

Norian (Late Triassic) Conodonts from the Raohe Area, Heilongjiang, Northeastern China

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ABSTRACT: The Raohe area of Heilongjiang Province, Northeast China belongs to the Nadanhada Terrane, which was in low latitudes of Panthalassa during the Triassic. The composition of the Late Triassic conodont fauna, derived from limestone lenses interpreted to formed on seamounts, provides important new information on the pelagic biota in this ocean. New conodont samples collected from sections at Minzhu, Minnan and Chigangbei sections belong to three Norian conodont zones. In ascending order, they are: *Mockina postera* Zone, *Mockina bidentata* Zone and *Parvigondolella andrusovi* Zone. The Norian conodont fauna in the Raohe area has distinct attributes: there are a lot of cosmopolitan species (e.g., *Mockina postera*, *Mockina bidentata*, *Parvigondolella andrusovi*) which enable good global correlation; endemic conodont species are also present (e.g., *Mockina sakurae*, *Mockina shamiseni*, *Norigondolella nadanhadaensis*) indicating that Panthalassa Ocean conodont populations also contained unique taxa; and some conodonts belong to taxa with much shorter ranges in surrounding epeiric seas (e.g., *Carnepigondolella pseudoechinata*, *Neocavittella cavitata* and *Epigondolella vialovi*). The presence of the latter “relicts” indicates that the seamounts were persistently suitable habitats for many millions of years in the Late Triassic.

KEY WORDS: Norian, conodont biostratigraphy, paleoecology, Nadanhada Terrane, climate change.

0 INTRODUCTION

Conodonts play an important role in the biostratigraphy of the Norian, with numerous studies undertaken in Europe (Kolar-Jurkovšek and Jurkovšek, 2019; Karádi, 2018; Rigo et al., 2018; Mazza et al., 2012; Donofrio et al., 2003; Mastandrea et al., 1997; Kolar-Jurkovšek, 1982; Krystyn, 1980; Kozur and Mostler, 1971), North America (Orchard, 2014, 1991a, b, 1983), Japan (Yamashita et al., 2018; Mikami et al., 2008; Ishida and Hirsch, 2001; Nogami, 1968), Far East of Russia (Klets, 1995; Buryi, 1989) and China (Lyu et al., 2024; Zeng et al., 2023, 2021; Du et al., 2020; Wang et al., 2019; Ji et al., 2003; Wang, 1995; Tian, 1982). However, the occurrence of conodonts within the Panthalassa Ocean is relatively poorly known. Raohe, a county located in the eastern part of Heilongjiang Province, Northeastern of China, belongs to the Nadanhada Terrane (Li et al., 2017; Yang

et al., 1992; Shao et al., 1990; Mizutani et al., 1990, 1986; Zhang et al., 1989), which is part of the Sikhote-Alin Orogen. The investigated sections in this study are shown in Figure 1.

The Nadanhada Terrane and the Mino-Tamba Terrane in Japan are considered a super terrane in Panthalassa (Mizutani et al., 1990, 1986). Palaeomagnetic studies of the Mino-Tamba Terrane showed that it was located in an equatorial region during the Triassic (Hirooka et al., 1985; Hattori, 1982). A case study in the Inuyama area of Japan (Shibuya and Sasajima, 1986) suggested that the palaeolatitude of the Mino-Tamba Terrane was $0.7 \pm 3.4^\circ\text{N}$ (or S) in the Middle Triassic. The palaeolatitude of the Nadanhada Terrane was 21.8°N during the Late Triassic to Early Jurassic (Shao et al., 1991), indicating a low latitude location (cf. Zhou et al., 2022, Figure 5 therein).

Wang et al. (1986) were the first to report Triassic conodonts from some supposedly ‘Jurassic’ strata in the Nadanhada Terrane. They found numerous Late Triassic conodonts, e.g., *Epigondolella abneptis*, *E. spatulata*, *E. postera* (= *Mockina postera*), *E. mutidentata*, *E. bidentata* (= *Mockina bidentata*), and *Parvigondolella andrusovi* from the limestones at Chigangshan and Dongjia, and also obtained suspected *Neospathodus* sp. from chert at

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the Wupao Treefarm Section. These findings changed the age of the strata from Jurassic to Triassic. Wang et al. (1995) restudied several limestone lenses in the Nadanhada Terrane, including the Chigangshan and Dongjia sections, and reported abundant Late Triassic conodonts. They erected four conodont zones: *Metapolygnathus polygnathiformis* Zone, *Metapolygnathus nodosus* Zone, *Epigondolella spatulata* Zone and *Epigondolella bidentata* Zone. Unfortunately, they did not show conodont species distribution in their sections. Buryi (1996) also reported Triassic conodonts, e.g., *Neospathodus cf. dieneri*, *Neospathodus kockeli*, *Neogondolella mombergensis*, and *Metapolygnathus cf. parvus*, from some bedded chert sections near Dakhedzheng Town (= Dajiahe Town), Shichang and Tsiertsin of the Nadanhada Terrane.

The previous work has opened a window for understanding the Triassic conodont in the Nadanhada Terrane. However, the composition of conodont fauna and its evolution are still unclear. For better understanding the conodont fauna and biostratigraphy at this area, herein we report our new conodont materials from the Minnan, Minzhu and Chigangbei sections of the area. The palaeoecology of these oceanic occurrences during the Norian is also explored.

1 MATERIALS AND METHOD

There are several sections with limestone lenses, up to several tens of metres in extent distributed in the Nadanhada Terrane (Figures 1, 2), including the above mentioned Chigangshan and Dongjia sections. In addition, three new sections close to the Chigangshan Section were measured in working quarries: The Minnan, Minzhu and Chigangbei sections of the area. The palaeoecology of these oceanic occurrences during the Norian is also explored.

and Chigangbei sections (Figure 2a), which are about 33, 34 and 32 km north-east of Xiaojiahe Town, respectively. The Minzhu Section, is covered at the top and bottom, and dominated by medium grey, thick bedded wackestone with numerous nodular cherts or banded cherts interbedded, and is assigned to the Shengli Formation (Wang et al., 1986). The lithology of the lower part of the Minnan Section is similar to that of the Minzhu Section but the upper part is dominated by brown, thin-bedded siliceous rock (Figure 2b). The lithology of the Chigangbei Section is similar to that of the Minnan Section, while numerous small folds can be observed in the limestones. Petrographic thin-sections were observed under the polarized light microscope. Cluster analysis (CA) and non-metric multidimensional scaling (NMDS) were used to assess the palaeobiogeographic patterns (Qiao and Shen, 2015; Clarke et al., 2014; Huang et al., 2012;).

A total of 54 samples (7–8 kg) were collected from the three sections for the purpose of obtaining conodonts, including 22 samples from Minnan, 15 samples from Minzhu and 17 samples from Chigangbei. All samples were crushed into 1–2 cm³ rock fragments and dissolved by 10% acetic acid. The residue was wet filtered by two mesh sieves (20 mesh and 160 mesh) and dried at indoor temperature. LST (a solution of lithium heteropolytungstates in water) was used for the separation of the dry residue (Yuan et al., 2015). In total, we obtained 2 737 P₁ elements from the three sections. Of these 1 452 P₁ elements were obtained from the Minnan and Minzhu sections with 687 being well preserved and 1 285 P₁ elements from Chigangbei with 221 being well preserved (Figures 3–9).

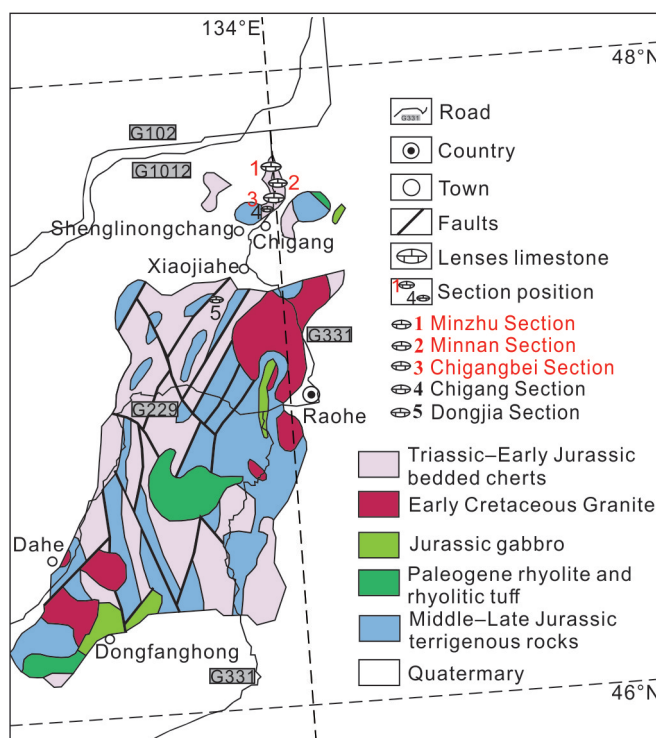


Figure 1. Simplified geological map of the Nadanhada Terrane (modified after Khanchuk et al., 2016).

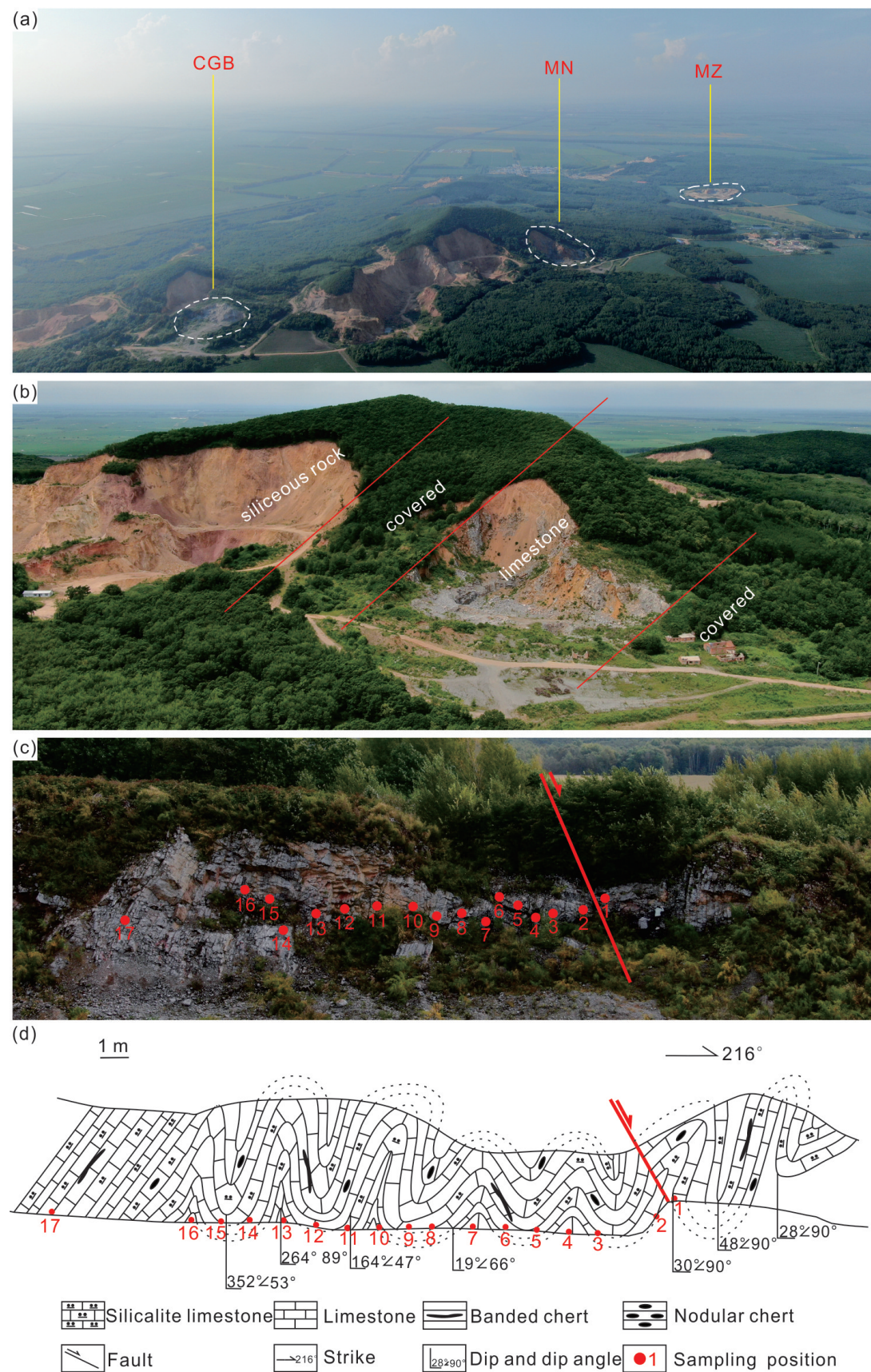


Figure 2. (a) A bird's eye view on the Minnan Section, the Minzhu Section and the Chigangbei Section of Raohe, Heilongjiang Province. MN. Minnan Section; MZ. Minzhu Section; CGB. Chigangbei Section. (b) A bird's eye view on the Minnan Section, shows limestone and siliceous rock from Shengli Formation. (c) (d) Outcrop photo and field sketch of the Chigangbei Section showing sampling positions in the tightly folded strata.

The strata of the Nadanhada Terrane are tightly folded and at the Chigangbei Section this hindered measurement of the succession of beds. Thus, the sampling positions at Chigangbei are shown in a schematic cross sec-

tion profile instead of a stratigraphic column (Figures 2c, 2d). However, conodonts from the Minnan and Minzhu sections can be used both for taxonomic identification and biostratigraphic analysis (Figure 10). All specimens

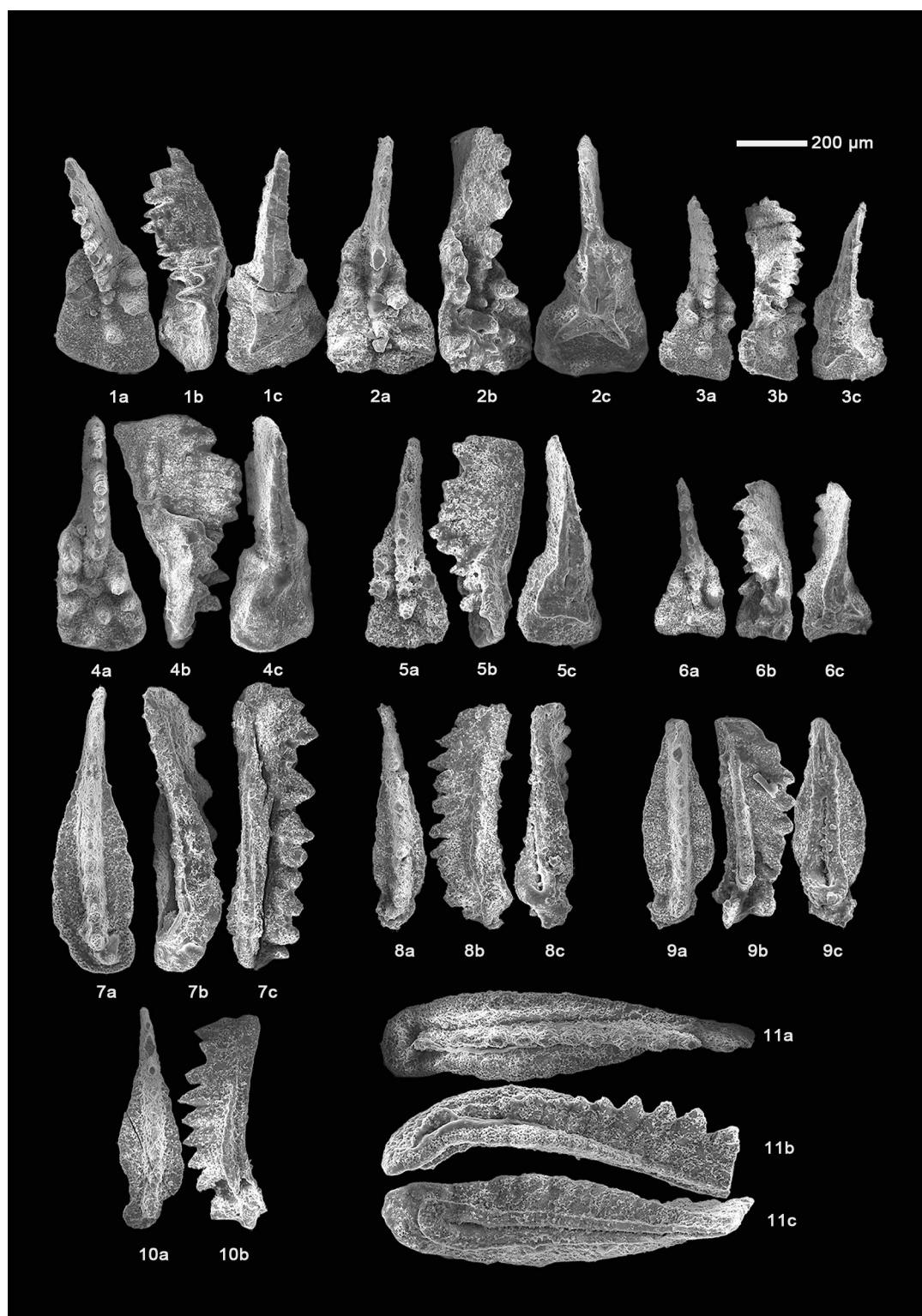


Figure 3. SEM images of conodonts from the Shengli Formation of the Minnan Section. 1–6. *Epigondolella rigoi* (Noyan and Kozur, 2007); 1. RH-001, sample MN-6; 2. RH-002, sample MN-5; 3. RH-003, sample MN-7; 4. RH-004, sample MN-7; 5. RH-005, sample MN-9; 6. RH-006, sample MN-9; 7–11. *Norigondolella nadanhadaensis* (Wang, 1995); 7. RH-008, sample MN-6; 8. RH-008, sample MN-6; 9. RH-009, sample MN-7; 10. RH-010, sample MN-9; 11. RH-011, sample MN-9.

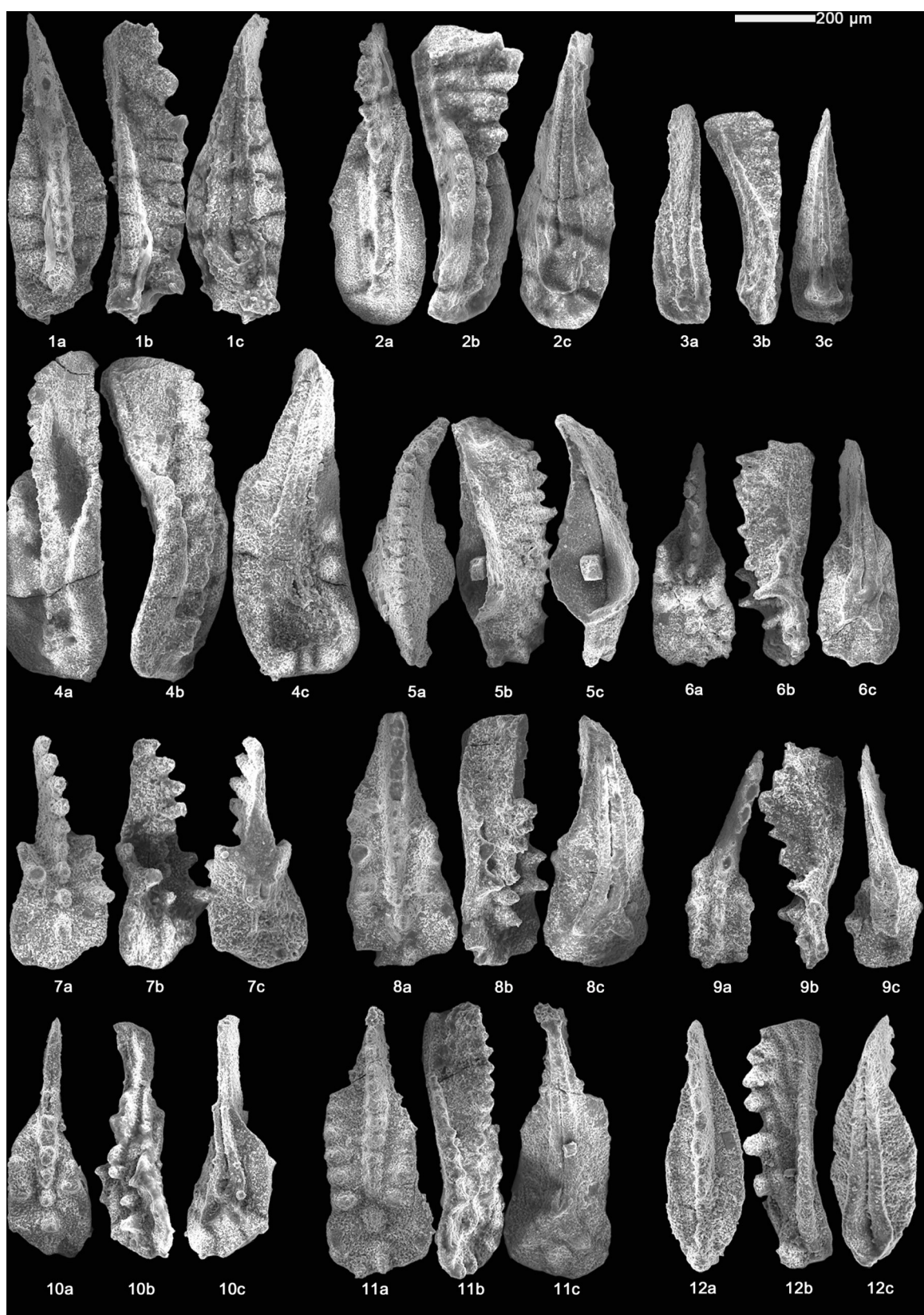


Figure 4. SEM images of conodonts from the Shengli Formation of the Minnan Section. 1–2. *Norigondolella hallstattensis* (Mosher, 1968); 1. RH-012, sample MN-7; 2. RH-013, sample MN-7; 3. *Norigondolella* sp., RH-014, sample MN-7; 4. *Carnepigondolella tuvalica* (Mazza et al., 2012), RH-015, sample MN-7; 5. *Neocavitella cavitata* (Sudar and Budurov, 1979), RH-016, sample MN-7; 6–9. *Epigondolella quadrata* (Orchard, 1991a); 6. RH-017, sample MN-7; 7. RH-018, sample MN-14; 8. RH-019, sample MN-12; 9. RH-020, sample MN-12; 10. *Epigondolella slovenica* (Karádi et al., 2021), RH-021, sample MN-7; 11. *Epigondolella uniformis* (Orchard, 1991a), RH-022, sample MN-7; 12. *Norigondolella carlae* (Rigo et al., 2018), RH-023, sample MN-14.

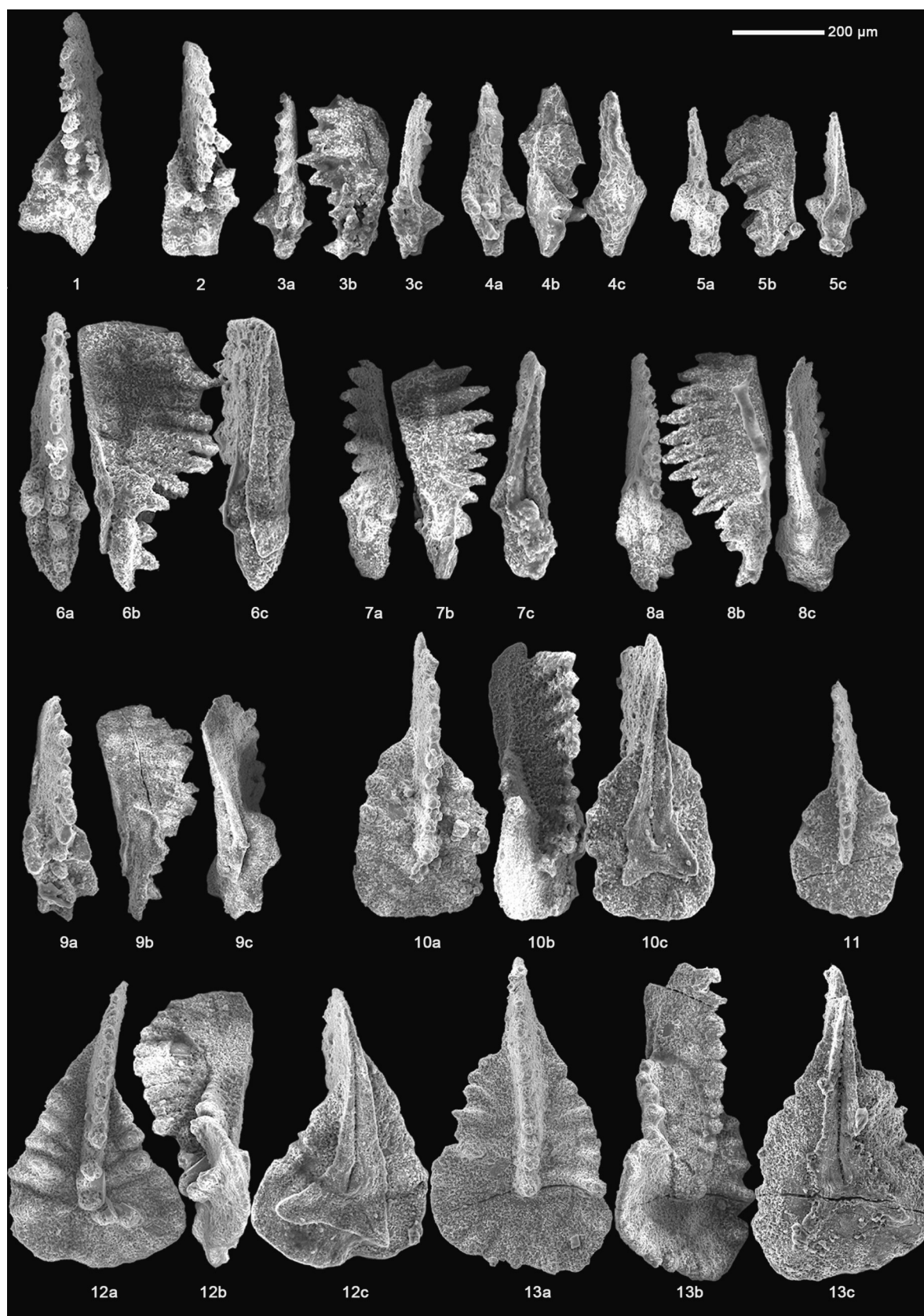


Figure 5. SEM images of conodonts from the Shengli Formation of the Minnan Section. 1–2. *Mockina postera* (Kozur and Mostler, 1971); 1. RH-024, sample MN-6; 2. RH-025, sample MN-6; 3–8. *Mockina bidentata* (Mosher, 1968); 3. RH-026, sample MN-9; 4. RH-027, sample MN-9; 5. RH-028, sample MN-22; 6. RH-029, sample MN-14; 7. RH-030, sample MN-7; 8. RH-031, sample MN-7; 9. *Mockina sakurae* (Ishida and Hirsch, 2001), RH-032, sample MN-11; 10–13. *Epigondolella spatulata* (Hayashi, 1968); 10. RH-033, sample MN-14; 11. RH-034, sample MN-14; 12. RH-035, sample MN-14; 13. RH-036, sample MN-14.

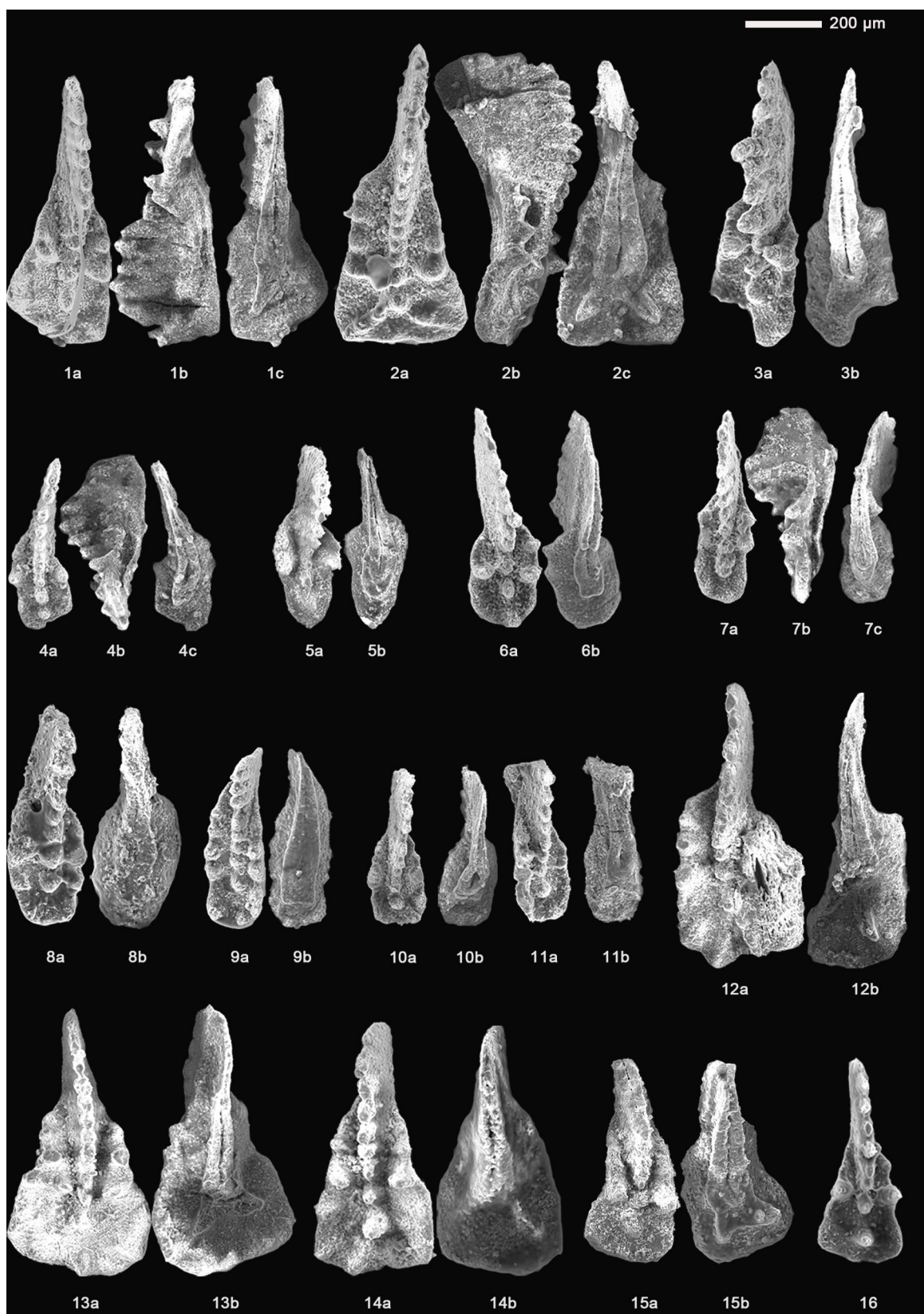


Figure 6. SEM images of conodonts from the Shengli Formation of the Minzhu Section. 1–2. *Epigondolella vialovi* (Buryi, 1989); 1. RH-037, sample MZ-1; 2. RH-038, sample MZ-1; 3–7. *Mockina postera* (Kozur and Mostler, 1971); 3. RH-039, sample MZ-5; 4. RH-040, sample MZ-1; 5. RH-041, sample MZ-8; 6. RH-042, sample MZ-1; 7. RH-043, sample MZ-1; 8–9. *Carnepigondolella pseudoechinata* (Kozur, 1990); 8. RH-044, sample MZ-5; 9. RH-045, sample MZ-1; 10–12. *Epigondolella* sp.; 10. RH-046, sample MZ-1; 11. RH-047, sample MZ-3; 12. RH-048, sample MZ-5; 13–16. *Epigondolella rigoi* (Noyan and Kozur, 2007); 13. RH-049, sample MZ-5; 14. RH-050, sample MZ-5; 15. RH-051, sample MZ-8; 16. RH-052, sample MZ-4.

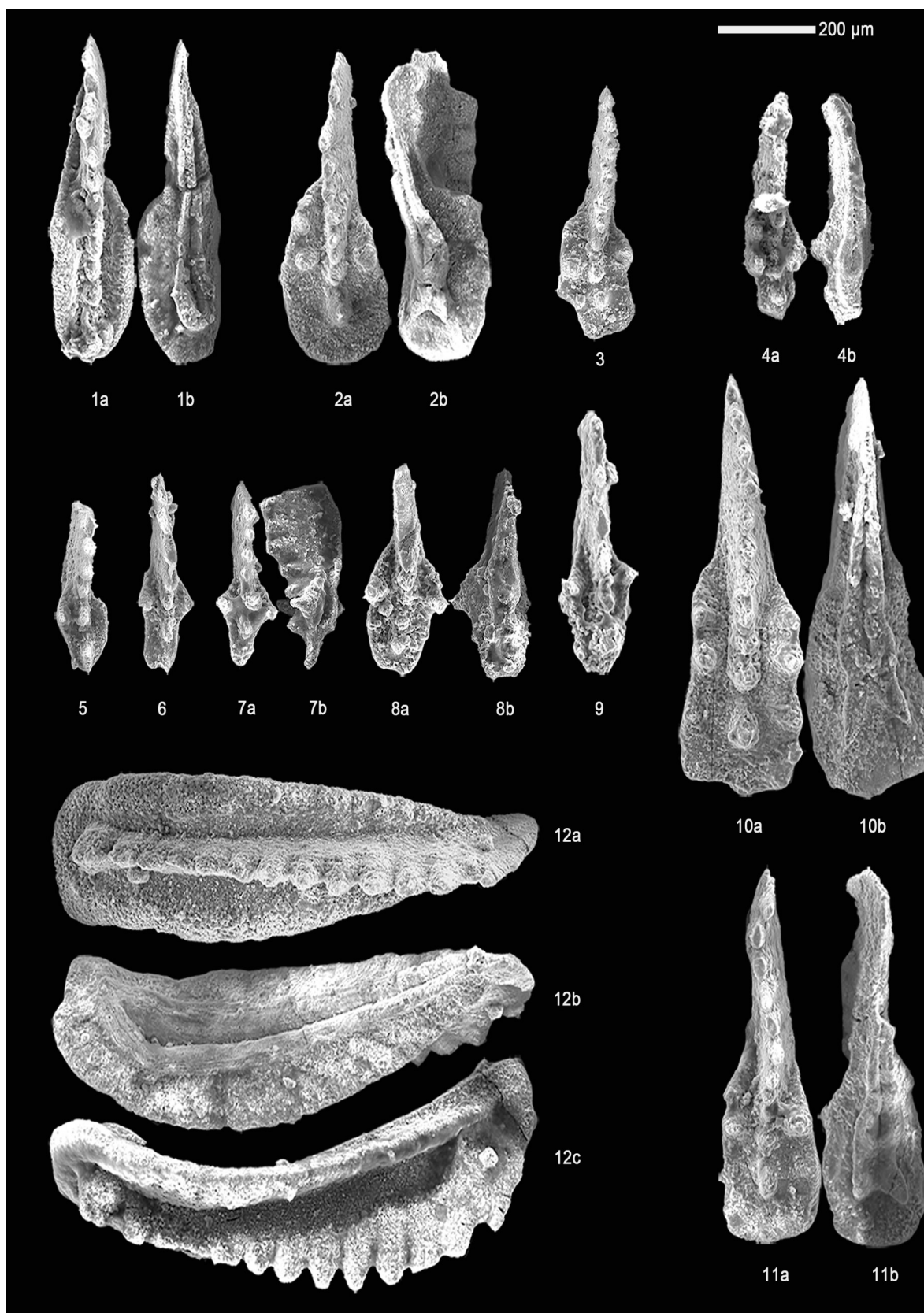


Figure 7. SEM images of conodonts from the Shengli Formation of the Minzhu Section. 1. *Norigondolella hallstattensis* (Mosher, 1968), RH-053, sample MZ-5; 2. *Epigondolella spatulata* (Hayashi, 1968), RH-054, sample MZ-5; 3. *Mockina shamiseni* (Ishida and Hirsch, 2001), RH-055, sample MZ-8; 4. *Mockina hisaidaniensis* (Ishida and Hirsch, 2001), RH-056, sample MZ-4; 5–9. *Mockina bidentata* (Mosher, 1968); 5. RH-057, sample MZ-7; 6. RH-059, sample MZ-6; 7. RH-060, sample MZ-6; 8. RH-058, sample MZ-7; 9. RH-061, sample MZ-6; 10–11. *Epigondolella quadrata* (Orchard, 1991a); 10. RH-062, sample MZ-5; 11. RH-063, sample MZ-5; 12. *Norigondolella* sp., RH-064, sample MZ-1.

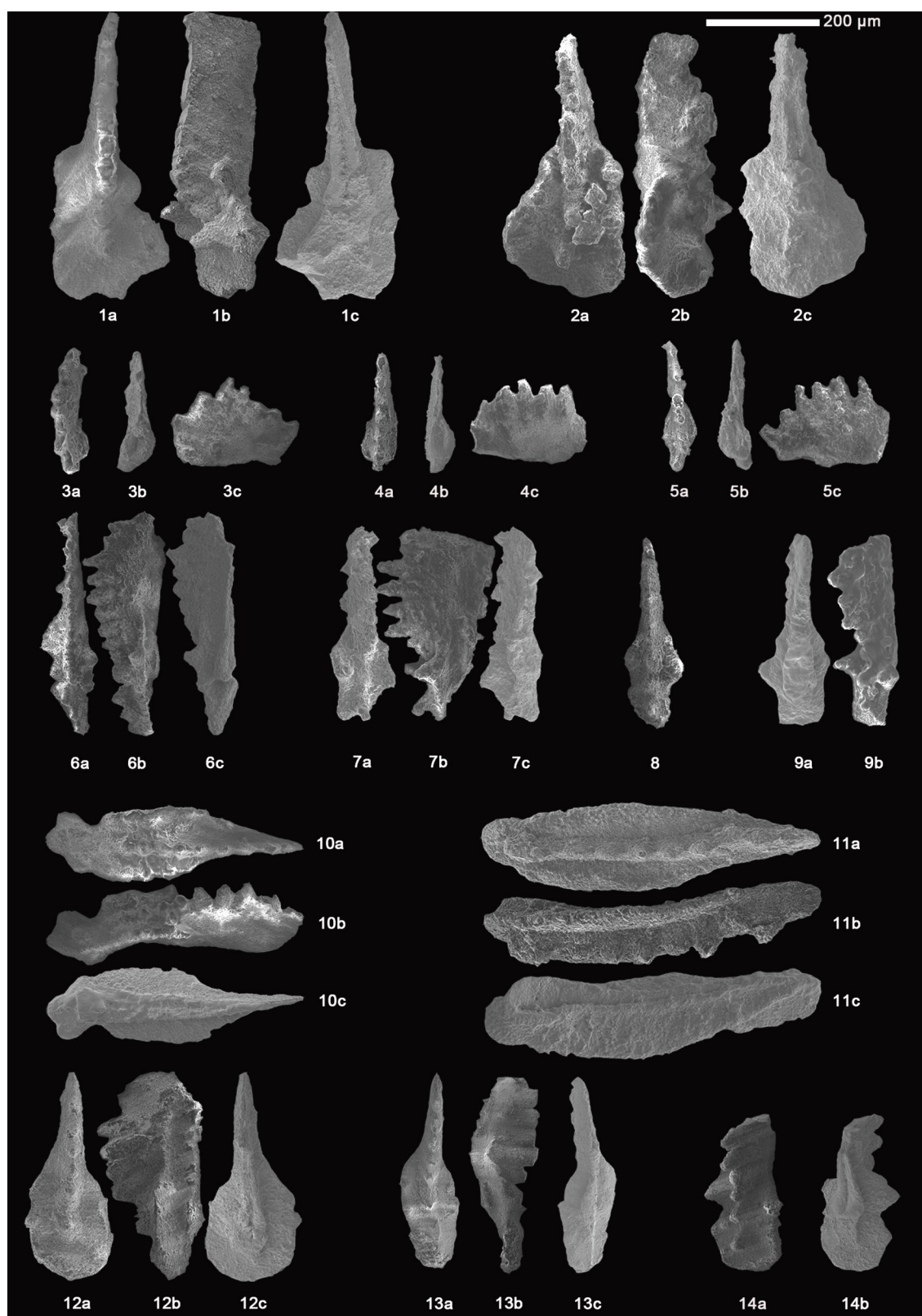


Figure 8. SEM images of conodonts from the Shengli Formation of the Minzhu Section. 1–2. *Epigondolella rigoi* (Noyan and Kozur, 2007); 1. RH-065, sample 2MZC-2; 2. RH-066, sample 2MZC-1; 3–5. *Parvigondolella andrusovi* (Kozur and Mock, 1972); 3. RH-067, sample 2MZC-3; 4. RH-068, sample 2MZC-3; 5. RH-069, sample 2MZC-3; 6. *Mockina hisaidaniensis* (Ishida and Hirsch, 2001), RH-070, sample 2MZC-1; 7. *Mockina shamiseni* (Ishida and Hirsch, 2001), RH-071, sample 2MZC-1; 8–9. *Mockina bidentata* (Mosher, 1968); 8. RH-072, sample 2MZC-2; 9. RH-073, sample 2MZC-1; 10–11. *Norigondolella nadanhadaensis* (Wang, 1995); 10. RH-074, sample 2MZC-3; 11. RH-075, sample 2MZC-2; 12. *Epigondolella spatulata* (Hayashi, 1968), RH-076, sample 2MZC-3; 13–14. *Mockina postera* (Kozur and Mostler, 1971); 13. RH-077, sample 2MZC-2; 14. RH-078, sample 2MZC-3.

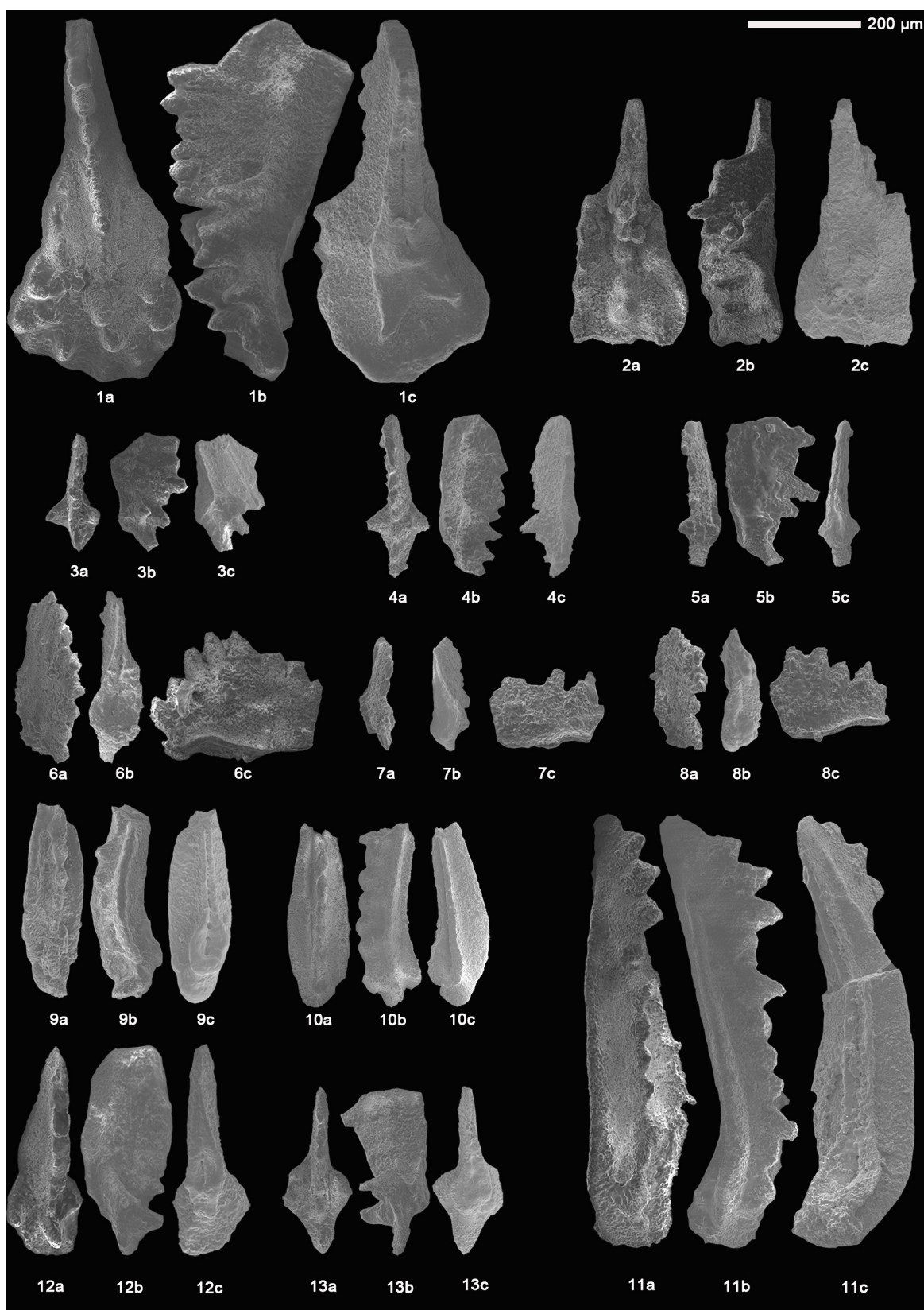


Figure 9. SEM images of conodonts from the Shengli Formation of the Chigangshanbei Section. 1–2. *Epigondolella rigoi* (Noyan and Kozur, 2007); 1. RH-079, sample CNC-4; 2. RH-080, sample CNC-12; 3–5. *Mockina bidentata* (Mosher, 1968); 3. RH-081, sample CNC-5; 4. RH-082, sample CNC-10; 5. RH-083, sample CNC-16; 6–8. *Parvigondolella andrusovi* (Kozur and Mock, 1972); 6. RH-084, sample CNC-6; 7. RH-085, sample CNC-16; 8. RH-086, sample CNC-16; 9–10. *Norigondolella nadanhadaensis* (Wang, 1995); 9. RH-087, sample CNC-6; 10. RH-088, sample CNC-17; 11. *Norigondolella* sp, RH-089, sample CNC-17; 12–13. *Mockina postera* (Kozur and Mostler, 1971); 12. RH-090, sample CNC-4; 13. RH-091, sample CNC-12.

are housed at the School of Earth Sciences, China University of Geosciences (Wuhan). For better communication, the genus name of conodont follows with that of in Rigo et al., (2018).

2 CONODONT BIOSTRATIGRAPHY

In total, six conodont species belonging to four genera were identified from the Shengli Formation at Chigangbei: *Epigondolella rigoi*, *Norigondolella nadanhadaensis*, *Norigondolella* sp., *Mockina postera*, *Mockina bidentata*, and *Parvigondolella andrusovi*. Despite the complicated structure of this section, a *Parvigondolella andrusovi* Zone is likely to be present at this location.

Nineteen conodont species belonging to six genera are identified from the Shengli Formation at the Minnan and Minzhu sections in Raohe area, which have enabled

us identifying three conodont zones, in ascending order, they are: *Mockina postera* Zone, *Mockina bidentata* Zone and *Parvigondolella andrusovi* Zone (Figure 10).

2.1 *Mockina postera* Zone

Lower limit: The first occurrence (FO) of *Mockina postera*.

Upper limit: FO of *Mockina bidentata*.

The *Mockina postera* Zone ranges from the base of sample MN-5 to the base of sample MN-7 at Minnan and the base of sample MZ-1 to the base of sample 2MZC-6 at Minzhu.

Associated taxa include: *Epigondolella rigoi*, *Epigondolella quadrata*, *Epigondolella uniformis*, *Epigondolella vialovi*, *Epigondolella slovenica*, *Epigondolella spatulata*, *Epigondolella* sp., *Mockina sakurae*, *Mockina hasaidani*

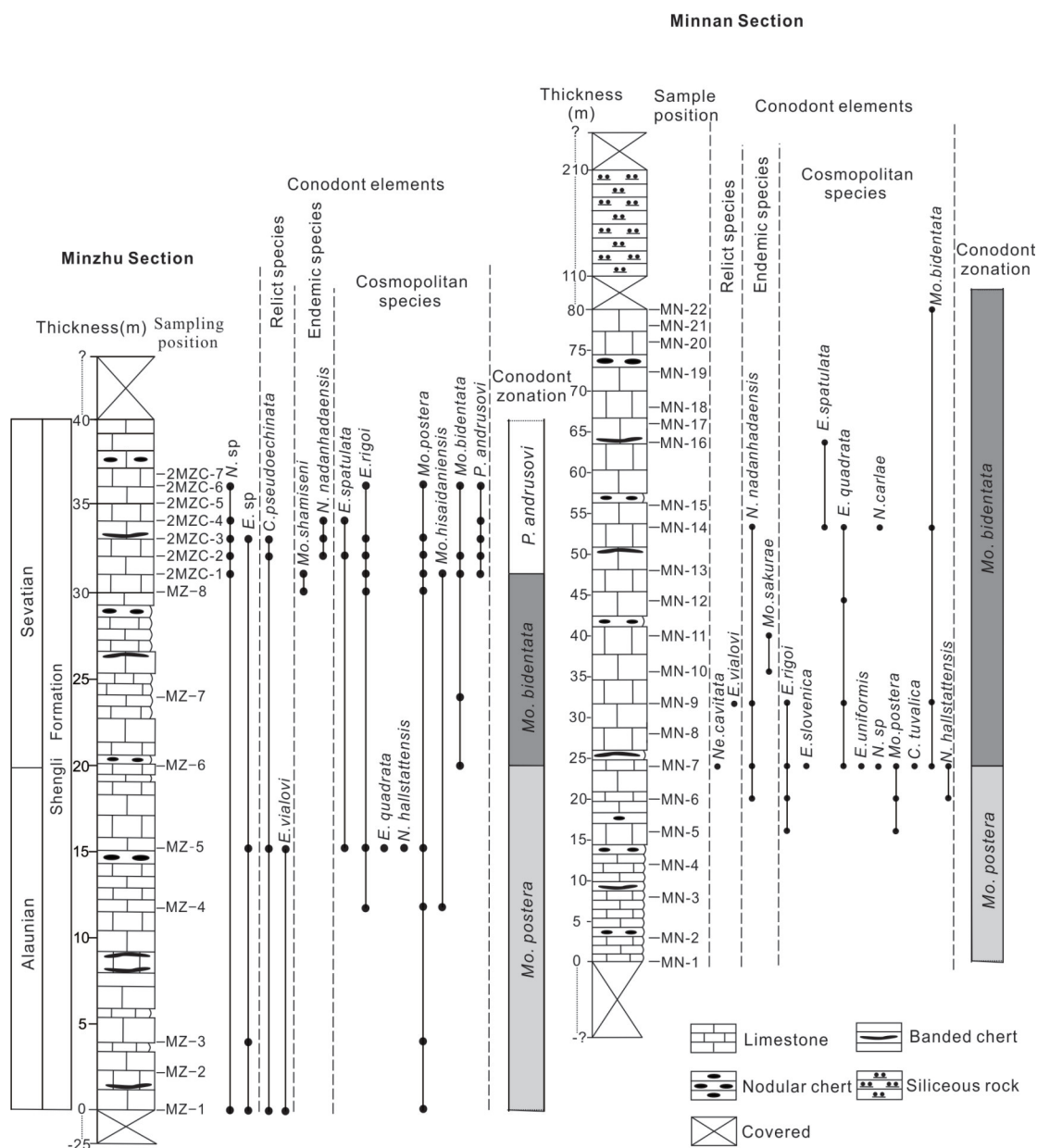


Figure 10. Log of the Minzhu and the Minnan sections, showing sampling positions and conodont ranges. *C.* *Carnepigondolella*; *E.* *Epigondolella*; *Mo.* *Mockina*; *Ne.* *Neocavittella*; *N.* *Norigondolella*; *P.* *Parvigondolella*.

ensis, *Norigondolella nadanhadaensis*, *Norigondolella hallstattensis*, *Norigondolella* sp., *Carnepigondolella pseudoechinata* and *Neocavitella cavitata*.

Mockina postera (Kozur and Mostler) was established from the Middle Norian strata of Sommeraukogel, Austria (Kozur and Mostler, 1971). Krystyn (1980) first proposed an *Epigondolella postera* (= *Mockina postera*) assemblage Zone, placing it above the *Epigondolella spatulata* assemblage Zone, and below the *Epigondolella bidentata* Zone. Orchard (1983) also proposed an *Epigondolella postera* (= *Mockina postera*) Zone from the Middle Norian of British Columbia, between the *Epigondolella* n. sp. C Zone and *Epigondolella* n. sp. D Zone. Kozur (1989), in summarizing Permian and Triassic conodont zones, put the *Epigondolella postera* assemblage Zone between the *Epigondolella mutidentata* assemblage Zone and *Epigondolella bidentata* Zone. Orchard (1991a) further clarified that the *Epigondolella postera* Zone as occurring between the *Epigondolella elongata* Zone and *Epigondolella serrulata* Zone after Orchard (1983) (Figure 4). Rigo et al., (2018) suggested a *Mockina postera* Interval Zone, from above the *Mockina spiculata* Interval Zone and below the *Mockina serrulata* Interval Zone in the Middle Norian (Figure 11). Our *Mockina postera* Zone correlates with the *Epigondolella postera* assemblage Zone of Krystyn (1980) and Kozur (1989), the *Epigondolella postera* Zone of Buryi (1989), the *Epigondolella postera* and *Epigondolella serrulata* zones of Orchard (1991a), the upper part of the *Epigondolella spatulata* Zone of Wang (1995), the *Epigondolella postera* Zone of Klets (1995), the *Mockina postera* Interval Zone and the *Mockina serrulata* Interval Zone of Rigo et al., (2018), and the *Mockina postera* Zone in Yamashita et al. (2018). All indicate a Middle Norian Age (Figure 11).

Most of the associated species in the *Mockina postera* Zone belong to *Epigondolella* which has been widely reported from Western Tethys (Kolar-Jurkovšek and Jurkovšek, 2019; Rigo et al., 2005; Kozur, 1989; Krystyn, 1980), North America (Orchard, 1991a, 1983) and Panthalassa (Yamashita et al., 2018; Ishida and Hirsch, 2001; Wang et al., 1995). Rigo et al. (2018) evaluated Late Triassic conodonts in Tethys and showed that *E. ri-*

goi, *E. quadrata*, *E. uniformis* and *E. vialovi* first occur in the latest Carnian, become common in the Lacin (lower Norian), and can range up into the lower part of the Alauanian (Middle Norian). *E. spatulata* is common in the Lacin and survives into the Lower Alauanian (Rigo et al., 2018). *E. slovenica* appears in the lower part of Alauanian (Karádi et al., 2021).

Of the species recorded from our sections, *Norigondolella hallstattensis* was first reported from Hallstatt, Austria (Mosher, 1968) and later it was widely reported from other western Tethyan locations (Karádi et al., 2021; Krystyn, 1980), Panthalassa (Ishida and Hirsch, 2001) and Tibet (Wu et al., 2023). *Carnepigondolella pseudoechinata* and *Neocavitella cavitata* are known from the Tuvanian (upper Carnian) in Western Tethys (Mazza et al., 2012) and North America (Orchard, 2014) and are here found to be still extant in the Middle Norian. *Norigondolella nadanhadaensis* is only known from the Norian strata of the Nadanhada Terrane (Wang, 1995). *Mockina sakurae* was reported from the Middle Norian strata of Japan in Panthalassa (Ishida and Hirsch, 2001). *E. quadrata*, *E. uniformis*, *E. spatulata*, *Norigondolella hallstattensis* and *M. postera*, are all found in Middle Norian strata of our study, but they occur in the topmost Norian of Panthalassa sections in Japan (Ishida and Hirsch, 2001).

2.2 *Mockina bidentata* Zone

Lower limit: FO of *Mockina bidentata*.

Upper limit: FO of *Parvigondolella andrusovi*.

The *Mockina bidentata* Zone ranges from the base of sample MN-7 to the top of sample MN-22 at Minnan, and the base of sample MZ-6 to the base of sample 2MZC-6 at Minzhu. Associated taxa include: *Epigondolella rigoi*, *Epigondolella vialovi*, *Epigondolella quadrata*, *Epigondolella spatulata*, *Mockina sakurae*, *Norigondolella nadanhadaensis*, *Norigondolella hallstattensis*, *Norigondolella carlae*, *Mockina postera* and *Mockina shamiseni*.

Mockina bidentata (Mosher) was established based on numerous specimens from the Late Norian strata of Europe and North America (Mosher, 1968). Krystyn (1980) first proposed an *Epigondolella bidentata* (= *Mocki-*

Stage	Conodont zones							
	Location	Tethys (Rigo et al., 2018)	Pangea (Orchard, 1991)	Southwestern China (Zeng et al., 2023)	Panthalassa Ocean (Yamashita et al., 2018)	Raohe area, Nadanhada Terrane		
	Substage					(Wang, 1995)	(this study)	
Norian	Sevastian	<i>Mi.hernsteini</i>	<i>Mi.posthernsteini</i>	<i>P.andrusovi</i>	<i>Mo.bidentata</i>	<i>Mi.posthernsteini</i>		
		<i>P.andrusovi</i>	<i>Mo.bidentata</i>			<i>P.andrusovi</i>		
		<i>Mo.bidentata</i>	<i>Mo.bidentata</i>	<i>Mo.bidentata</i>		<i>Mo.bidentata</i>	<i>Mo.bidentata</i>	
	Alaunian	<i>Mo.slovakensis</i>	<i>E.serrulata</i>		<i>Mo.postera</i>	<i>E.spatulata</i>	<i>Mo.postera</i>	
		<i>Mo.serrulata</i>	<i>E.postera</i>					
		<i>Mo.elongata</i>	<i>E.elongata</i>					
		<i>Mo.postera</i>	<i>E.spiculata</i>					
		<i>Mo.spiculata</i>	<i>E.multidentata</i>					
	Lacian	<i>E.rigoi-E.quadrata</i>	<i>E.triangularis</i>		<i>E.triangularis</i>			
		<i>C.gulloae</i>	<i>E.quadrata</i>		<i>E.quadrata</i>			
		<i>Me.parvus</i>	<i>Me.primitius</i>					

Figure 11. Correlation of Norian conodont zones amongst different areas. *C.* *Carnepigondolella*; *E.* *Epigondolella*; *Me.* *Metapolygnathus*; *Mi.* *Misikella*; *Mo.* *Mockina*; *Ne.* *Neocavitella*; *N.* *Norigondolella*; *P.* *Parvigondolella*.

na bidentata) Zone, from above the *Epigondolella postera* assemblage Zone, and below the *Gondolella* (= *Norigondolella*) *steinbergensis* assemblage Zone. Orchard (1983) also proposed an *Epigondolella bidentata* (= *Mockina bidentata*) Zone in British Columbia. Kozur (1989) put the *Epigondolella bidentata* Zone between the *Epigondolella postera* assemblage Zone and the *Pavigondolella andrusovi* assemblage Zone. Orchard (1991a) refined his analysis (Orchard, 1983) and put the *Epigondolella bidentata* Zone between the *Epigondolella serrulata* Zone and the *Misikella posthernsteini* Zone (Figure 11). Rigo et al., (2018) suggested a *Mockina bidentata* Interval Zone, above the *Mockina slovakensis* Interval Zone and below the *Pavigondolella andrusovi* Interval Zone (Figure 11). Our *Mockina bidentata* Zone correlates to the lower part of *Epigondolella bidentata* Zone of Krystyn (1980), the *Epigondolella bidentata* Zone of Kozur (1989), the lower part of *Epigondolella bidentata* Zone of Orchard (1991a, 1983), the lower part of *Epigondolella bidentata* Zone of Buryi (1989), the lower part of *Epigondolella bidentata* Zone of Klefs (1995), the lower part of *Epigondolella bidentata* Zone of Wang (1995), the *Mockina bidentata* Interval Zone in Rigo et al., (2018), and the *Mockina bidentata* Zone in Yamashita et al. (2018) and Zeng et al., (2023, 2021). It is the lowermost conodont zone of the Late Norian (Figure 11). The base of *Mockina bidentata* Zone also marks the boundary between Alaunian and Sevatian (Rigo et al., 2018; Kozur, 1989).

N. carlae was used as a guide form for the Upper Tethys in Tethys (Rigo et al., 2018). This is the first record in the study area. *Mockina sakurae* and *Mockina shamiseni* were also only previously reported from Japan from the uppermost of Triassic (Ishida and Hirsch, 2001).

2.3 *Parvigondolella andrusovi* Zone

Lower limit: FO of *Parvigondolella andrusovi*.

Upper limit: FO of *Misikella hernsteini*.

The *Parvigondolella andrusovi* Zone ranges from the base of sample 2MZC-1 to the top of sample 2MZC-6 at the Minzhu Section.

Associated taxa include: *Epigondolella rigoi*, *Epigondolella spatulata*, *Epigondolella* sp., *Norigondolella nadanhadaensis*, *Norigondolella* sp., *Mockina postera*, *Mockina bidentata*, *Mockina shamiseni*, *Mockina hisaidaniensis* and *Carnepigondolella pseudoechinata*.

Parvigondolella andrusovi (Kozur and Mock) was established based on specimens from the Late Norian strata of Slovakia where Kozur and Mock (1972) proposed a *Parvigondolella andrusovi* assemblage Zone from above the *Epigondolella bidentata* (= *Mockina bidentata*) assemblage Zone and below the *Spathognathodus* (= *Misikella*) *hernsteini* assemblage Zone. An interest point is that many of the *Parvigondolella andrusovi* specimens from the Raohe area in our collection are smaller than those reported from other areas. However, this is not seen in specimens from the underlying strata below the *Parvigondolella andrusovi* Zone and they are not considered to be juveniles of other species.

Parvigondolella andrusovi occurs in western Tethys (Kolar-Jurkovšek and Jurkovšek, 2019; Rigo et al. 2016; Kozur and Mock 1991), East Tethys (Zeng et al., 2023, 2021; Dong and Wang, 2006), North America (Orchard et al. 2007) and Panthalassa (Yamashita et al., 2018; Wang, 1995). The *Parvigondolella andrusovi* Zone is used widely in correlation of Upper Norian strata (Zeng et al., 2023, 2021; Rigo et al., 2018; Wang and Wang, 2016; Korte et al., 2005; Channell et al., 2003; Kozur, 2003), and is clearly present in our study.

3 DISCUSSION

3.1 Norian Conodont Fauna in Raohe Area

The twelve conodont species identified from our collection in the *Mockina postera* Zone represent a diverse middle Norian (Alaunian) assemblage. They include cosmopolitan elements: *Epigondolella rigoi*, *Epigondolella quadrata*, *Epigondolella uniformis*, *Epigondolella spatulata*, *Epigondolella slovenica*, *Mockina postera*, *Norigondolella hallstattensis*. More endemic taxa include *Mockina sakurae* known from SW Japan (Ishida and Hirsch, 2001) and *Norigondolella nadanhadaensis* known only from the study area (Wang, 1995), although this later species is very similar to the Tethyan (Upper Carnian) *Metapolygnathus lindae* (Kozur). As well as these species, two typical Tethyan species, *Carnepigondolella pseudoechinata* and *Neocavitella cavitata*, and one typical Lacinian (Lower Norian) species, *Epigondolella vialovi*, occur in this Middle Norian assemblage thereby considerably extending the known ranges of these species.

Eleven conodont species are recovered from our collection in the Sevatian *Mockina bidentata* Zone with most being cosmopolitan. Among them, only *Mockina bidentata* is common in the Sevatian, while *Epigondolella rigoi*, *Epigondolella quadrata*, *Epigondolella spatulata*, *Norigondolella hallstattensis* and *Mockina postera* are more common in the Alaunian and *Epigondolella vialovi* is common in Lacinian. *Norigondolella carlae* and *Neocavitella cavitata* are usually Tethyan species, their survival into the Sevatian indicates a considerable range extension. *Norigondolella nadanhadaensis*, and *Mockina sakurae*, *Mockina shamiseni* (two Alaunian species previous were reported from Panthalassan terranes of Japan (Mikami et al., 2008; Ishida and Hirsch, 2001)) can be also found in the *Mockina bidentata* Zone of Raohe area.

Eleven conodont species have been recovered from the Sevatian *Parvigondolella andrusovi* Zone in our study and again most of them are cosmopolitan. Among them, only *Mockina bidentata* is common in Sevatian, while *Epigondolella rigoi*, *Epigondolella spatulata*, *Mockina postera* are common Alaunian species and *Carnepigondolella pseudoechinata* is a typical Tethyan species. The prolonged survival of these species into the Mid Sevatian suggests that they may be interpreted as relict species that were formerly more widespread. Except *Norigondolella nadanhadaensis*, two Panthalassan Alaunian species, *Mockina sakurae*, *Mockina shamiseni* (reported from Japan (Mikami et al., 2008; Ishida and Hirsch,

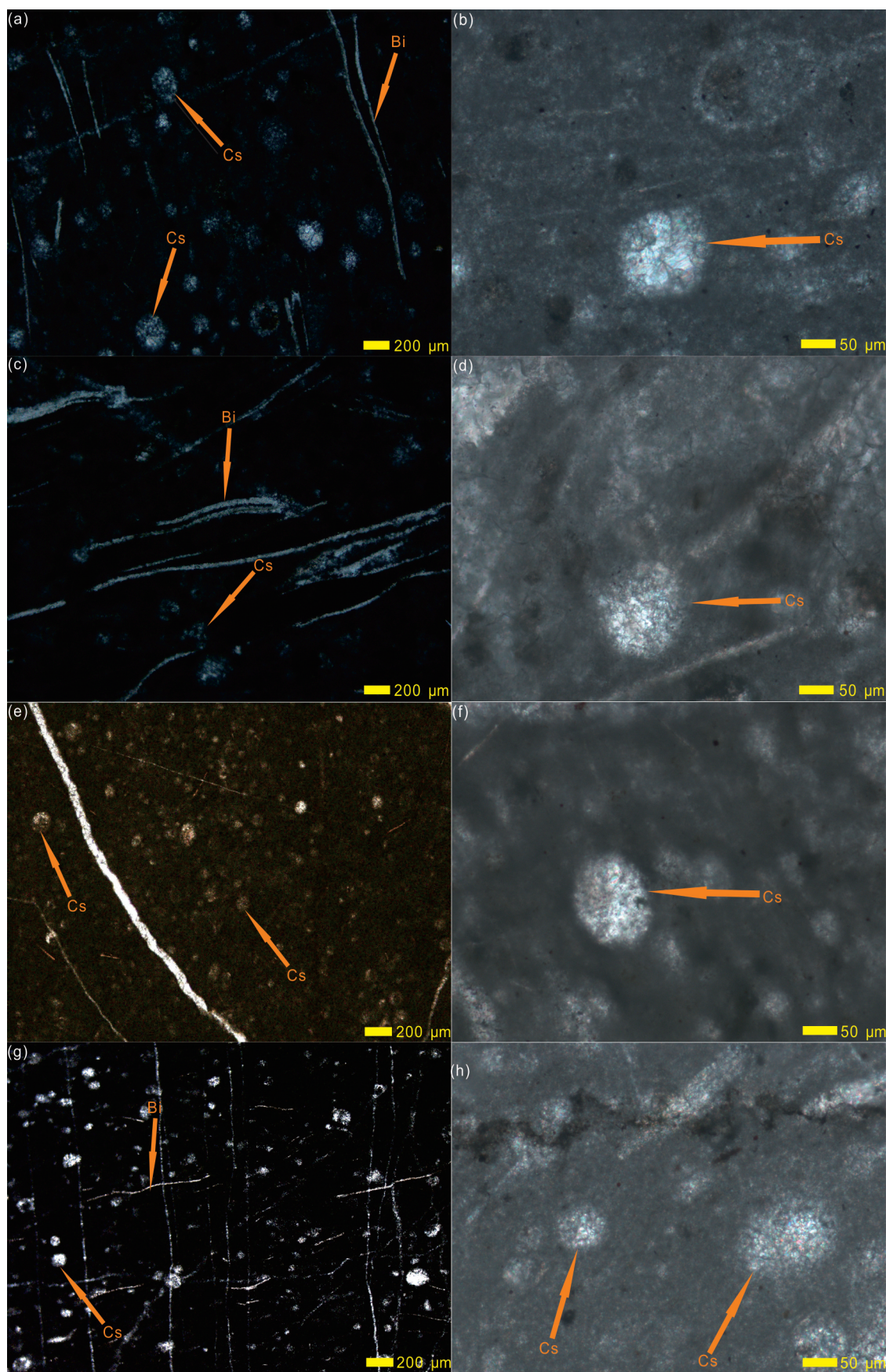


Figure 12. Thin-section photos of Minnan Section, Minzhu Section and Chigangbei Section. (a) (c) (e) (g) Under the polarized light microscope, single polarized light, scale bar = 200 μm ; (b) (d) (f) (h) under the polarized light microscope, crossed nicols, scale bar = 50 μm . (a) (b) from MN-22; (c) (d) from MN-25; (e) (f) from MZ-12; (g) (h) from CGB-2. Bi. Bivalves; Cs. calcispheres.

2001)) are also found in the *Parvigondolella andrusovi* Zone of Raohe area.

In summary, there are four characteristics of the distinctive Norian conodont fauna of the Raohe area. Firstly, numerous conodont species, although with small number of specimens, occur in our collection. More than ten conodont species are found in each conodont zone, including many cosmopolitan elements which enable global correlation. Secondly, the overall composition of the assemblages is unlike that seen in many other regions. Thirdly, some endemic species (e.g., *Mockina sakurae*, *Mockina shamiseni*, *Norigondolella nadanhadaensis*) are similar to those of Japan indicating that the Panthalassa Ocean had its own distinct fauna that was combined with the more pandemic species. Fourthly, several conodont species have greater ranges in the Raohe Norian conodont fauna. Thus, Lacinian and Tuvanian species occur in the Alaniian *Mockina postera* Zone, whilst Lacinian, Tuvanian and Alaniian species occur in the Sevastian *Mockina bidentata* Zone, and the Tuvanian and Alaniian species range up into the Sevastian *Parvigondolella andrusovi* Zone indicating a much greater longevity of many conodont species in the open ocean seamount conditions of Raohe.

Aspects of these characteristics were also found in the other Norian regions of Panthalassa. Diverse (≥ 20) conodont species are reported from the Upper Norian of Chichibu Shikoku in Japan (Ishida and Hirsch, 2001), including many cosmopolitan elements (e.g., *Epigondolella quadrata*, *Epigondolella uniformis*, *Epigondolella spatulata*, *Mockina postera*, *Norigondolella hallstattensis*, *Norigondolella navicula*, *Metapolygnathus primitus* and *Metapolygnathus echinatus*). Among them, *Epigondolella quadrata*, *Epigondolella uniformis*, *Epigondolella spatulata*, *Mockina postera* usually occur in the Middle Norian, while *Metapolygnathus primitus* and *Metapolygnathus echinatus* occur around the Carnian-Norian Boundary. Once again, they all survived considerably longer in this

Panthalassan location. These species coexist with the species only encountered in Panthalassa: *Mockina sakurae*, *Mockina shamiseni* and *Mockina hisaidaensis*.

3.2 Paleoenvironment of the Norian in the Raohe Area

The Permian and Triassic carbonates in the Raohe area have been attributed to seamounts environment (Zhou et al., 2022; Yang and Liu, 2017). Petrographic analysis of the limestones from Raohe reveals numerous thin-shelled bivalves, and abundant calcispheres (Figure 12). The thin-shelled bivalves are difficult to identify, but, given the Norian Age, they may be *Halobia*. Micrite mud dominates the limestones indicating a low energy deposition but this does not necessarily indicate an abyssal site (where carbonate dissolution would be likely). The limestones form deformed pods or lenses within the radiolarian-chert dominated Shengli Formation (Figure 12). We interpret the limestones to be thrust sheets derived from carbonate seamounts where water depths were likely tens not thousands of metres.

Seamounts are globally important and essential ecosystems for supporting and maintaining marine biodiversity in the modern ocean. The Raohe Seamount environment in Panthalassa, provided a home for both cosmopolitan and endemic conodont species but they were also a refuge for relict conodont species that had been extirpated from other regions. The occurrence of the last category suggests palaeoenvironments may have been stable for prolonged intervals in the Late Triassic of Panthalassa allowing survival of taxa that had gone extinct millions of years earlier in surrounding epeiric seas.

3.3 Quantitative Evaluation the Norian Conodont Palaeobiogeography in the Raohe Area

To evaluate the palaeobiogeographic significance of the conodonts from the Raohe area, we have collated conodont species occurrences from different areas, in-



Figure 13. Late Triassic (Norian) paleogeographic map, show some key areas of Late Triassic conodont biostratigraphy research (modified after Scotese, 2021). A. Japan; B. the Nadanhada Terrane; C. North America; D. Western Tethys; E. Baoshan; F. Far East of Russia.

cluding Japan (the Chichibu Belt and the Inuyama area), the Nanhada Terrane (Raohe area, this paper), North America (Canadian Cordillera and British Columbia), Western Tethys (Italy, Austria, Slovenia and Hungary), Far East of Russia (Sikhote-Alin) and the Baoshan Block (Figure 13). Indeterminate species, species with aff. and cf. are not included. In total, 35 Alauian conodont species and 29 Sevatian conodont species from five areas have been counted in this study, the list of conodont species and the selected sections are shown in Table S1 and Table S2 (in supplementary materials).

In assessing the palaeobiogeographic patterns (Qiao and Shen, 2015; Clarke et al., 2014; Huang et al., 2012), both the results of CA and NMDS are affected by the option of the similarity coefficients used, the Jaccard

similarity coefficient was chosen in this paper because it satisfies almost all the discriminant criteria (Shi, 1993). Besides, the cophenetic correlation coefficient (CPCC) and Stress were shown in CA and NMDS. The higher CPCC values indicate the greater reliability of CA results, whilst the lower the Stress values indicate the better the reliability of the NMDS. Generally, if the numerical value of Stress is below 0.3, the result of NMDS is reliable (Takane et al., 1977). In addition, the minimum spanning tree (MST) shows the distance relationship between different areas by connecting all points with the smallest possible distance (Shen et al., 2009). Shepard scatter diagram reflects the regression relationship between the low-dimensional transformed data and the original data, where the population of the scatter is closer to the 45°

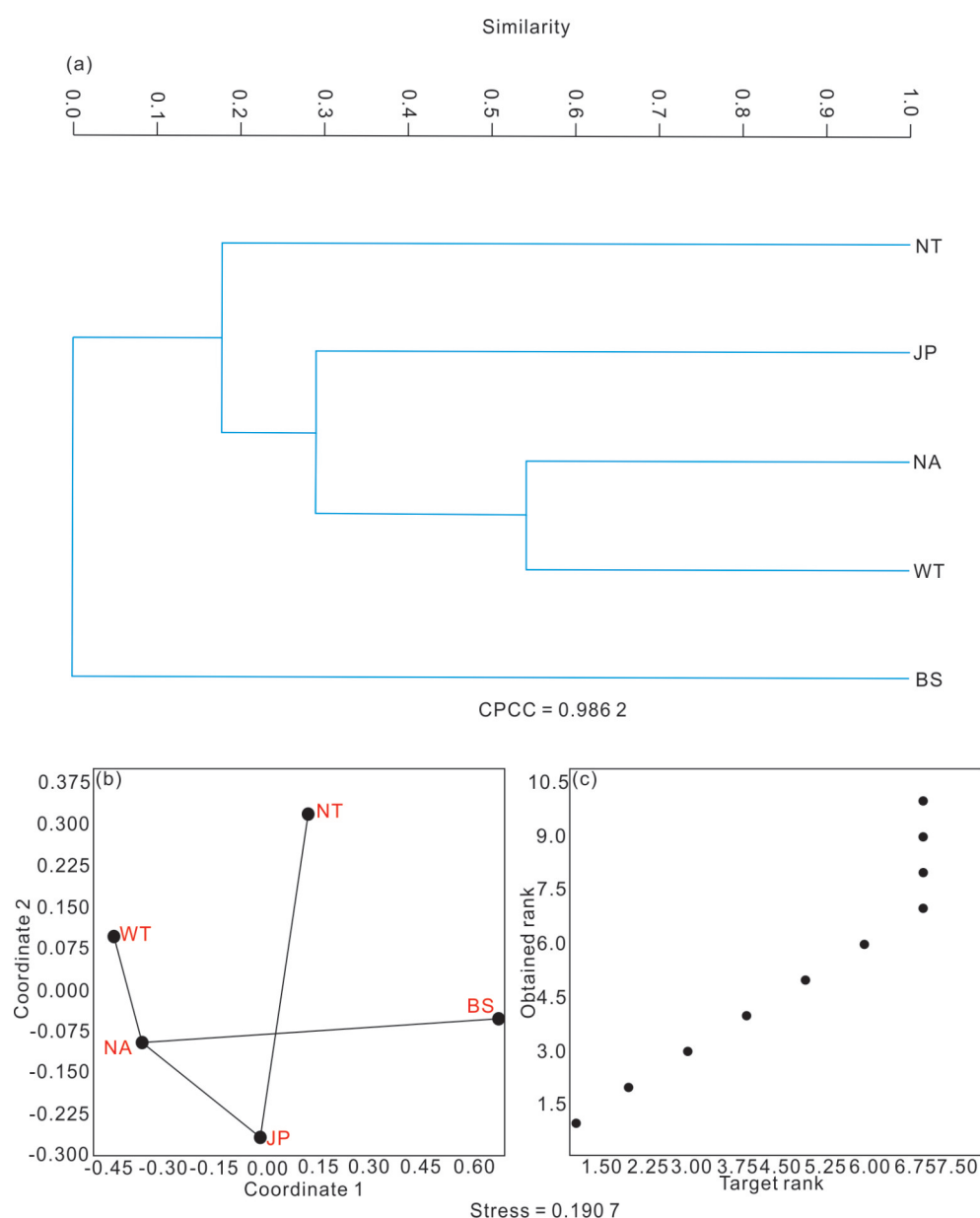


Figure 14. (a) Dendrograms of Alauian conodont species from five areas derived from CA by PAST based on the Jaccard coefficients. (b) Minimum spanning tree and Shepard scatter diagram of Alauian conodont species from five areas derived from NMDS by PAST based on the Jaccard coefficients. NT. Nadanhada Terrane; JP. Japan; WT. western Tethys; BS. Baoshan; NA. North America; FER. Far East of Russia.

line ($Y = X$), the more closely the analysis matches the original data itself (Shepard, 1980). The Cluster analysis (CA) and non-metric multidimensional scaling (NMDS) analyses were conducted by the software PAST (Hammer et al., 2001).

Results of CA and NMDS for Alaunian conodont species from six regions with the Jaccard similarity coefficient are shown in Figure 14. The cophenetic correlation coefficient (CPCC) is quite high (0.977 8) and Stress (0.168) is lower than 0.3, indicating that the simulated results are close to the real situation (Takane et al., 1977). The results show that five areas, the Nadanhada Terrane (NT), Japan (JP), North America (NA), western Tethys (WT) and Far East of Russia (FER), are closely grouped whilst the Baoshan Block (BS) is distinct because no Alaunian conodonts have yet to be found in the Baoshan Block. The NMDS results show a similar result with the identification of two groups, but it also shows that the Alaunian conodonts from the Nadanhada Terrane (NT) are most similar to those of the Far East of

Russia (FER) and Japan (JP).

Results of CA and NMDS for Sevatian conodont species are shown in Figure 15. CPCC is 0.858 9, and Stress is 0.142, showing that the result is reliable. From the result of CA using the Jaccard coefficient, we can see that two groups are recognized besides the Nadanhada Terrane (NT): one is composed of Japan (JP), Western Tethys (WT) and Baoshan (BS), and the other is Far East of Russia (FER) and North America (NA). The Nadanhada Terrane (NT) shows little similarity to other regions because of the existence of some relict species, such as *C. pseudoechinata*, *E. vialovi* and *Ne. cavitata*. The result of NMDS corresponds to the result of CA, and indicates that the Sevatian conodont fauna from the Nadanhada Terrane (NT) is closer to the Far East of Russia (FER) area compared to the other areas. Overall, the Alaunian and Sevatian conodont faunas from the Nadanhada Terrane are quite different from those in other regions. Being somewhat similar to the Japan and Far East of Russia (FER) assemblages, three areas (the Nadanhada Ter-

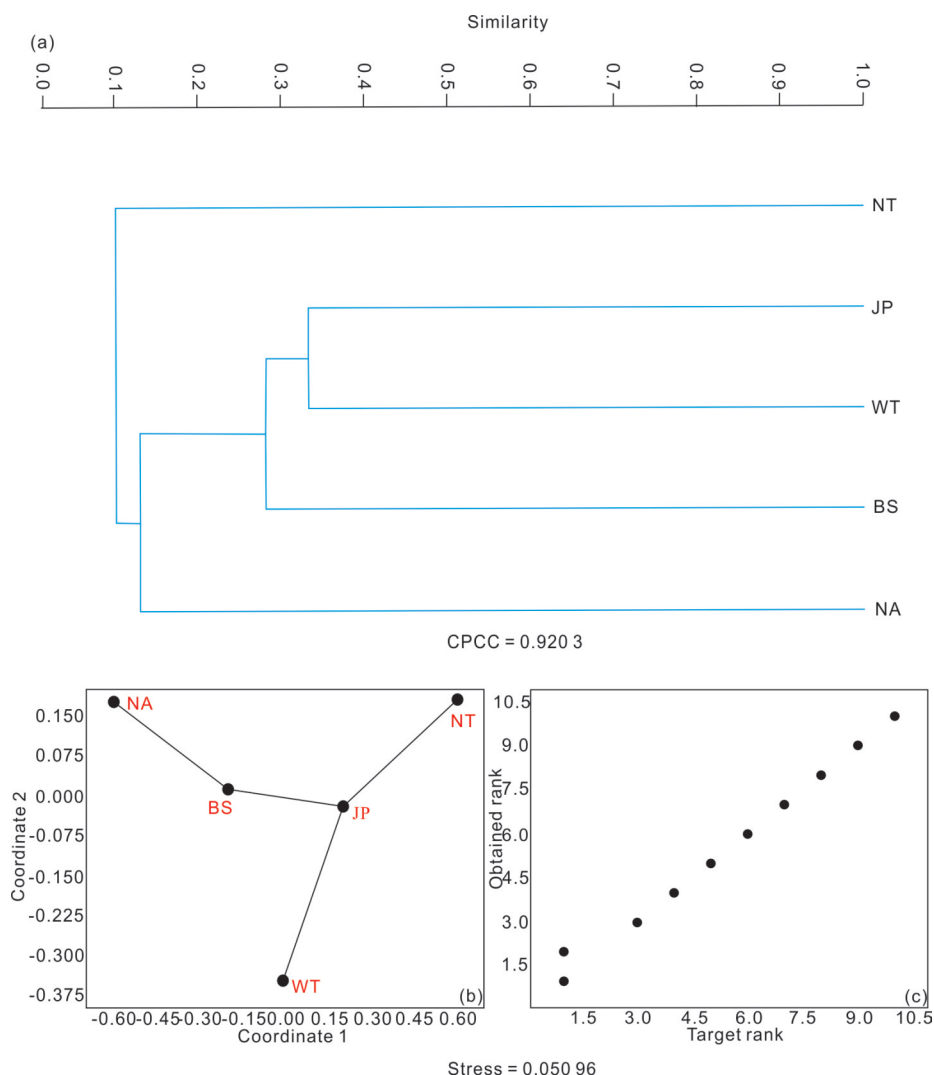


Figure 15. (a) Dendrograms of Sevatian conodont species from five areas derived from CA by PAST based on the Jaccard coefficients. (b), (c). Minimum spanning tree and Shepard scatter diagram of Sevatian conodont species from five areas derived from NMDS by PAST based on the Jaccard coefficients. NT, Nadanhada Terrane; JP, Japan; WT= Western Tethys; BS, Baoshan; NA, North America; FER, Far East of Russia.

rane, Japan and Sikhote-Alin) are considered to be a super-terrane of Panthalassa (Mizutani et al., 1990, 1986).

4 CONCLUSION

Investigations of the Minnan, Minzhu and Chigangbei sections of the Raohe area has established three Norian conodont zones: *Mockina postera* Zone, *Mockina bidentata* Zone and *Parvigondolella andrusovi* Zone. Three kinds of conodonts are present, cosmopolitan species, (e. g., *Mockina postera*, *mockina bidentata*, *Parvigondolella andrusovi*), species restricted to Panthalassa, (e. g., *Mockina sakurae*, *Mockina shamiseni*, *Norigondolella nadanhadaensis*) and “relict” elements surviving in this Panthalassan location long after their extirpation in epeiric settings (e.g., *Carnepigondolella pseudoechinata*, *Neocavitella cavitata* and *Epigondolella vialovi*). A pelagic, carbonate seamounts environment is surmised for the Raohe conodont fauna based on the associated carbonate facies (micritic limestones with thin-shelled bivalves and calcispheres). This seamounts terrane was in the low northern latitudes of the Panthalassa Ocean where environmental conditions were suitably benign for diverse conodont populations to thrive that included several species that had gone extinct elsewhere.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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