Zhao et al., 1981, pl. II, fig. 29) = *Pachyphloides* cf. *lanceolata* (A. Miklukho-Maclay) (present paper)

Pseudoglandulina ornata (A. Miklukho-Maclay) (Zhao et al., 1981, pl. III, figs 6, 12) = *Pachyphloia* sp. 3 (present paper)

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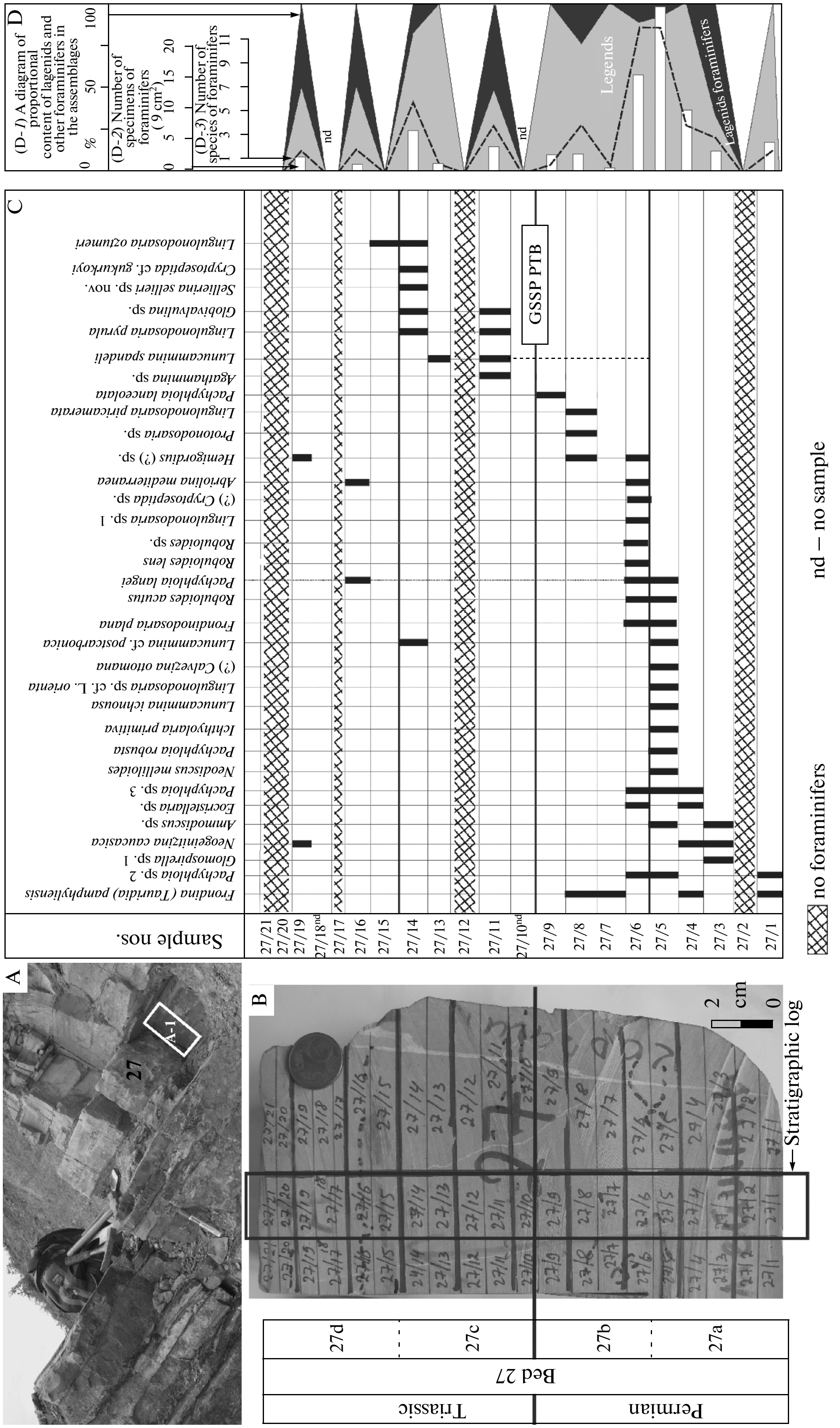
Fig. 2. (A) A photograph of the Permian–Triassic boundary beds in the Meishan section (sector D), (A-1) locality in Bed 27; (B) a photograph of the sample cut out of Bed 27 showing interval of sampling, (C) distribution of foraminifers in Bed 27, (D) diagrams showing changes in the number of specimens and species of foraminifers in Bed 27.


A
27
A-1
B
2 cm 0
Stratigraphic log
27d
27c
27b
27a
Bed 27
Triassic
Permian
C
Sample nos.
27/21
27/20
27/19
27/18nd
27/17
27/16
27/15
27/14
27/13
27/12
27/11
27/10nd
27/9
27/8
27/7
27/6
27/5
27/4
27/3
27/2
27/1
Frondina (Tauridia) pamphyliensis
Pachyphloia sp. 2
Glomospirella sp. 1
Neogeinitzina caucasica
Ammodiscus sp.
Eocristellaria sp.
Pachyphloia sp. 3
Neodiscus milliloides
Pachyphloia robusta
Ichthyolaria primitiva
Lunucammina ichnusa
Lingulonodosaria sp. cf. L. orienta
(?) Calvezina ottomana
Lunucammina cf. postcarbonica
Frondinodosaria plana
Robuloides acutus
Pachyphloia langei
Robuloides lens
Robuloides sp.
Lingulonodosaria sp. 1
(?) Cryptoseptida sp.
Abriolina mediterranea
Hemigordius (?) sp.
Protonodosaria sp.
Lingulonodosaria piricamerata
Pachyphloia lanceolata
Agathammina sp.
Lunucammina spandeli
Lingulonodosaria pyrula
Globivalvulina sp.
Sellierina sellieri sp. nov.
Cryptoseptida cf. gukurkoyi
Lingulonodosaria oztumeri
GSSP PTB
D
(D-1) A diagram of proportional content of lagenids and other foraminifers in the assemblages
0 % 50 100
(D-2) Number of specimens of foraminifers (9 cm²)
0 5 10 15 20
(D-3) Number of species of foraminifers
1 3 5 7 9 11
nd
nd
Legends
Lagenids foraminifers
no foraminifers
nd – no sample

Nodosaria netchajevi (Tcherd.) (Zhao et al., 1981, pl. II, fig. 19) = *Protonodosaria netchajevi* (Tcherd.) (present paper)

Pseudolangella primitiva (Pot.) (Zhao et al., 1981, pl. III, fig. 13) = *Langella perforata* Sellier de Civrieux et Dessauvagie (present paper)

Pachyphloia multiseptata Lange (Zhao et al., 1981, pl. III, fig. 25) =*Pachyphloia robusta* A. Miklukho-Maclay (present paper)

Astacolus aff. *aphrastus* Loeblich et Tappan (Zhao et al., 1981, pl. III, fig. 29) = (?) *Calvezina ottomana* Sellier de Civrieux et Dessauvagie (present paper)

Globivalvulina globosa Wang (Zhao et al., 1981, pl. II, figs. 4, 8) = *Globivalvulina globosa* Wang (present paper)

Hemigordius sp. A (Song et al., 2007, fig. 5) = *Hemigordiellina* sp. (present paper)

Frondina permica (Song et al. 2007, figs. 5-J, 7-O, P) = *Pachyphloides lanceolata* (present paper)

Geinitzina anaxensis (Song et al., 2007, fig. 7-JJ) = *Neogeinitzina caucasica* (K. Miklukho-Maklay) (present paper)

Geinitzina anaxensis (Song et al., 2007, fig. 7-I) = *Lunucammina postcarbonica* (present paper)

Geinitzina anaxensis (Song et al., 2007, figs. 7-Y, Z, T) = *Lunucammina spandeli* (present paper)

Rectostipulina quadrata (Song et al., 2007, fig. 5-O) = (?) oblique section *Robuloides* sp. (present paper)

Ichthyofrondina palmata Wang (Song et al., 2007, fig. 5-Q) =(?) *Frondinodosaria pyrula* Sellier de Civrieux et Dessauvagie (present paper)

A general classification of genera and species of foraminifers found in Bed 27 is proposed at the end of the paper

RESULTS AND DISCUSSION

Bed 27 is composed of light-gray fine-grained clayey dolomitized partly recrystallized limestones with a constant thickness of 15–16 cm. Foraminifers found in Bed 27 cannot be extracted from the rock (therefore their external morphology cannot be studied), are satisfactorily preserved, and are represented recrystallized and broken (sometimes significantly) shells. Some species are represented by a few specimens only. Thus, the precise identification of species and generic assignment of some lagenids are quite difficult. The distribution of foraminifers found in Bed 27 is figured in Fig. 2C, the diagrams of changes of species, number of specimens of species of foraminifers and proportion of different taxonomic groups are shown in Fig. 2D. Foraminifers studied are figured in Plates I and II.

Lagenids are the most diverse and numerous foraminifers in assemblages of Bed 27. Ammodiscids, cornuspirids, and globivalvilinids are less common (Fig. 2D-1). Lagenids are dominated by representatives of *Lunucammina* s.s., *Neogeinitzina*, *Pachyphloia, Frondinodosaria*, and also by *Nodosinelloides* and *Cryptoseptida*, which are found both in the Permian and Triassic parts of Bed 27. Apart from lagenids, the lower and the upper parts of Bed 27 contain occasional occurrences of globivalvilinids – (genus *Globivalvulina*), cornuspirids – genus *Hemigordius*, and of the genus *Abriolina* of uncertain taxonomic affinity. The Permian part of Bed 27, apart from the above genera contain the lagenid genera *Robuloides, Protonodosaria, Calvezina, Eocristellaria, Tauridia*, ammodiscid genera *Ammodiscus, Glomospiranella*, and cornuspirid genera *Hemigordiellina* and *Neodiscus*, while the cor-

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Plate 1. Foraminifers from Bed 27 in the Meishan section (P–T boundary GSSP, South China). All specimens photographed under a transmission light microscope. The scale bar is 200 μm.

Fig. 1. *Ammodiscus* sp.: oblique axial section; Sample 27/5.

Fig. *2. Glomospira* sp. 1: oblique axial section; Sample 27/3.

Fig. 3. *Neodiscus* cf. *melliloides* A. Miklukho-Maclay: oblique axial section; Sample 27/5.

Fig. 4. *Agathammina* sp.: axial section; Sample 27/11.

Fig. 5. *Hemigordius* (?) sp.: axial section; Sample 27/6a.

Fig. 6. *Hemigordiellina* sp.: oblique section; Sample 27/8.

Fig. 7. *Sellierina sellieri* Korchagin sp. nov.: holotype 4900, axial section; Sample 27/14.

Figs. 8, 9. *Lunucammina postcarbonica* Spandel: axial sections; Sample 27/14.

Figs. 10, 11. *Lunucammina spandeli* Tcherd.: (10) axial section; Sample 27/5; (11) axial section; Sample 27/11.

Figs. 12, 13, 14. *Neogeinitzina caucasica* K. Miklukho-Maclay: (12) axial section; Sample 27/4; (13) axial section; Sample 27/3; (14) axial section; Sample 27/19.

Figs. 15, 16, 17. *Pachyphloia langei* Sosnina: (15) axial section; Sample 27/5; (16) axial section; Sample 27/16; (17) axial section; Sample 27/5.

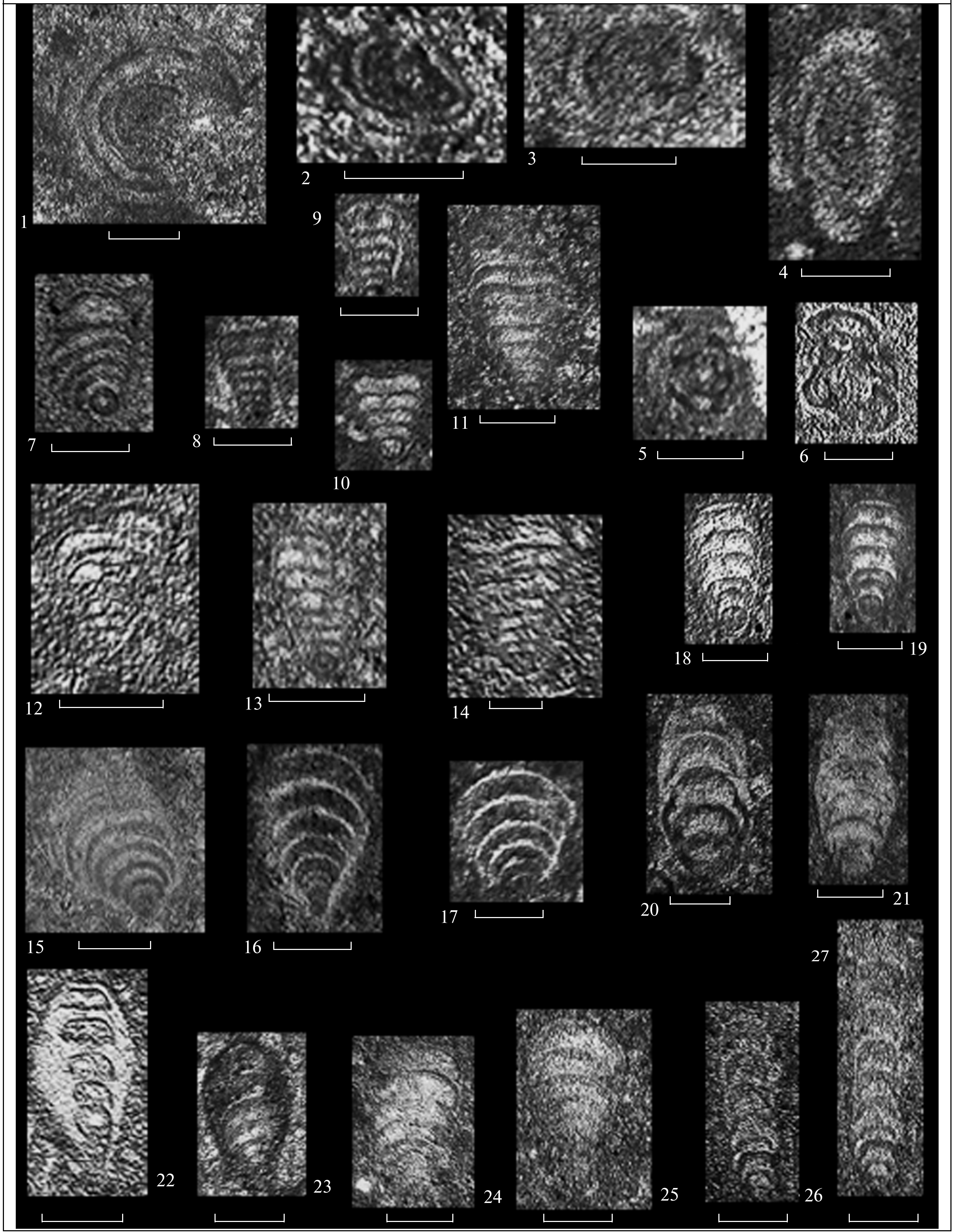
Figs. 18, 19, 20, 21. *Pachyphloides* cf. *lanceolata* (A. Miklukho-Maclay): (18, 19) longitudinal oblique axial sections; Sample 27/6; (20) longitudinal oblique axial section; Sample 27/5; (21) longitudinal oblique axial section; Sample 27/5.

Fig. 22. *Pachyphloia robusta* A. Miklukho-Maclay: cross-section; Sample 27/5.

Figs. 23, 24, 25. *Pachyphloia* sp. 3: (23) longitudinal oblique axial section; Sample 27/5; (24) longitudinal oblique axial section; Sample 27/5; (25) longitudinal oblique axial section; Sample 27/6.

Figs. 26, 27. *Pachyphloides lanceolata* A. Miklukho-Maclay—*Pseudowanganella* sp. 1; longitudinal axial sections; Sample 27/9.

Plate I



nuspirid genus *Agathammina* is restricted to the upper (Triassic) portion only (Fig. 2C).

Thus, assemblages of foraminifers in the lower (Permian) portion of Bed 27 are more diverse (both genera and species) than in the upper (Triassic) portion due to the presence of *Robuloides*, *Protonodosaria, Calvezina, Eocristellaria, Tauridia, Ammodiscus, Glomospiranella, Hemigordiellina,* and *Neodiscus* (Fig. 2D-3).

The assemblage of foraminifers of Bed 27 contained many shells previously assigned to *Neogeinitzina caucasica* (Zhao et al., 1981).

The foraminiferal records, which were absent from my samples from Bed 27, but recorded by previous workers, are listed below. Both the lower and the upper portions of Bed 27, according to Song et al. (2007) contained species of *Diplosphaerina*, *Frondina, Ichthyofrondina, Tuberitina*, and *Rectostipulina*. In contrast to my data, Song et al. (2007) recorded from Bed 27 a considerably more diverse assemblage of species of genera *Nodosinelloides* and *Cryptoseptida*, whereas from the upper portion these authors listed *Ammodiscus* and *Robuloides*, which I could only find in the lower portion.

In addition, the above list of lagenids from associations of Bed 27 shows that most of them have a "nodosariid-like" shell, i.e. are multicamerate and single-rowed. A small proportion of lagenids had spiral (*Robuloides*) or uncoiled-spiral tests (*Eocristellaria, Calvezina*).

The number of individual tests in associations of foraminifers in different portions of Bed 27 changes significantly from bottom to top (Figs 2D-2). are associations of foraminifers in the lower (Permian) portion of Bed 27 are the most numerous, especially in the upper portion of Layer 27a and lower portion of Layer 27b; while in the middle and upper part of Layer 27b they become impoverished and less diverse and remain so at the base of the upper (Triassic) portion of Bed 27 – in Layer 27c, they become impoverished near the boundary of layers 27c and 27d and disappear altogether by the upper portion of Layer 27d.

Bed 27 includes several portions which contained no foraminifers, which is apparently not connected with any lithological change in the rock. The lower (Permian) portion of the bed contains one such interval (27/2), and three were revealed in the upper (Triassic) portion (27/12, 27/17 and 27/20-21) (Fig. 2C). The nature of these "barren intervals", lacking foraminifers but with no apparent lithological changes, is not yet clear.

Large shells of foraminifers are missing from the assemblages studied. For instance, medium-sized shells of foraminifers are 2/3 the size of the shells of the same species from the Permian beds in other regions within the Tethyan Realm.

All species and genera of foraminifers in Bed 27 first appeared in the Paleozoic and existed in various regions of the Tethyan Realm prior to the crisis, whereas some existed beyond its borders in the middle or even high (boreal) latitudes. Representatives of Ammodiscida (*Ammodiscus, Glomospiranella*) are cosmopolitan, appeared in the Paleozoic, and have continued until the present.

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Plate II. Foraminifers from Bed 27 in the Meishan section (P–T boundary GSSP; South China). All specimens photographed under a transmission light microscope. The scale bar is 200 μm.

Fig. 1. *Frondinodosaria (?) piricamerata* (Efimova): axial section; Sample 27/8).

Fig. 2. *Ichtyolaria primitiva* Sellier de Civrieux et Dessauvagie: axial section; Sample 27/4.

Fig. 3. *Cryptoseptida* cf. *gukurkoyi* (Sellier de Civrieux et Dessauvagie): oblique axial section; Sample 27/14.

Fig. 4. *Cryptoseptida* (?) sp. (oblique axial section; Sample 27/6.

Figs. 5, 6. *Frondinodosaria oztumeri* (Sellier de Civrieux et Dessauvagie): (5, 6) axial sections; Sample 27/14.

Figs. 7, 20. *Frondinodosaria orienta* (Sosnina): (7) axial section; Sample 27/5; (20) oblique axial section; Sample 27/5.

Figs. 8, 9, 10, 11. *Tauridia pamphyliensis* (Sellier de Civrieux et Dessauvagie): (8) oblique axial section; Sample 27/1 (fragments of dark gray limestone); (9) oblique axial section; Sample 27/7; (10) oblique axial section; Sample 27/4; (11) oblique axial section; Sample 27/1.

Fig. 12. *Langella perforata* Sellier de Civrieux et Dessauvagie: axial section; Sample 27/6).

Figs. 13, 14. *Frondinodosaria pyrula* (Sellier de Civrieux et Dessauvagie): (13) axial section; Sample 27/11; (14) axial section; Sample 27/14.

Fig. 15. *Protonodosaria netchajevi* (Tcherd.): oblique axial section; Sample 27/8.

Figs. 16, 17, 18. *Nodosinelloides* sp. (16, 17, 18): oblique axial sections; Sample 27/5.

Fig. 19. (?) *Calvezina ottomana* Sellier de Civrieux et Dessauvagie: oblique axial section; Sample 27/5.

Figs. 21, 22. *Eocristellaria* sp.: (21) axial section; Sample 27/4; (22) axial section; Sample 27/6.

Figs. 23, 24, 28. *Robuloides acutus*: Reichel (23, 24) axial sections; Sample 27/6; (28) oblique section; Sample 27/4.

Figs. 25, 26. *Robuloides* sp.: axial sections; Sample 27/6.

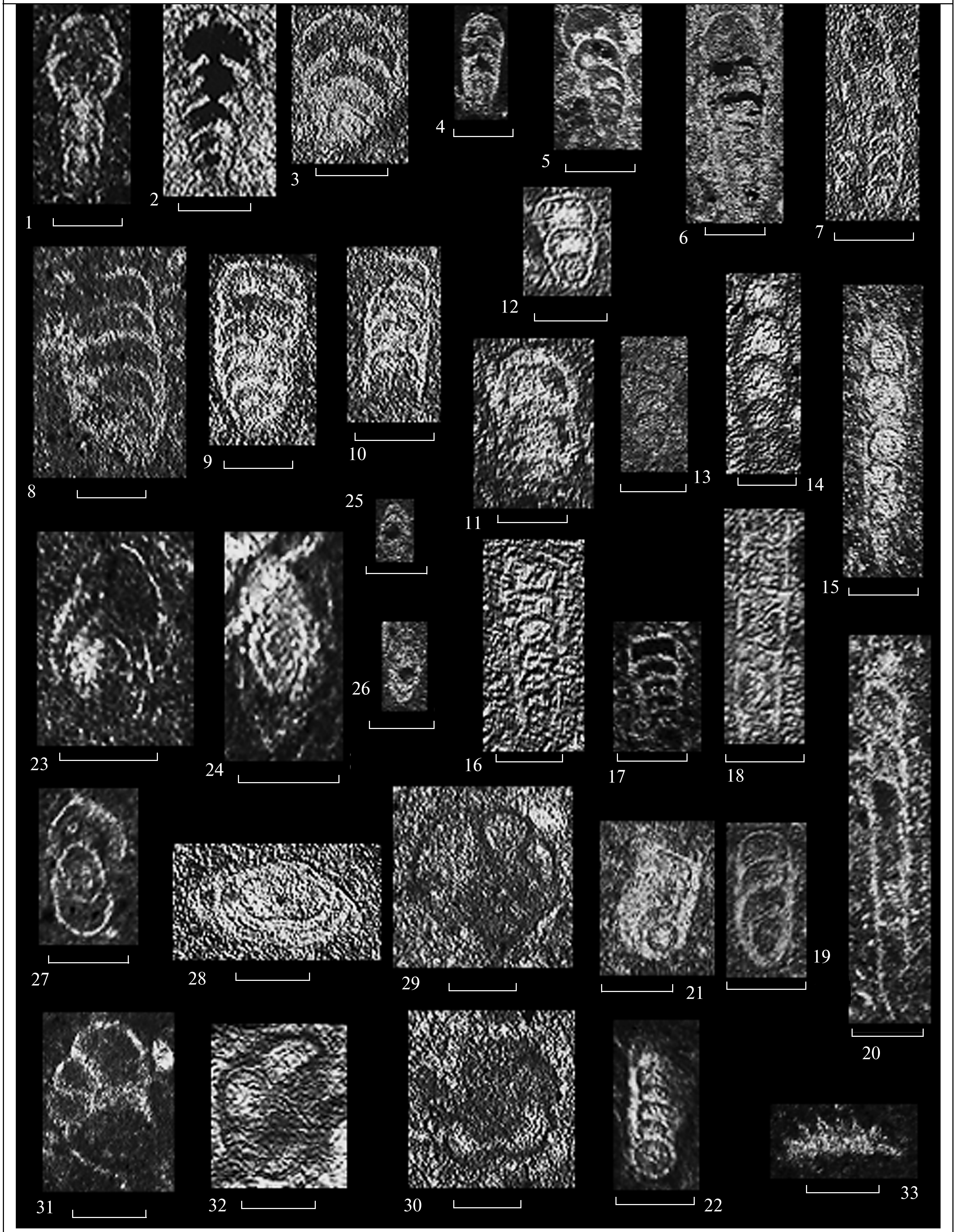
Fig. 27. *Robuloides lens* Reichel: axial section; Sample 27/6.

Figs. 29, 30. *Globivalvulina globosa*: Wang: (29) axial section, coil view; Sample 27/14; (30) axial section, umbilical view; Sample 27/11.

Figs. 31, 32. *Abriolina mediterranea* Luperto: (31, 32) axial sections, umbilical view; Sample 27/6.

Fig. 33. A conodont, lateral view (in thin section); Sample 27/16.

Plate II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Such genera as *Neogeinitzina*, *Rectostipulina, Cryptoseptida, Eocristellaria, Tauridia, Calvezina*, which were considered extinct at the end of the Permian, are show to have survived the main extinction episode at the P–T boundary (top of Bed 24), but disappeared from Bed 27. The genera *Eocristellaria, Calvezina*, and *Tauridia* disappeared in the lower (Permian) portion of Bed 27, whereas the genera *Neogeinitzina* and *Cryptoseptida* disappeared in its upper (Triassic) portion. The genera *Lunucammina* (= *Geinitzina*), *Robulides*, and *Pachyphloia*, existing throughout the Permian, survived up to the Late Triassic, while the genus *Agathammina*—up to the Jurassic, inclusive. The distribution of the genus *Abriolina* is usually restricted to the Permian (Luperto, 1963; Loeblich and Tappan, 1987), but there are records in the Middle Triassic (Marquez, 2005).

It can also be suggested that the genera *Protonodosaria, Frondinodosaria, Pachyphloides, Neodiscus*, and *Hemigordiellina* disappeared in Bed 27. However, it should be noted that the morphological criteria used for identification of these genera are still undeveloped, and they have been used for stratigraphy only recently, therefore their presence in the Triassic is also possible. The genera *Hemigordius* and *Globivalvulina*, which were also considered typically Permian, in fact survived the main extinction episode at the top of Bed 24 and continued up to and within Bed 27, up to its upper (Triassic) portion, which was recorded by Song et al. (2007), and supported in this study.

The poor preservation of shells of foraminifers, in my opinion, precludes precise generic assignment of some lagenids. Therefore recognition of some taxa of foraminifers, as transitional genera A, B, C, D, and E (Song et al., 2007), can be explained by difficulties of identification resulting from poor preservation and undeveloped classifications (lack of good diagnoses), rather than possible biological "innovations" in benthic foraminifers, which increased during or after a large biosphere event.

The dynamics of changes in taxonomic composition of foraminifers in various regions of the Tethys at the end of the Permian–beginning of the Triassic was discussed by Leven and Korchagin (2001). Note that in many regions of the world the Late Permian assemblages were dominated by lagenids (Miklukho-Maclay, 1954; Sosnina, 1965, 1977; Reitlinger, 1965; Pande and Kalia, 1994; Groves et al., 2003, 2005). In the western region of the Tethys – in Turkey (Altiner et al., 1980; Groves et al., 2003, 2005), Iran (Bronnimann et al., 1972a, 1972b, 1973), in the Caucasus (Efimova, 1979), in Bulgaria (Trifonova, 1967, 1978), in the Alps (Jenny-Deshusses, 1991), Poland (Styk, 1975), the Carpathians (Salaj et al., 1983), in the Pamir (Korchagin, 2008) – foraminifers in the lowermost Triassic horizons, immediately after the end-Permian extinction are very uncommon and form mainly monospecific associations. For instance, in Iran and Turkey such associations include the cornuspirid genus *Rectocornuspira* (Altiner et al., 1980; Bronnimann et al., 1972a, 1972b, 1973) and lagenids of the genera "*Nodosaria*" and *Tezaquina* (Groves et al., 2003; Groves et al., 2005). Only in the Caucasus (not stratigraphically located or figured) the Early Induan associations of foraminifers are taxonomically diverse – including rare cornuspirids (genera *Hemigordius, Cornuspira*), lagenids (genera *"Lingulonodosaria"*, *Rectoglandulina*, "*Nodosaria*", *Lingulina*, "*Spandelina*"), endothyrids (genus *Endothyra* ?) (Reitlinger, 1965) or ammodiscids (genera *Ammodiscus*, *Glomospira*, *Glomospirella*), lagenids (genera *"Frondicularia"*, "*Dentalina*", *"Astacolus"*) and textulariids (genus *Verneuilinoides*) (Efimova, 1979). In the Alps, slightly above the P–T boundary, associations of foraminifers include lagenids ("nodosariids"), and in the Balkans – lagenids and ammodiscids (Trifonova, 1967, 1978). In the Himalayas, the basal Triassic beds also contain lagenids (genus *"Astacolus"*). In the Pamir and eastern Kunlun the lower part of the Triassic lacks foraminifers altogether (Korchagin, 2008).

Thus, the early Induan post-crisis associations of foraminifers in most regions of Tethys usually contain lagenids, which are represented either by taxa with a straight single-rowed shell (nodosariid), or by taxa with a spiral shell, with a single-rowed portion. It should be noted that the synchronous post-crisis associations of foraminifers in the western and central regions of Tethys are considerably more taxonomically impoverished and less abundant than in the Eastern Tethys (Meishan Section).

Lagenids are interpreted as eutrophic organisms adapted to the uppermost beds of sediment enriched with organic matter (Tappan and Loeblich, 1988) and can be considered as indicators of "dysaerobic facies" formed in the oxygen-deprived conditions (Wignall, 1990). Therefore it could be suggested that as result of the biotic crisis at the P–T boundary, the upper layer of marine sediment in various regions of Tethys and adjacent regions both in the south and in the north developed dysaerobic conditions favorable for lagenids. However, this conclusion derived from the study of Bed 27 is still waiting to be supported by independent data on the geochemistry and mineralogy of these horizons, although rocks in beds 25 and 26 contain various sulfide minerals including pyrite framboids, as well as cristobalite, which can indicate dysoxic conditions. Therefore it is still not resolved whether the associations of foraminifers dominated by lagenids either with a straight single-rowed spiral or with a spiral, but straightened at the later stage shell, indicate dysoxic or postdisyxic conditions.

CONCLUSIONS

The transitional Bed 27 of the Meishan section contains the earliest post-crisis association foraminifers, including the terminal Permian and the earliest Triassic assemblages. These associations are strongly impoverished both taxonomically and in number of individuals in comparison to pre-crisis assemblages (Bed 24). Nevertheless associations of Bed 27 are polytaxonomic and are related to typical Permian assemblages. The associations contain members of four orders – lagenids, cornuspirids, ammodiscids, and globivalvulinids – and of 15 genera. The associations are clearly dominated by lagenids, particularly by the genera *Lunucammina* s.s., *Neogeinitzina*, *Pachyphloia*, *Frondinodosaria*, and *Nodosinelloides*. The associations of the lower (Permian) portion of Bed 27 are more diverse and numerous than those of the upper (Triassic) portion. The earliest pot-crisis associations of foraminifers in the Meishan section are more diverse taxonomically and are richer in number of individuals than in the western and central regions of the Tethyan Realm.

The associations of foraminifers in Bed 27 suggest that some typically Permian genera of foraminifers, mainly from lagenids and globivalvulinids survived the main extinction episode (at the top of Bed 24 in the Meishan section) and disappeared in Bed 27. Hence, their extinction supposedly continued for some time after the main extinction event at the end of the Permian (at the top of Bed 24 in the Meishan Section). Bed 27 also contains some typically Permian genera which survived the main extinction episode but became extinct later (*Neogeinitzina*, *Globivalvulina, Eocristellaria, Calvezina, Tauridia, Cryptoseptida*, and also *Rectostipulina*). All these genera mostly inhabited the Tethyan Realm, but are also found in some places in the middle latitudes of the Northern Hemisphere outside Tethys. A significant proportion of taxa in associations survived the event is also represented by lagenids which appeared in the carboniferous and Permian but disappeared considerably later than the mass P–T extinction – in the Middle and Late Triassic. These taxa also mainly inhabited the Tethyan Realm and some regions outside it, in the middle and possibly in the higher latitudes of the Northern Hemisphere. A smaller proportion of taxa in the associations are cosmopolitan genera with wide stratigraphic and geographical distributions.

It should be emphasized that foraminifers are relatively uncommon in Bed 27, with some species represented by only a few specimens, while the foraminifers are not particularly well preserved and many shells are recrystallized. Thus, the study of the taxonomic composition of the associations is not yet complete, and the taxonomic affinity of many lagenid specimens both in this part, and in the previous works, needs further study. The associations of foraminifers revealed are represented by species of wide stratigraphic distribution, which makes an independent stratigraphic identification of these associations in the section difficult. *Neogeinitzina caucasica* (appeared in the Permian and terminating in Bed 27) is in my opinion the most noticeable species in these associations. Following Zhao et al. (1981) this species can be used as a marker of the biostratigraphic zone of the regional stratigraphic scheme for the uppermost Permian and lowermost Triassic.

No biological innovations, changes in variability, or appearance of new taxonomic groups of any rank has been recorded. In the light of the interpretation of the extinction beginning at the end of the Midian and finishing at the end of the Changhsigian (Leven and Korchagin, 2001) as of a multistage process, this study suggests that after a sharp decrease in specific diversity and extinction of some taxa (top of Bed 24) the specific diversity of foraminifers increases to form an association of foraminifers composed of taxa that survived the extinction (many of these taxa were previously considered as extinct). However this post-crisis association of foraminifers did not survive for long, while many taxa in it became finally extinct. This, after (or during) the crisis, the specific diversity of foraminifers increased, whereas the extinction of the taxa that survived the crisis continued for some time. It would be useful to determine whether this pattern is a local artefact of the Meishan section, or it was typical of mass extinctions in other regions of the world. It is noteworthy that at the K–T boundary, during and immediately after the Cretaceous–Tertiary extinction, the sharp decrease in diversity and abundance of planktonic foraminifers was followed by a short-lived association with slightly increased diversity and abundance of foraminiferal taxa due to those species that survived the extinction but finally terminated (Korchagin and Kollmann, 2009). I consider this pattern which I named a "re-pulse effect", as an independent element of the mechanism of a biotic crisis.

SYSTEMATIC PALEONTOLOGY

Classification of Species from Bed 27

Type Foraminifera D'orbigny, 1826

Order Ammodiscida Reuss, 1862

Family Ammodiscidae Reuss, 1862

Genus *Ammodiscus* Reuss, 1862

Ammodiscus sp.

Family Glomospirellidae Ciarapica et Zaninetti, 1985

Genus *Glomospirella* Plummer, 1945

Glomospirella sp. 1

Order Globivalvulinida Reitlinger, 1950

Family Globivalvulinidae Reitlinger, 1950

Subfamily Globivalvulininae Reitlinger, 1950

Genus *Globivalvulina* Schubert, 1921

Globivalvulina globosa Wang

Order Cornuspirida Schultze, 1854

Family Cornuspiridae Schultze, 1854

Subfamily Agathammininae Ciarapica, Cirilli et Zaninetti, 1987
Genus *Agathammina* Neumayr, 1887
Agathammina sp.

Family Hemigordiidae Reitlinger, 1993
Subfamily Hemigordiinae Reitlinger, 1993
Genus *Hemigordius* SCHUBERT, 1908
Hemigordius (?) sp.
Genus *Hemigordiellina* Marie, 1961
Hemigordiellina sp.

Family Neodiscidae Lin, 1984
Genus *Neodiscus* A. Miklukho-Maclay, 1953
Neodiscus cf. *melliloides* A. Miklukho-Maclay

Order Lagenida Lankester, 1885
Superfamily Ichthyolariidacea Loeblich et Tappan, 1986

Family Protonodosariidae Mamet et Pinard, 1992
Subfamily Protonodosariinae Mamet et Pinard, 1992
Genus *Protonodosaria* Gerke, 1959
Protonodosaria netchajevi (Tcherd.)
Genus *Nodosinelloides* Mamet et Pinard, 1992
Nodosinelloides sp.
Genus *Frondinodosaria* Sellier de Civrieux et Dessauvagie, 1965
Frondinodosaria pyrula Sellier de Civrieux et Dessauvagie
Frondinodosaria oztumeri Sellier de Civrieux et Dessauvagie
Frondinodosaria orienta (Sosnina)
Frondinodosaria (?) piricamerata (Efimova)

Family Ichthyolariidae Loeblich et Tappan, 1986
Subfamily Ichthyolariinae Loeblich et Tappan, 1986
Genus *Ichthyolaria* Wedekind, 1937
Ichtyolaria primitiva Sellier de Civrieux et Dessauvagie

Subfamily Frondininae Gaillot et Vachard, 2007
Genus *Tauridia* Sellier de Civrieux et Dessauvagie, 1965
Tauridia pamphyliensis Sellier de Civrieux et Dessauvagie

Subfamily Langellinae Gaillot et Vachard, 2007
Genus *Langella* Sellier de Civrieux et Dessauvagie, 1965
Langella perforata Sellier de Civrieux et Dessauvagie
Genus *Cryptoseptida* Seilier de Civrieux and Dessauvagie, 1965
Cryptoseptida cf. *gukurkoyi* (Sellier de Civrieux et Dessauvagie)
Cryptoseptida (?) sp.

Superfamily Robuloidacea Reiss, 1963
Family Robuloididae Reiss, 1963
Genus *Eocristellaria* K. Miklukho-Maclay,1954
Eocristellaria sp.
Genus *Calvezina* Sellier de Civrieux et Dessauvagie, 1965
(?) Calvezina ottomana Sellier de Civrieux et Dessauvagie
Genus *Robuloides* Reichel, 1946
Robuloides acutus Reichel
Robuloides lens Reichel
Robuloides sp.
Insertae Sedus

Genus *Abriolina* Luperto, 1964
Abriolina mediterranea Luperto

Superfamily Geinitzinacea Bozorgnia 1973
Family Geinitzinidae Bozorgnia 1973
Genus *Lunucammina* [= *Geinitzina* Spandel, 1901]
Lunucammina postcarbonica Spandel
Lunucammina spandeli Tcherd
Genus *Sellierina* Korchagin, gen. nov.
Sellierina sellieri Korchagin sp. nov
***Genus Neogeinitzina* K. Miklukho-Maclay, 1954 emend. Korchagin**
Neogeinitzina caucasica K. Miklukho-Maclay

Family Pachyphloiidae Loeblich Et Tappan, 1984
Genus *Pachyphloia* LANGE, 1925
Pachyphloia langei Sosnina
Pachyphloia robusta A. Miklukho-Maclay
Pachyphloia sp. 3
Genus *Pachyphloides* Sellier de Civrieux et Dessauvagie, 1965
Pachyphloides lanceolata (A. Miklukho-Maclay)
Pachyphloides cf. *lanceolata* (A. Miklukho-Maclay)

Order Lagenida Lankester, 1885
Superfamily Geinitzinacea Bozorgnia 1973
Family Geinitzinidae Bozorgnia 1973
Genus *Sellierina* Korchagin, gen. nov.

Type species. *Geinitzina* ? ou *Pachyphloia* ? Sellier de Civrieux et Dessauvagie, 1965 (Sellier de Civrieux, Dessauvagie, 1965, pl. 14, fig. 1; pl. 16, figs. 1, 3, 4), Upper Permian, Turkey.

Etymology. In honor of Dr. J.M. Sellier de Civrieux, who was the first to figure typical representatives of the genus.

Diagnosis. Shell two-chambered, oval-triangular, initially narrow and gradually expanding toward the aperture with serrated or angular outline. At early stages with large spherical initial chamber followed by second chamber, which is at first loop-like and becoming conically coiled with, 5–6 (up to 10) volutions and forming low, wide cross-sections; wall dark calcite, possibly bilayered, with internal microgranular layer and external, possibly fibrose layer; sutures at later stages deepened and arched towards aperture. Aperture not observed.

Occurrence. Upper Permian–Lower Triassic; Turkey, Iran, China (Meishan).

Sellierina sellieri Korchagin sp. nov.
Plate I, fig.7

Etymology. In honor of Dr. J.M. Sellier de Civrieux, who was the first to figure typical representatives of the genus.

Holotype. *Geinitzina ? ou Pachyphloia ?* Sellier de Civrieux et Dessauvagie, 1965 (Sellier de Civrieux and Dessauvagie, 1965, pl. 14, fig. 1; pl. 16, figs 1, 3, 4), Upper Permian; Turkey.

Hypotype. No. 4900, collection of Geological Institute, Russian Academy of Sciences; Meishan, lower part of the lower Triassic.

Diagnosis. Shell two-chambered, oval-triangular, initially narrow and gradually expanding toward the aperture with serrated or angular outline. At early stages with large spherical initial chamber followed by second chamber, which is first loop-like and becoming conically coiled with, 5–6 (up to 10) volutions and forming low and wide cross-sections; wall dark calcite, possibly bilayered, with internal microgranular layer and external, possibly fibrose layer; sutures at later stages deepened and arched towards aperture. Aperture not observed.

Occurrence. Permian–Triassic, Cretaceous (Meishan); Upper Permian, Turkey and Iran.

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