Size variation of the end Permian conodont *Neogondolella* at Meishan Section, Changxing, Zhejiang and its significance

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Abstract   This study is based on both a generic and species level investigation of the individual size of the latest Permian conodont *Neogondolella* Pa elements collected from Meishan Section A, Changxing, Zhejiang Province. In this study, an obvious size reduction of *Neogondolella* Pa elements within bed 24e of the upper Changxing Limestone is recognized. The size variation of the *Neogondolella* occurs simultaneously with some important events including the negative shift of δ^{13}C, change in the ratio of the abundance of cyanobacterial biomarkers versus that of other general bacterial biomarkers and the shallowing of the sea water. Through the investigation of the paleoenvironmental changes and the analysis of the paleoecology of the conodont genus *Neogondolella*, the authors propose that the major factors for the size reduction of species of the conodont genus *Neogondolella* are food shortages caused by the mass extinction, the shallowing of the sea water as well as the increase in opacity of the sea water during the end Permian. The same phenomenon of *Neogondolella* size reduction is also observed in preliminary research from the same horizon at Shangsi Section, Sichuan Province. All the evidence suggests that there was a mass extinction that occurred at the horizon of bed 24e, and the evidence supports the viewpoint of a multi-phase mass extinction during the Permian and Triassic transition in South China.

Keywords: Meishan Section, end Permian, conodont, *Neogondolella*, size reduction.

Recent works reveal that the size reduction of organisms during the Permian-Triassic transition is of great importance for research on biotic mass extinction and recovery in this period[1,2]. Initially, Urbanek (1993) observed a decrease in the size of Silurian graptolites during the biotic crisis, and used the term "Lilliput Effect" to define the size reduction in surviving animal taxa[3]. Subsequently, researchers reported a decrease in size of late Devonian conodonts[4], heart urchins across the Cretaceous/Tertiary boundary[5], and various organisms around the Permian/Triassic boundary[1,2,6]. Generally, former studies considered the Lilliput Effect to be the dwarfism of organisms caused by the reduction of original productivity in the living environment.

The largest mass extinction in the Phanerozoic occurred during the Permian-Triassic transitional period[7−9]. The study of this mass extinction is significant in assisting our understanding of the current relationship between the biosphere and the environ-

ment, and hence it is attracting global attention. Therefore, the Global Stratotype Section and Point (GSSP) of the Permian-Triassic Boundary, Meishan Section in Zhejiang has received intensive multidisciplinary study by various research groups, including lithostratigraphy, biostratigraphy, sedimentology, sequence stratigraphy, isotope geochemistry, eventostratigraphy, and magnetostratigraphy[10].

The cause and the pattern for the Permian-Triassic mass extinction is still controversial[11−13]. Some authors propose a single-episode catastrophic mass extinction occurred, while others argue for a multi-episode mass extinction. Wu *et al*. (1994)[14] proposed that the Permian-Triassic mass extinction is a multi-episode mass extinction consisting of three episodes. Their contention is based on research at Huayingshan Section in Sichuan Province. This three-episode model has been widely applied in South China including the Meishan Section[15,16].

The three episodes of mass extinction at Meishan Section have been recognized, at the top of bed 24d, top of bed 26 and the bottom of bed 28[15], or at the top of bed 24d, top of bed 24e and the bottom of bed 28[16]. With regard to these three episodes, Yin *et al*. (1998, 2001) think the major extinction line is located at the top of bed 26[10,15], but Wignall and Hallam (1993) assume the major extinction line is at the junction of top of bed 24e and the bottom of bed 25[16]. Conversely, Fang (2004a, b) proposed that the Permian-Triassic mass extinction is a double-episode extinction, and places the major extinction line at the connection between the top of bed 24e and the bottom of bed 25, and the end extinction line at the base of bed 28. Fang's (2004a, b) contention is primarily based on a study of bivalves in South China, however Fang also points out that the ammonites, brachiopods, gastropods, and non-fusulinids foraminifera have the same double-episode extinction pattern[11,17]. In contrast, Jin *et al*. (2000) consider the end Permian mass extinction to be an abrupt catastrophic event, and this single-episode mass extinction to have happened at the junction of beds 24e/25[18]. Their theory is based on an analysis of the confidence interval of the fossil genera and species during the end Permian. Therefore, although the multi-episode mass extinction viewpoint has documented the extinction at the top of bed 24d,

this extinction is not yet widely accepted.

Conodonts survived throughout the Permian-Triassic mass extinction event and into the Triassic, and as a result many authors assume that there was no obvious change in conodonts during this time[19]. However, the study of large samples may provide insight into conodont changes in this interval. The size measurement of abundant conodont specimens is time-con- suming, and so far this kind of study has not been undertaken for the Permian-Triassic transition. In the current study measurements of large samples of conodonts from Meishan Section were recorded. The measurements indicate that the number of small sized individuals of the conodont *Neogondolella* were found to increase abruptly in bed 24e.

Normally, the size variation of an organism is related to its living environment. Ongoing research into the relationship between an organisms size and its paleoenvironment is significant for better understanding the event and the mechanism of the mass extinction during the Permian-Triassic transition. The size reduction of *Neogondolella* coincides with some important geological events that happened in the same period. It reveals that the conodonts were influenced by geological events in the Permian-Triassic transition (Fig. 1).

The reason for conodont survival to early Triassic appears to be due to its relatively strong anti-catastrophe ability[20]. On the other hand, the "size reduction" of *Neogondolella* in bed 24e supports the theory that the junction of beds 24d/24e is an important extinction line. Therefore, to recognize precisely the variation of *Neogondolella* and other conodonts is very useful for in-depth research into the geological events during the P/T transition.

The size reduction of end-Permian conodonts may be caused by the following two factors. Firstly, the catastrophic environment led to the death of abundant juvenile conodonts. Secondly, the increase of dwarfed adult conodonts was caused by the paleoenvironmental changes. The differences between juvenile and adult *Neogondolella* can be distinguished by the characteristic shape of the platform, carina and denticulation. Normally, a juvenile specimen of this species has a slender platform, undeveloped carina and isolated denticles. In contrast, the adult *Neogondolella* element

possesses a robust platform, well-developed carina as well as denticles merging in the lower part. Based on the collections used for this study, the authors consider most of the small size *Neogondolella* Pa elements to be juveniles. Considering the 'Lilliput Effect' is defined as the dwarfism of organisms caused by the reduction of productivity in the living environment, and most of the small size *Neogondolella* in this study caused by the death of abundant juvenile conodonts. Herein we adopt the term 'size reduction' instead of 'Lilliput Effect' to refer to the size variation phenomenon in present study.

1 Samples and analytical method

Thirteen successive bulk samples ranging from bed 24 to bed 29 were collected from Section A at Meishan, Zhejiang. The sample from bed 24 was divided into 5 sub-beds (beds 24a-e). Bed 27 was also evenly separated into 4 sub-beds (beds 27a-d). Each of these 13 samples weighed 20 kg. The clay samples collected from beds 25 and 28 were processed directly by water. The dissolving of other samples followed by Jiang *et al.* (2004)[21]. These samples were crushed into 1 cm³ size fragments. Diluted acetic acid (10%) was used to dissolve the samples. A 2.80－2.81 g/mL gravity liquid made of bromoform (2.89 g/mL) and acetone (0.79 g/mL) was used in conodont separation for all the samples. Except for the sample from bed 26 (black shale), which has not yet completely dissolved, all the other samples have been entirely processed over 20 months.

Over 20,000 specimens were obtained for this work. More than 14,000 were Pa elements of *Neogondolella, Hindeodus* and *Isarcicella*. A binocular stereoscope and micrometer were used to measure the length between the anterior and posterior ends of each well-preserved *Neogondolella* Pa element.

2 Size variation of *Neogondolella*

The top Changxing limestone (bed 24) was found to contain plenty of conodont specimens and the abundance of *Neogondolella* is very high in Meishan Section A. The average size of the *Neogondolella* Pa element in bed 24e is obviously smaller than those in its

upper and lower beds. Detailed investigation and statistical work were undertaken to reveal temporal patterns in size variation. Firstly, we counted and measured the size of all the well-preserved Pa elements of the genus *Neogondolella* in each bed. In order to illustrate that the size variation of *Neogondolella* at the end-Permian is not caused by different *Neogondolella* species occurring in different beds, the authors also independently counted and measured all the complete Pa elements of the species *Neogondolella changxingensis*-a dominant species with clearly identifiable characteristics.

2.1 Size distribution and change pattern of the genus *Neogondolella*

In statistical analyses, a larger sample provides a more precise result. Only a few conodont *Neogondolella* specimens were found in the beds above bed 24e, and they were poorly preserved. In bed 25 (white clay), only one complete *Neogondolella* Pa element was found, and its size is 0.557 mm. Only 4 complete *Neogondolella* Pa elements were obtained from bed 26 (black clay). The mean size of these elements is 0.970 mm. In bed 27 (beds 27a, 27b, 27c and 27d) only 16 complete *Neogondolella* Pa elements were obtained. Their mean size is 0.827 mm. Hence, the statistics presented in this paper focus on the complete *Neogondolella* Pa elements gained from bed 24. The number, mean and size variance of the *Neogondolella* Pa zlement in each bed are shown in Table 1 and Fig. 2.

According to the statistical data, the regulation of size distribution of *Neogondolella* in each bed is clear. In ascending order，the dominant peak of bed 24a and bed 24b is about 0.5 mm, that of bed 24c is between the interval of 0.6mm and 0.7 mm, and that of bed 24d is between 0.7 mm and 0.8 mm, while the dominant peak of the size of *Neogondolella* of bed 24e sharply declines to 0.3 mm to 0.4 mm, which is smaller than that of all the other beds of bed 24. Furthermore, the percentage of the *Neogondolella* Pa elements larger than 0.5 mm decreases from 81.6% in bed 24d to 39.1% in bed 24e.

The mean size of all the individuals within a community can more precisely reflect the living environment of this community. According to the results shown in Table 1, it can be observed that the size of
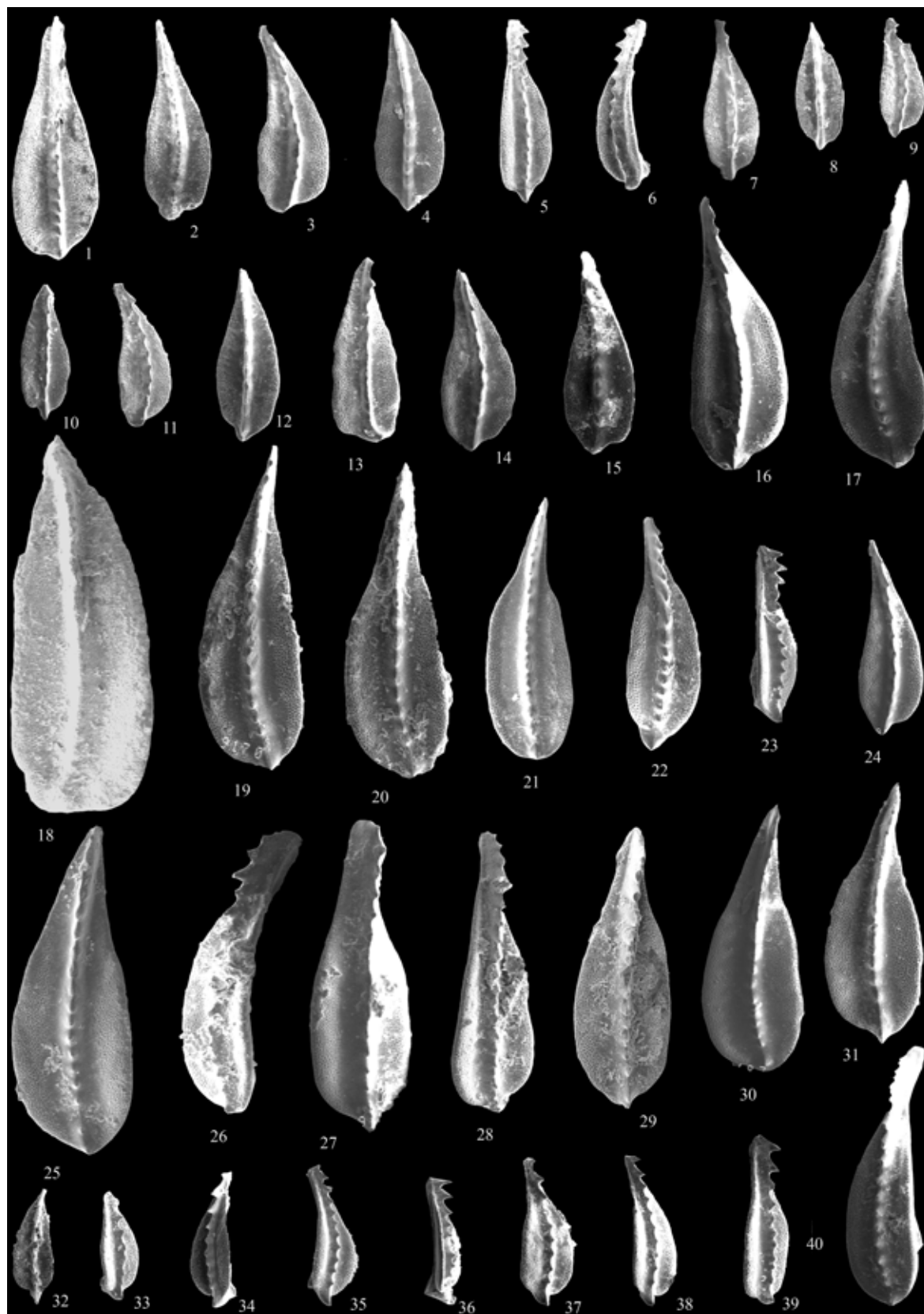
Fig. 1.   Magnification for all illustrations x66，all the samples are preserved in the Palaeontology Section, China University of Geosciences, Wuhan. 1-9 All from bed 24a of Meishan Section A. 1-2, 4-6, 9 *Neogondolella changxingensis* Wang and Wang, 1981(Pa element). 1, CHX9151, adult; 2, CHX9145, adult; 4, CHX9149, adult; 5, CHX9154, youth; 6, CHX9144, adult; 9, CHX9143, juvenile.3 *Neogondolella deflecta* Wang and Wang, 1981(Pa element), CHX9141,youth. 7-8   *Neogondolella postwangi* Tian, 1993 (Pa element). 7, CHX9148, juvenile; 8, CHX9142, juvenile. 10-17 All from bed 24b of Meishan Section A. 11,14-15,17 *Neogondolella changxingensis* Wang and Wang, 1981(Pa element). 11, CHX9162, juvenile; 14, CHX9163, youth; 15, CHX9165, youth; 17, CHX9159, adult. 10, 12   *Neogondolella postwangi* Tian, 1993(Pa element), 10，CHX9164, juvenile; 12, CHX9155, juvenile. 13   *Neogondolella deflecta* Wang and Wang, 1981(Pa element), CHX9166, youth. *Neogondolella subcarinata* Sweet, 1973 (Pa element). CHX9160, adult. 18-24   All from bed 24c of Meishan Section A. 18, *Neogondolella deflecta* Wang and Wang, 1981(Pa element), CHX5964, youth. 19-20, 22-23   *Neogondolella changxingensis* Wang and Wang, 1981(Pa element). 19, CHX9170, adult; 20, CHX9171, adult; 22, CHX9175, youth; 23, CHX9173, juvenile. 24, *Neogondolella yini* (mei, 1998) (Pa element) CHX9168, youth. 21 *Neogondolella* zhejiangensis (Mei,1996) (Pa element). CHX5962, youth. 25-31   All from bed 24d of Meishan Section A. 25, *Neogondolella yini* (Mei, 1998) (Pa element), CHZ5972, adult. 26, 29-31   *Neogondolella changxingensis* Wang and Wang, 1981(Pa element). 26, CHX9184, adult; 29, CXP0027, adult; 30, CHX9187, adult; 31, CHX9180, adult. 27-28   *Neogondolella* sp. (Pa element). 27, CHX9181, adult; 28, CHX9177, adult. 32-40 All from bed 24e of Meishan Section A. 32, 34-40   *Neogondolella changxingensis* Wang and Wang, 1981(Pa element). 32, CHX9193, juvenile; 34, CHX9194, juvenile; 35, CHX9191, juvenile; 36, CHX9195, juvenile; 37, CHX9197, juvenile; 38, CHX9192, juvenile; 39, CHX9198, youth; 40, CHX9200, adult. 33, *Neogondolella subcarinata*, Sweet, 1973(Pa element), CHX9196, juvenile.

Neogondolella Pa elements experienced a gradual increase from bed 24a to bed 24d, and a sharp drop at bed 24e from 0.688 mm down to 0.490 mm (Fig. 3).

2.2   Size distribution pattern of the species *Neogondolella changxingensis*

In order to discuss the species level size variation of the genus *Neogondolella,* the same statistical analysis was applied on the dominant species *N.changxingensis* (Table 1). The dominant peak of size of *Neogondolella changxingensis* Pa element in bed 24a and bed 24b is around 0.5 mm, and that of beds 24c and 24d is between 0.7 mm and 0.8 mm. The dominant peak of bed

24e abruptly declines to 0.3 mm and 0.4 mm (Fig. 4). The percentage of the *Neogondolella changxingensis* Pa elements larger than 0.5 mm decreases from 74.8% in bed 24d to 25.4% in bed 24e.

The mean size and variance of all the *Neogondolella changxingensis* Pa elements in each bed are shown in Table 1. Based on these data, the size variation pattern of the *Neogondolella changxingensis* Pa element is similar to that of the genus *Neogondolella.* That is, the size of the *Neogondolella changxingensis* Pa element progressively increases from bed 24a to bed 24d, and abruptly declines at bed 24e (average size from 0.623 mm down to 0.426 mm) (Fig. 5). The

Table 1   The number, mean and size variance for the genus *Neogondolella* and the species *N.changxingensis* at Meishan Section A

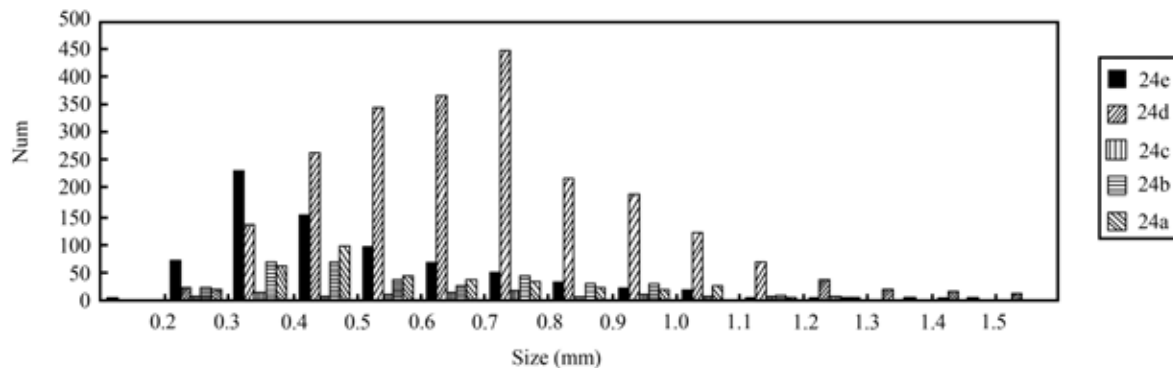| Bed	*Neogondolella* Pa element			*N.changxingensis* Pa element		
	Number	Mean (mm)	Variance	Number	Mean (mm)	Variance
24e	742	0.490	0.045	409	0.426	0.018
24d	2247	0.688	0.065	1005	0.623	0.035
24c	68	0.658	0.079	32	0.600	0.056
24b	353	0.596	0.076	134	0.541	0.045
24a	228	0.538	0.039	130	0.523	0.025

Fig. 2.   The individual size distribution histogram of the genus *Neogondolella* from bed 24 at Meishan Section A.
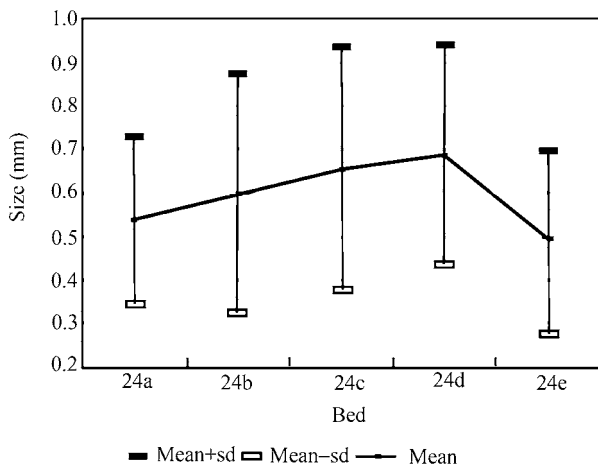
Fig. 3. Curve of the size variation (mean and standard deviation) distribution of *Neogondolella* Pa element from bed 24 of Meishan Section A.

only difference is that the mean size of the conodont *N.changxingensis* is about 0.05 mm smaller than that of the genus *Neogondolella* within the same bed. Comparing the size variation tendency both of *Neogondolella changxingensis* and the genus *Neogondolella,* the high similarity between that of species level and generic level indicates that the size reduction of end Permian *Neogondolella* in the Meishan section is not caused by taxonomic changes.

2.3 Comparison with the Shangsi Section

This research group is also undertaking the processing of large samples for conodonts from Shangsi Section, Guangyuan city, Sichuan Province. Although the large samples collected from Shangsi section are not yet completely dissolved, preliminary results indicate that a similar size reduction of *Neogondolella* Pa

elements happened at bed 26 of this section. The characteristics of the genus *Neogondolella* in bed 26 at Shangsi Section are similar to that of bed 24e at Meishan Section; most of the specimens are juveniles with a slender platform, undeveloped carina and isolated denticles. The mean size of 67 complete *Neogondolella* Pa elements from bed 26 is 0.532 mm, and the variance is 0.036. All the *Neogondolella* specimens gained from bed 27 are broken, but some characteristics indicate these specimens are adults, including a robust platform, well-developed carina and denticles merging in the lower part. The *Neogondolella* Pa elements from both bed 24e at Meishan Section and bed 26 at Shangsi Section show noticeable size reduction. However, the mean size of *Neogondolella* in bed 26 at Shangsi Section is larger than that of bed 24e at Meishan Section. This phenomenon may be caused by difference in the paleoenvironment. The sea level in Shangsi was deeper than that in Meishan during the P-T transition, and it has already been suggested that paleoenvironment affects the scope of organism size variation[4].

3 Discussions on *Neogondolella* variation

The genus *Neogondolella* flourished at the end Permian, survived the P/T mass extinction and extended into the early Triassic at Meishan Section. Taxonomically, this genus has no obvious changes after the major extinction events during the P/T transition. However, *Neogondolella* had apparent size reduction at the late end Permian (at bed 24e) at both generic and species level. Regardless of whether the size reduction of *Neogondolella* was caused by the
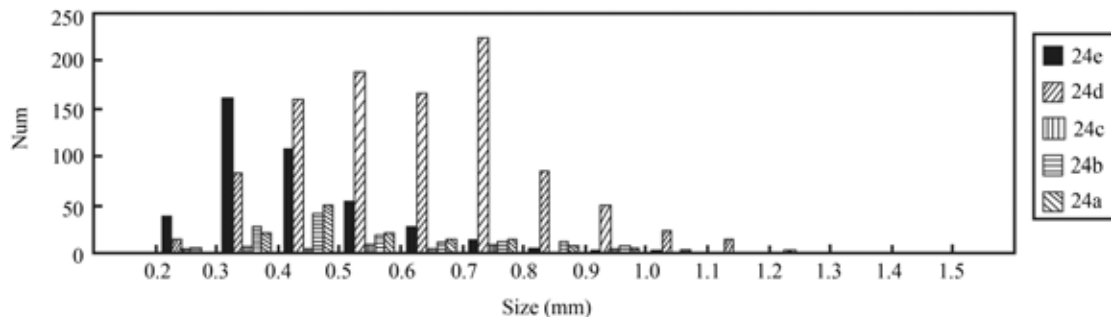

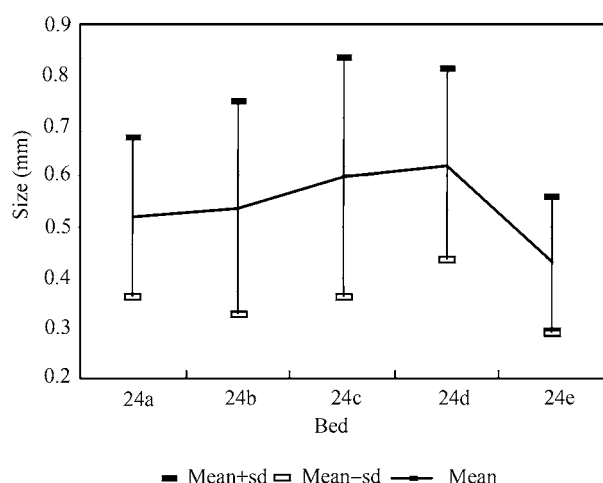Fig. 4. The individual size distribution histogram of *N.changxingensis* of bed 24 at Meishan Section A.

Fig. 5. Curve of the size variation (mean and standard deviation) distribution of *N.changxinensis* of bed 24 at Meishan Section A.

abrupt death of many juvenile individuals, or by dwarfism of adult individuals, both scenarios reflect the drastic changes to the living environment of this organism. In this sense, the conodont did respond to the Permian-Triassic mass extinction. The conodont size variation is also coincident with some other important geological events (Fig. 6).

3.1 Paleoenvironmental changes

The main lithology of bed 24 is medium–thick bedded bioclastic micrite, the siliceous contents increased from bed 24a to bed 24d, and the color of these beds is dark grey with black bands, which indicates a deeper depositional environment[22]. Zhang *et al.*[23] described the base of bed 24e as a type II sequence boundary, and bed 24e as an upward shallowing parasequence. This indicates that there was a regression occurring from bed 24d to bed 24e. In this sense, the size reduction *Neogondolella* is happening in accord with drop of the sea level. Additionally, the color of bed 24e is grey, and the silicious content is apparently less than in the lower beds. Observations while dissolving conodont samples indicate that there was a larger muddy component in bed 24e compared with the underlying beds. Similarly, Yin *et al.*[24] described that the lithology changed from chert nodule-bearing crystalline limestone in bed 24d to thin bedded micrite in bed 24e. Wu *et al*. (1991) also considered that bed 24e contained lots of muddy clastics, and that the sea water was very cloudy[25]. The above evidence supports the idea that the sea water became turbid at the interval of bed 24e. Li *et al*.[26] found pyrite in bed 24d and supposed that the anoxic event of the end Permian started at bed 24d. In this study, many pyrites have been found in bed 24d, but most are radiated or cubic aggregates. The authors argue that this type of pyrite is epigenetic rather than connate, and it can not stand anoxia. Furthermore, abundant and diverse conodonts found in bed 24d also go against the viewpoint of anoxia taking place during deposition of bed 24d. Wignall *et al*.[16,27] considered that the anoxia started at bed 25, while Zhang *et al*.[23] supposed the anoxic event at the end Permian started at bed 24e.

3.2 Biotic changes

Xie *et al*.[28] presented a two-episode mass extinction, that happened at bed 25 and bed 28 based on the study of cyanobacteria at the P/T boundary of Meishan Section. From their results, the ratio of the abundance of cyanobacterial biomarkers versus that of other general bacterial biomarkers reached the lowest value at bed 24e. The change of cyanobacteria coincides with the size reduction of *Neogondolella*. Additionally, the quantity of other organisms experienced abrupt decline at bed 24e, and the brachiopods also showed the Lilliput Effect phenomenon (He Weihong, personal communication 2005).

3.3 Geochemical changes

There are lots of scholars engaged in geochemical study across the P/T boundary, including the iridium element, rare earth element, carbon isotope, oxygen isotope and sulfur isotope. Herein we mainly discuss the research on carbon isotopes.

Previously, many researchers have reported the change of carbon isotope during the P/T transition[18,26,29−31], including the carbonate carbon isotope and the organic carbon isotope. Generally, when organisms reproduction is thriving the $\delta^{13}C$ of the sediments has a high value (positive value), however when the organisms become extinct or decline in number, the value of the $\delta^{13}C$ of sediments will decline[32]. It is commonly accepted in previous studies that the carbon isotope has an obvious negative shift at the " boundary clay" (bed 25). Jin *et al*.[18] investigated carbon isotopes at Meishan Section and suggested that the $\delta^{13}C$ reaches its minimum value at bed 25 and bed 26. Their
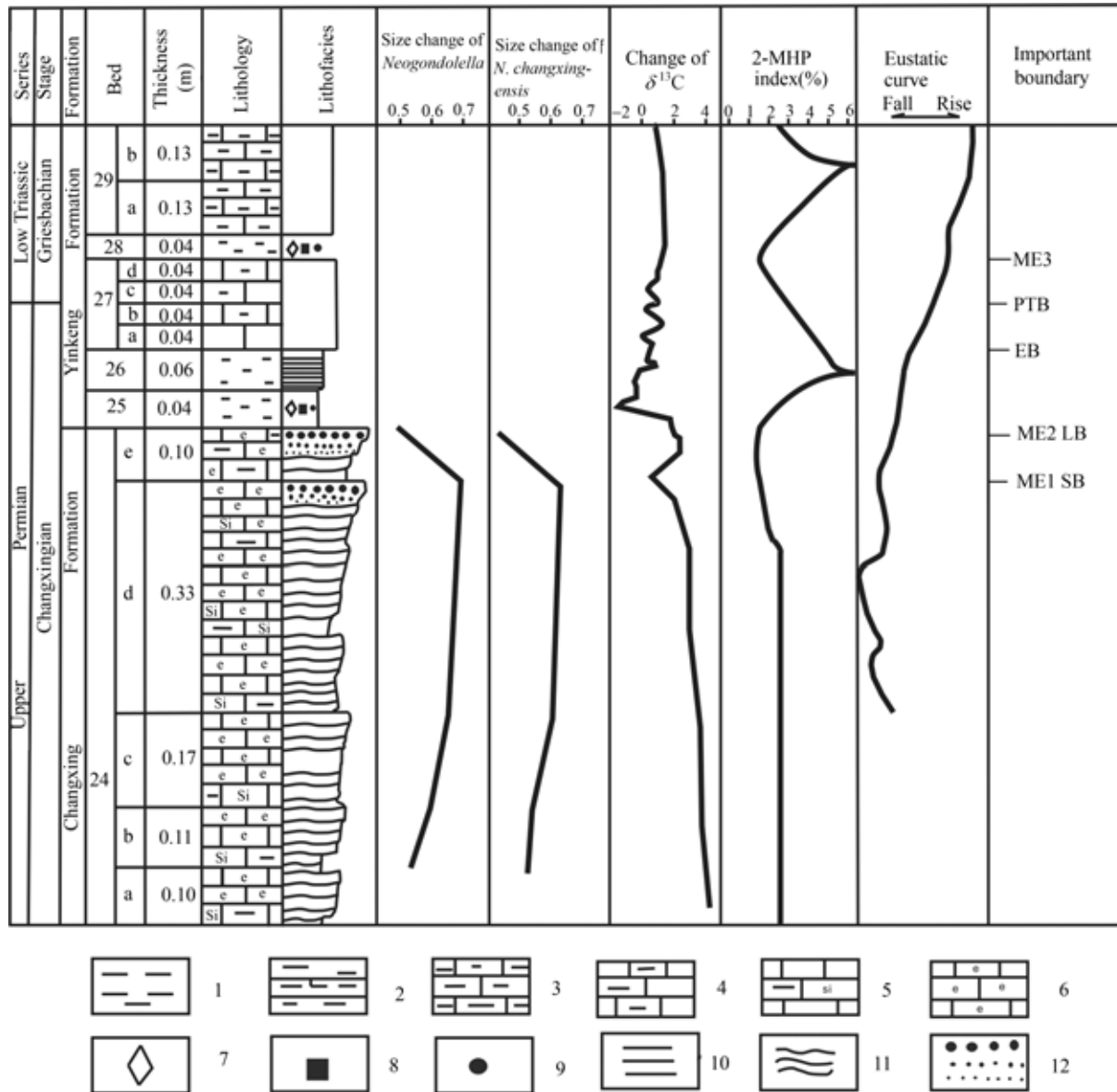
Fig. 6.   Columnar section and some important changes in the Permian-Triassic boundary beds of Meishan Section in Changxing County, Zhejiang Province, South China. 1, clay; 2, calcareous mud; 3, argillaceous limestone; 4, mud bearing limestone; 5, mud and silicious-bearing-limestone; 6, biodetritus limestone; 7, high temperature quartz; 8, zircon; 9, microspherule; 10, horizontal bed; 11, microwave bed; 12, inverse grading bed; ME: mass extinction; PTB: Permian-Triassic boundary（biostratigraphy boundary; SB:sequence stratigraphy boundary; LB: lithostratigraphy boundary; EB: event stratigraphy boundary; 2-MHP: ratio of the abundance of cyanobacterial biomarkers to more general bacterial biomarkers (some data from refs. [18,22,28,31]).

work also shows an abrupt decline of δ^{13}C at bed 24e. Similarly, according to a study of carbon isotopes at Meishan Section by Cao et al.[33], the δ^{13}C also has an abrupt decline at bed 24e. Therefore, the negative shift of carbon isotope at bed 24e is in accord with the size reduction of the conodont genus *Neogondolella*.

3.4   Discussion on the factors for size reduction of *Neogondolella*

Most authors agree that *Neogondolella* was a deep water, nektobenthic taxon that mainly lived in an off-shore environment[34]. The genus *Hindeodus* is known to have replaced *Neogondolella* during the Per-

mian-Triassic transition at Meishan Section, some authors attribute the decrease of *Neogondolella* to that the dysoxic-anoxic bottom water[22,34]. Alternatively some authors think it is due to *Neogondolella* being very susceptable to the silty water during the Permian-Triassic transition[35].

There is a consistency between the size reduction of the conodont genus *Neogondolella* and the changes to the depositional environment around bed 24e at Meishan Section. The main factors that may have caused the size reduction of *Neogondolella* are: (1) The sharp decline food. The decline of abundance of cyanobacterial biomarkers, represents decease in the productivity of the primary producers. As a superior consumer, the conodont (*Neogondolella*) is sarcophagi or saprozoic[36]. Hence, due to the sharp reduction of biomass in the living environment, the food sources of *Neogondolella* was in sharp decline, and it lead to the dwarfism of some *Neogondolella*. Twitchett[6] also proposed that the dwarfism of fossils found in all Permian-Triassic sections studied, is caused by the mass extinction of organisms. (2) The sharp increase of the water turbidity. Compared with the upper and lower beds, there is a greater muddy component in bed 24e. This implies that the sea water was turbid. *Neogondolella* is known to be sensitive to silty water[35] and could not adapt to the environmental change. Therefore, the many juvenile conodonts died abruptly and/or were affected by a reduction in size; (3) The shallowing of the sea water. It is believed that *Neogondolella* is a deep water taxon. As mentioned above, there was a regression occuring at the junction of bed 24d and bed 24e. The regression may have lead to the sudden death of juvenile conodonts, and caused the size reduction of the genus *Neogondolella*. Most small size *Neogondolella* from bed 24e at Meishan Section are juveniles, therefore their size reduction may have been caused by the death of abundant juvenile conodonts during the physical changes to the paleoenvironment.

Some authors concluded that the anoxia is the major factor that led to the Permian-Triassic mass extinction[16,37]. So far, it is hard to deduce that the size reduction of the conodont genus *Neogondolella* at bed 24e is related to anoxia. As noted above, it appears that the anoxia was not serious at bed 24e, and secondly, there was no size reduction of *Neogondolella* in bed 26 which is though to have been a very anoxic environment. In bed 26 the mean size of 4 complete *Neogondolella* elements is 0.970 mm, which is a much larger size than those of bed 24e.

4   Conclusions

Based on the study of large conodont samples collected from Permian-Triassic transitional interval at Meishan Section A, a detailed investigation of *Neogondolella* has been undertaken. This work yields the following conclusions:

(1) An apparent size reduction of *Neogondolella* occurred at bed 24e at Meishan Section during the late end Permian. Both the genus *Neogondolella*, and the species *Neogondolella changxingensis* show a similar size variation pattern. This confirms that the size reduction of end Permian *Neogondolella* is not caused by taxonomic changes. It is also proposed that the shortage of food in the living environment; the increase of water turbidity and regression are the main factors that caused the size reduction of conodonts.

(2) The size reduction of *Neogondolella* at bed 24e is in accord with some important changes that reflect the decline of organisms, *i.e.* the size reduction of brachiopods, the negative shift of $\delta^{13}C$, the decrease of the ratio of the abundance of cyanobacterial biomarkers to general bacterial biomarkers and a regression at this period. The same phenomenon can be also observed from materials from Shangsi Section. This demonstrates that the size reduction of conodonts is a widespread biotic event, and implies that there was a important extinction in this interval. Combining with previous works, this study supports that the Permian-Triassic mass extinction is a multi-phase one.

(3) As a new analytical method, research on size variation of organisms can provide new evidence for the mass extinction during the P/T transition. In this study, the size reduction of a paleontological population and community maybe caused by dwarfism of adult individuals due to the decline of productivity of the living environment, or by the abrupt death of juvenile individuals in an adverse living environment. Although both phenomena are affected by environmental changes, the intrinsic meanings of them are quite different. The death of juvenile individuals suggests that

the organism is unsuitable to the change of environ-ments; while the dwarfism of adult individuals is an adaptive strategy for organisms during change to a severe living environment. Therefore, the study of size reduction of various organisms requires detailed investigation into the ontogeny of each taxon, so as to distinguish the dwarfed adult and juvenile individuals.

(4) Every organism including the conodont has a close relationship with its living environment. The conodont was traditionally thought to be a taxon that was not greatly influenced by the Permian-Triassic transition. The investigation of the size reduction of the conodont genus *Neogondolella* indicates that conodonts can provide reliable evidence for the biotic evolution and paleoenvironmental changes in this period.

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