Although some distinguishing criteria are proposed based on foraminiferal associations for the cratonic (e.g. South China) and oceanic settings (Paleotethyan-, Neotethyan- and Panthalassa-type) of the Far East in the latest Permian (Ueno et al., 2010) these domains correspond largely to the Northern Biofacies Belt of Altiner et al. (2000), extending from northern Turkey through Crimea, Transcaucasia, central and northern Iran, Afghanistan, the Pamirs to China including Indochina, South China, north China, and Japan. This belt, characterized by highly diversified ozawainellids and schubertellids and the absence of some distinct evolutionary trends in smaller foraminifera in the Changhsingian lies north of the Southern Biofacies Belt of Altiner et al. (2000), which extends from North Hungary through South Turkey and Oman to Thailand possibly including the Boashan and Sibumasu terrains.

-Pre-extinction interval and evolutionary changes in Changhsingian foraminifera

Although a considerable number of new genera from calcareous foraminifera has been added in recent years to the Lopingian foraminiferal inventory, one of the conclusions of Groves & Altiner (2005) regarding the increase in foraminiferal generic diversity in the Changhsingian stage still remains a valid observation. In the Northern Biofacies Belt, following the extinction of schwagerinids, neoschwagerinids and verbeekinids in the mid-Capitanian, the remaining fusulinoidean genera were schubertellids, ozawainellids and staffellids. Some schubertellid genera, such as Russiella, Codonofusiella, Paradoxiella and Paradanbarula, declined or totally disappeared at the Wuchiapingian-Changhsingian boundary. Three distinct evolutionary trends occurred in the Changhsingian: Gallowayinella (Zigiella is the possible synonym) originated from Russiella in the early Changhsingian; Nanlingella originated in the Wuchiapingian and later gave way to two distinct daughter taxa in the Changhsingian. Palaeofusulina evolved from Nanlingella with several distinct populations (P. minima, P. sinensis, P. nana, etc.). Paranangolinella was derived from Nanlingella and finally gave way to the most advanced genus of the group, Dilatofusulina. From ozawainellid fusulinoideans two main taxa, Reichelina and Parareichelina, survived into the Changhsingian.

Baudiella, a reichelinid with septal folds in the coiled stage, was derived from the Reichelina stock in the early Changhsingian. Many of the non-fusulinoidean fusulinids, comprising Pseudoammodiscidae, Lasiodiscidae, Globivalvulinidae, Tetrataxiidae and Paleotextulariidae, occur in abundance in the Changhsingian of the Northern Biofacies Belt. Among these taxa the most remarkable trend is the Paraglobivalvulina – Urshtenella lineage in the late Changhsingian. Paraglobivalvulinoides, which may have originated from Septoglobalvulina, represents the other lineage. Lasiotrochus, Retroseptellina and Postendothyra are the other characteristic taxa in the Northern Biofacies Belt.

Several families of the order Lagenida (Syraniidae, Protonodosariidae, Geinitzinidae, Robuloididae, Partisanidae, Frondinidae, Colaniellidae, Nodosariidae and Pachyphloiidae) frequently occur in the Changhsingian of the Northern Biofacies Belt. Among these taxa, the advanced populations of Colaniella (C. parva, C. pulchra, C. media, etc.) are among the most useful taxa in the Changhsingian stratigraphy. The genus Robuloides, comprising also some advanced forms, gave way to Hubeirobuloides in the late Changhsingian. Other genera like Nodosinelloides, Nestellorella and Nodosaria comprise some species confined to the Changhsingian stage.

In the Northern Biofacies Belt, Order Miliolida comprises many sporadic forms belonging to Hemigordiopsidae, Neodiscidae, Hemigordiidae,
Cornuspiridae and Calcivertellidae. Among these, Kamurana s.s. probably derived from a Glomomidiellopsis stock in the Southern Biofacies Belt and rarely occurs in the Northern Biofacies Belt. Pseudomidiella is a descendant of Midiella, one of the frequently occurring taxa in the latest Permian.

In the Changhsingian of the Southern Biofacies Belt both schubertellids and ozawainellids are extremely rare or sporadic. Nanlingella and Palaeofusulina are very rare. From ozawainellids, Reichelina is also rare and recently described Neomillerella became probably extinct in the early Changhsingian. From non-fusulinidean fusulinids two distinct evolutionary trends, both belonging to the family Globivalvulinidae, occur in the Changhsingian. In the globivalvulin trend, Paraglobivalvulina originated from Globivalvulina vonderschmitti in the latest Capitanian commonly occurs in the latest Permian. The other descendant in this stock, Charliella, seems to have gone extinct at the Wuchiapingian-Changhsingian boundary. From the Septoglobivalvulina-Paraglobivalvulinoideas lineage Paraglobivalvulinoideas is rather rare and sporadic. One of the most remarkable patterns in the Southern Biofacies Belt is the evolution of dagmaritin-type globivalvulinids. Paradagmarita derived from Crescentia in the latest Wuchiapingian and comprises two distinct species (P. monodi and P. planispiralis) in the Changhsingian. A new genus originated very close to the P-T boundary from Paradagmarita is characterized by a curved valvular tooth partially modifying the apertural system. In addition, Paradagmacrusta derived from Paradagmarita and Louiseitita originated from Dagmarita commonly occur in the Changhsingian of the Southern Biofacies Belt.

In the Southern Biofacies Belt, although lagenid-type foraminifers occur abundantly, colaniellids are totally absent. Genitzinidae, Fronsindidae, Pachyphloiidae and Nodosariidae frequently occur and genera such as Nodosinelloides, Ichthyofrondina and Nodosaria are highly diversified in the late Changhsingian. From robuloids, the genus Robuloides is frequent and displays distinct morphological variations close to the P-T boundary.

Several miliolid genera, such as Crassiglomella, Neodiscus, Graecodiscus, Glomomidiella, Glomomidiellopsis, Kamurana, Mendiella, Pseudomidiella, Hemigordius and Multidiscus, occur rarely to commonly in the Changhsingian of the Southern Biofacies Belt. Among these taxa, distinct evolutionary changes occurred in the populations of Glomomidiellopsis (G. uenoi, G. lyssitiformis). The genus Kamurana s. s. was probably derived from Glomomidiellopsis in the late Changhsingian.

1 Extinction

Although many authors defined the extinction at the P-T boundary as a sudden and sharp event, recent studies from the Northern Biofacies Belt, particularly at the Meishan section, South China, have revealed that the foraminiferal extinction occurred in two episodes near the P-T boundary (Song et al., 2009; 2013). The first episode is calibrated to the top of bed 24 and the second to the base of bed 28 corresponding to the extinction of remaining foraminifera. The P-T boundary is located below this upper extinction level, at the base of bed 27c.

In South Turkey sections, considered as the reference of the Southern Biofacies Belt, Changhsingian foraminifers display two marked diversity reductions, the lower corresponding to the base of the oolitic limestones and the upper to the base of microbials. The base of oolitic limestones characterized by the first diversity reduction in foraminiferal fauna most likely correlates with the base of bed 25 in the Meishan section. The top of the oolites, corresponding to the main (upper) extinction horizon, can be correlated with the base of bed 28. Following these correlations, I conclude that the first appearance of Hindeodus parvus, marker of the P-T boundary should lie within the oolitic limestones of the boundary sections in South Turkey.

2 Post-extinction recovery

In the aftermath of end-Permian mass extinction I distinguish four main steps from Griesbachian to Pelsonian based on the character of fauna, major changes in foraminiferal associations and diversification. These observations are based on both the Lower Triassic sections in South Turkey and the sections studied from the Great Bank of Guizhou, South China (Payne et al., in prep.).

Step 1. This step is characterized by a population of disaster taxa that bloomed at the base of Triassic and disappeared in the early Dienerian. The population consists of Postcladella (ex Rectocornuspira), Cornuspira and Earlandia. Derivation of Postcladella grandis from P. kalthori in the Griesbachian suggests the presence of some evolutive trends among the disaster taxa. We note that many failed survivors (Globivalvulina, Kamurana and possibly others) became extinct diachronously in this step.

Step 2. Following a gap in the occurrence of foraminifera in the Dienerian, the second step corresponds to the late Dienerian to Smithian interval. Most foraminifera in this step could be Lazarus taxa (hoyenellids, Pseudoammodiscus sp., ‘Glomospira’ sp. 1
and ‘Glomospirella’ cf. vulgaris). Among these taxa only hoyenellid foraminifera survived into the upper levels of the Triassic; the others became extinct in this step. A new Arenovidalina species is recorded and earliest involutinids appeared in the upper part of this step corresponding to the late Smithian.

Step 3. This step is characterized by a marked acceleration in the origination of new taxa. From Meandrospira, possibly a Lazarus taxon and related to Permian Streblospira (Altiner et al., 2005), three distinct populations, M. pusilla - M. cheni – M. n. sp., were successively derived in the Spathian. Endoteba reappeared at the base of Spathian and E. bithynica and Endotriadella wirzi made their first appearances in this interval. Two well known Triassic families (Duostominidae and Trochamminidae) originated and the proliferation of lagenid-type foraminifers occurred in this step. Most lagenids were possibly rooted from ‘Nodosaria’ hoae, a survivor from the end-Permian extinction and known from the Turkish Lower Triassic (Groves et al., 2005).

Step 4. Corresponding to the Aegean/Bithynian to Pelsonian interval in the Anisian, this step is characterized by a marked increase in the diversity of foraminiferal taxa. Most populations recognized in this interval are either species directly derived from taxa that had already appeared in the late Smithian or Spathian (Meandrospira dinarica, Endotabanella kocaeliensis, Endotriadella wirzi (large form), Triadodiscus sp., Trochammina almtalensis) or stepwise evolved species rooted from taxa already appeared in the Aegean to Pelsonian interval (derivations of Endotabanella, Endoteba, Endotriada and Endotriadella species; stepwise appearances of meandrospirid and Turroglomina species; derivation of Ophthalmidium sp. 3 from Arenovidalina, probably belonging to A. abriolense; derivation of Aulotortus ? eotriasicus from Triadodiscus sp.). However, there are also other taxa in step 4 whose origins can not be demonstrated with the available material from China. For example, Pilammina praedensa, a possible ancestor of the Pilammina densa-Pilamminella grandis group, has not been found in South China but is present in the Turkish Lower Triassic sections.

In conclusion, the foraminiferal diversity from Griesbachian to Smithian remained always low suggesting a stagnation and even a clear decline in diversity during mid-Dienerian times. The true recovery period started in the Spathian with several new originations which later became ancestors of many of the species appeared in the Anisian.

Key words: Changhsingian, Early Triassic, foraminifera, extinction, post-extinction recovery, Southern Biofacies Belt, Northern Biofacies Belt

References