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The conodont biostratigraphy of the upper Carnian (Upper Triassic) in the Tethys Himalaya area, South Tibet

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ABSTRACT

The conodonts from the Carnian have been well studied in western Tethys, eastern Tethys, middle and eastern Panthalassa. However, in the Tethys Himalaya, namely the northern periphery of Gondwana, the Carnian conodont data is limited. Our conodont biostratigraphic investigation was conducted at Jiesheng (JS) section of the Tethys Himalaya area, south Tibet. The majority of the conodont species found in the JS section, such as *Paragondolella(=Quadralella) polygnathiformis*, *P. praelindae*, *P. noah*, *P. oertlii*, *Carnepigondolella* cf. *zoae*, *C. tuvalica*, *C. pseudoechinata*, *Metapolygnathus* cf. *linguiformis*, *M. praecommunisti*, *Primatella triangulare*, *Pr. subquadrata*, and *Ancyrogondolella quadrata*, represent the first record in this region. According to the conodont biostratigraphy, large part of the measured JS section can be assigned to middle Tuvalian to uppermost Tuvalian (upper Carnian); the topmost strata can be assigned to lower Lacian (lower Norian). In addition, the puzzle of Carnian conodont taxonomy should be brought to the forefront of Upper Triassic conodont research. The over-simplified Tethyan and the over-complicated North American taxonomic concepts hamper the classifications of Carnian conodonts and chances of global correlation. A taxonomic revision including previously overlooked morphological features is necessary, in which microreticulation may have the potential to serve as one of the distinguishing characteristics between taxa of the Carnian-Norian boundary interval.

1. Introduction

The Carnian period has garnered significant scientific interest due to the Carnian Pluvial Event (CPE), which has emerged as a prominent subject of recent research (e.g., Simms and Ruffell, 1989; Simms et al., 1995; Stanley Jr, 2003; Furin et al., 2006; Rigo et al., 2007; Hornung et al., 2007a, 2007b; Preto et al., 2010; Mietto et al., 2012; Sun et al., 2016, 2018; Shi et al., 2017, 2019; Jiang et al., 2019; Tomimatsu et al., 2021; Jin et al., 2020, 2022a; Dal Corso et al., 2015, 2018, 2020, 2024). Conodonts play an important role in the study of CPE because they represent a reliable and significant tool for stratigraphic dating, subdivision, and correlation (e.g., Mazza et al., 2011, 2012; Sun et al., 2016; Zhang et al., 2018a, 2018b; Shi et al., 2017, 2019; Jiang et al., 2019; Tomimatsu et al., 2021). Furthermore, conodonts also contain a wealth of geochemical information, which can be used for the reconstruction of paleoenvironment (e.g., Rigo and Joachimski, 2010; Rigo et al., 2012; Trotter et al., 2015; Sun et al., 2012, 2020; Du et al., 2021a). The development of Carnian conodont research is not only due to the CPE, the study of Carnian conodonts from the aspects of biostratigraphy and palaeontology has a long history in Europe, Japan and North America (e.g., Mosher, 1968; Hayashi, 1968; Kozur, 1980, 2003; Channell et al., 2003; Muttoni et al., 2004; Orchard, 2007, 2014, 2019; Nicora et al., 2007; Moix et al., 2007; Rigo et al., 2007, 2018; Mazza et al., 2010, 2011, 2012, 2018; Karádi et al., 2016; Yamashita et al., 2018; Tomimatsu et al., 2022; Karádi and Korte, 2023).

The conodont assemblage from the upper Carnian has been well studied in the northern hemisphere of the Triassic world. For instance, the areas of western Tethys, eastern Tethys, mid-Panthalassa and eastern Panthalassa (e.g., Hayashi, 1968; Kozur, 1980, 2003; Channell et al., 2003; Orchard, 2007; Yamashita et al., 2018; Rigo et al., 2018; Shi et al.,

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2017, 2019; Zhang et al., 2019; Jin et al., 2022a; Tomimatsu et al., 2022). However, data from the southern hemisphere is scarce. McCartain et al. (2024) just presented a new integrated Triassic biostratigraphic microfossil database (conodonts, palynomorphs and radiolarians) from Timor-Leste, southeastern Tethys, including some Carnian conodonts. Our research area was also located in the southern part of the Tethys region, situated at the northern periphery of the Indian continent, which was a component of Gondwana during the Late Triassic (Fig. 1A). In this region, there has been a notable absence of research on the upper Carnian conodont fauna.

The Carnian Stage is regarded as a pivotal period for turnovers of conodont faunas, in particular the late Carnian (Mazza et al., 2012, 2018; Orchard, 2014, 2019; Rigo et al., 2018). The conodont fauna of the upper Carnian is characterized by large number of species and transitional forms, resulting in the difficulty and complexity of their classification. The research levels of Carnian conodonts vary across different regions. Additionally, another significant issue that deserves attention is taxonomy of the Carnian conodonts. A significant difference can be observed in the taxonomic schemes of Carnian conodonts between the western Tethys and North America (e.g., Mazza et al., 2012; Orchard, 2014). However, it has to be noted that this large contrast between the number of taxa is most probably artificial, generated by the remarkably different taxonomic concepts used by Tethyan and North American conodont specialists (e.g., Mazza et al., 2018; Orchard, 2019). Therefore, this problem remains unresolved to this day, which hampers very much the chances of global correlation, and presumably the real diversity of conodonts from this time frame lies somewhere between the over-simplified (lumping) Tethyan and the over-complicated (splitting) North American concepts (Mazza et al., 2012, 2018; Orchard, 2014, 2019; Rigo et al., 2018). Furthermore, the microreticulation is a significant feature of conodont platform and the distribution of microreticulation is related to the evolution processes of the conodont platform. It has potential in helping of Upper Triassic conodont genus and species classification (Orchard, 1983, 2023). However, the microreticulation has been overlooked in the study of Upper Triassic conodont evolution and species identification in most cases.

In this study, we collected samples from the JS section in an effort to conduct a new conodont biostratigraphical study in the Tethys Himalaya region, with the aim of utilizing conodonts for the purpose of stratigraphic dating and subdivision. On the other hand, we discussed the challenges encountered in the process of conodont classification in our study, along with our suggestions.

2. Geological setting

The studied JS section (Zanda County, GPS: 31°50′N, 79°03′E) is located in the western Tethys Himalaya of south Tibet, with a thickness of around 378 m, but only 240 m of the outcrop are shown in this study (Fig. 2). This area is a major part of the Himalaya which lies between the Yarlung Zangbo Suture Zone in the north and the Greater Himalaya in the south (Fig. 1B). During the Late Triassic, the Tethys Himalaya, situated at the northern edge of the Indian continent, was a mature passive continental margin with tectonically quiescent setting (e.g., Sciunnach and Garzanti, 2012).

Up to the present, the investigations on lithostratigraphy and biostratigraphy in the studied area are mainly from regional geological survey by Zhang et al. (2015). In this region, only a limited number of studies on Upper Triassic conodont biostratigraphy have been previously published (Wang and Wang, 1976; Tian, 1982; An et al., 2020). The pioneering study of Triassic conodont biostratigraphy within the Tethys Himalaya region, Tibet was initiated by Wang and Wang (1976), who reported the Norian conodont species *Epigondolella abneptis*. Subsequently, Tian (1982) identified and established 12 conodont biozones, encompassing 4 conodont zones specific to the Upper Triassic in this region. An et al. (2020) reported the presence of the conodont species *Metapolygnathus* sp. within the study area.

The Upper Triassic strata in the JS section can be divided into Qulonggongba and Qimala Formations from bottom to top. The

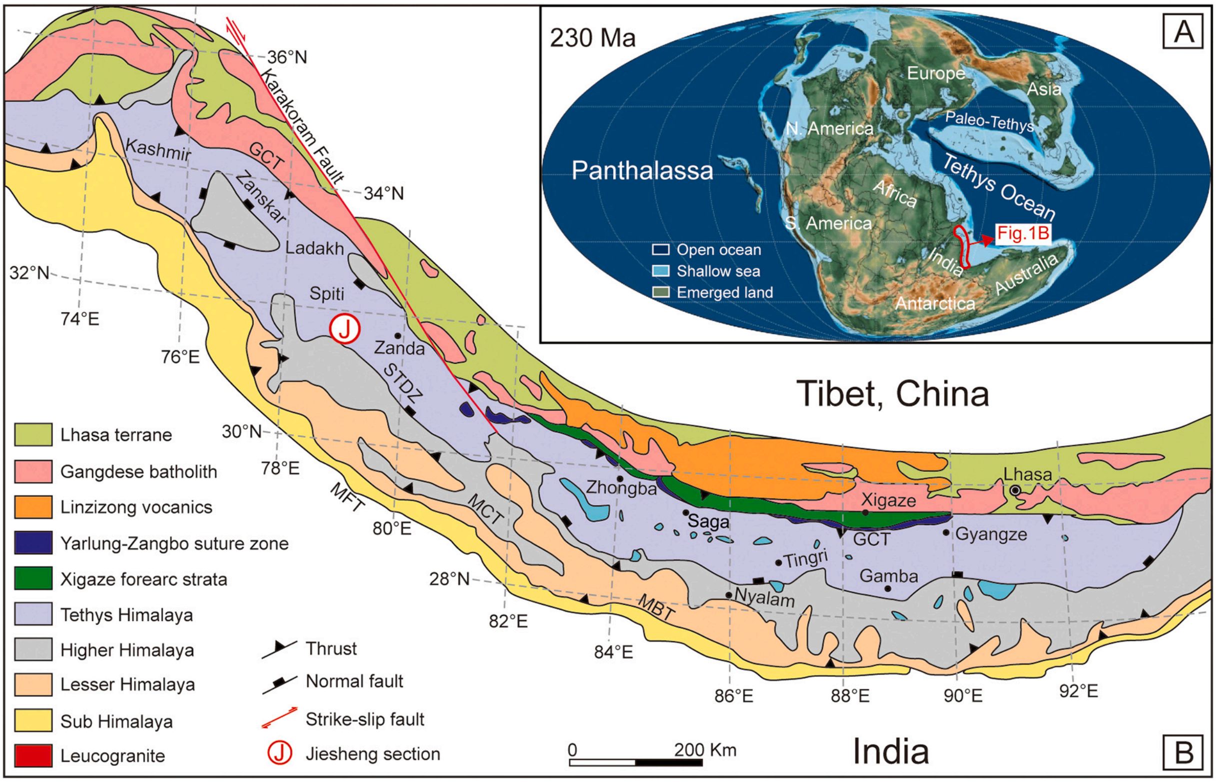

Fig. 1. (A): a global paleogeographic map of the Late Triassic (modified after Scotese and Schettino, 2017), and the general position of the study area. (B): location of the Jiesheng (JS) section within the Tethys Himalaya region that is now part of south Tibet (modified after Hu et al., 2016).

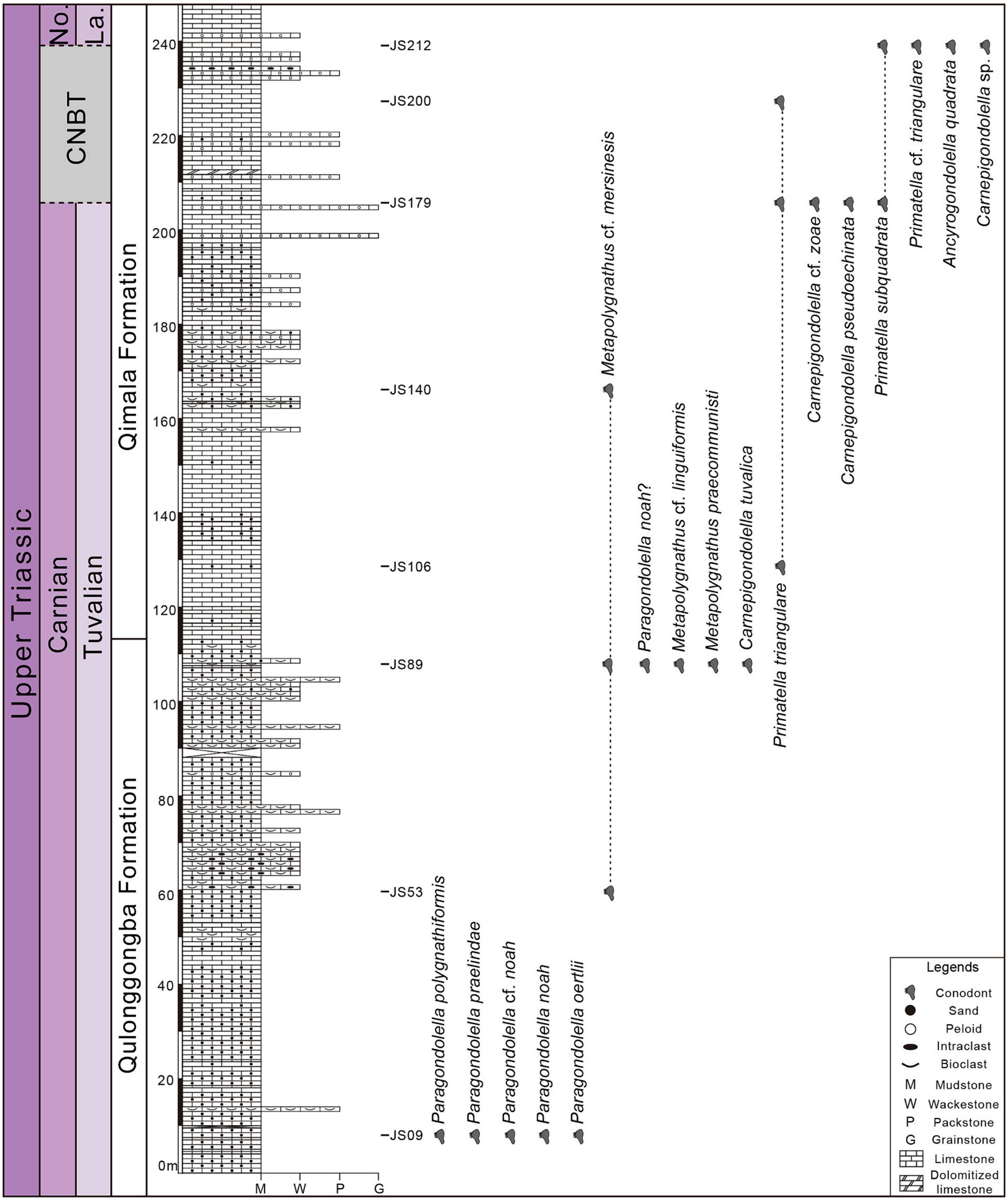

Fig. 2. Log of the JS section with lithostratigraphy and conodont distribution. Abbreviation: No. = Norian; La. = Lacian; CNBT = Carnian-Norian boundary transitional interval.

Qulonggongba Formation in the JS section is generally dominated by siliciclastic and mixed siliciclastic-carbonate sedimentation. This Formation can be further subdivided into two units: the lower part primarily consists of calcareous shale, siltstone, and silty shale, intercalated with sandy micrite and calcareous fine-grained sandstone; the upper part is mainly composed of sandy bioclastic limestone and sandy micrite intercalated with sporadic calcareous siltstone and shale. The sedimentary environment was interpreted as middle carbonate ramp that was located at the mature passive margin of north India (Zhang et al., 2015).

The overlying Qimala Formation is dominated by limestone, which is divided into two members (Zhang et al., 2015). The lower member is dominated by micrite, bioclastic packstone/wackestone, indicating a middle carbonate ramp, whereas the upper is characterized by ooid grainstone, intraclast grainstone, lump grainstone and bioclastic packstone/wackstone, indicating an inner carbonate ramp. This unit yields ammonoids assignable to *Arcestes* cf. *rotnletzi* Welter, *A.* (*Stenarcestes*) cf. *polysphictus* Mojs, *Parathisbites* cf. *ronaldshayi* Diener, corresponding to the *Cyrtopleurites socius* Zone. Together with the bivalve assemblage *Monotis-Indopecten,* the fossil assemblage suggests an age of Norian. Additionally, the conodonts and bivalve assemblage of the same lithostratigraphic unit from the adjacent Purang county suggest Norian age (Cui and Liu, 1987; Zhao and Zhang, 1991).

3. Methods and results

A total of 32 carbonate rock samples, designated as JS, each weighing approximately 4 kg, were collected for the purpose of conducting biostratigraphical research from the JS section. These samples underwent a process of comminution into smaller fragments, followed by dissolution using an 8% formic acid solution. The resulting residues were subjected to washing, sieving with a mesh size of 100 μm, and subsequently dried in an oven maintained at 40 °C. The sample preparation procedures were executed at the laboratory of Chengdu University of Technology.

Conodont fossils were successfully identified in eight samples, specifically JS09, JS53, JS89, JS106, JS140, JS179, JS200, and JS212, as depicted in Fig. 2. Detailed micrographs of these conodonts were captured using a scanning electron microscope and are presented in Figs. 3, 4, 5, and 6. The distribution of these conodonts is shown in Fig. 2. These conodonts exhibit a Color Alteration Index (CAI) ranging from 3 to 4. All conodont specimens have been archived and are accessible at Chengdu University of Technology.

The conodont species present in the samples include: *Paragondolella* (=*Quadralella*) *polygnathiformis*, *P. praelindae*, *P. noah*, *P. oertlii*, *Carnepigondolella tuvalica*, *C.* cf. *zoae*, *C. pseudoechinata*, *Metapolygnathus* cf. *linguiformis*, *M.* cf. *mersinensis*, *M. praecommunisti*, *Primatella triangulare*, *Pr. subquadrata*, and *Ancyrogondolella quadrata*. The conodont assemblage in the JS section indicates an age of Tuvalian (late Carnian) from the base to the position of JS179 (Fig. 2). The strata from the JS179 to JS212 range into the Carnian-Norian boundary transition (Fig. 2). The strata above JS212 belongs to lower Lacian (lower Norian) (Fig. 2).

4. Discussions

4.1. The taxonomy of Carnian conodonts

Conodont faunas of the Carnian are notable for their high species diversity and the presence of numerous transitional forms, which complicates the taxonomic study. In addition, conodont specialists from different regions have their own preferred taxonomic concept, further complicating the already confusing taxonomic schemes of Carnian conodonts. The main challenge in the taxonomic study of Carnian conodonts arises from the differences between the conodont faunas of the western Tethys and North America (Rigo et al., 2007, 2018; Mazza et al., 2012, 2018; Orchard, 2014, 2019). These two areas initiated Carnian conodont research early on and accumulated abundant data (e.g., Kozur, 1980, 2003; Channell et al., 2003; Rigo et al., 2007; Orchard, 2007, 2014; Balini et al., 2000, 2010, 2012; Mazza et al., 2012; Rigo et al., 2018; Karádi and Korte, 2023). However, specialists developed different schemes of conodont taxonomy due to the endemism of conodont faunas in these two areas (e.g., Mazza et al., 2012; Orchard, 2014). Recently, they have begun to realize that the differences between the populations of Carnian conodonts in the western Tethys and North American regions may be smaller than previously thought, and the apparent distinction observed today are likely to be more artificial in nature (e.g., Orchard, 2019). The taxonomic schemes of Carnian conodonts in the western Tethys and North American have their own characteristics and evident shortcomings. In the western Tethys, the taxonomic scheme displays the main evolutionary trends of conodonts but is oversimplified. The definition of some genera is broad or ambiguous, such as *Epigondolella*, which has been redefined by Orchard (2018). In contrast to the western Tethys, the taxonomic scheme is over-complicated in North America. For instance, the genera *Kraussodontus* and *Quadralella* have several characters in common and the differences are too minor to allow accurate distinction of these taxa (Karádi and Korte, 2023). Furthermore, there are differences in the definitions of some genera between the two regions, such as *Carnepigondolella*, *Metapolygnathus* and *Paragondolella*. Also, the ambiguous definitions of the genera *Primatella*. These contradictions and problems confuse non-experts or newcomers to understand the classification of Carnian conodonts and hinders them to apply them accurately.

The genera *Primatella* and *Ancrygondolella* have been rarely used in previous Tethyan conodont classifications. Orchard (2018) redefined *Ancrygondolella* and *Epigondolella*, assigned most of the Lacian species having a bifurcated keel to the genus *Ancyrogondolella*, and restricted the genus *Epigondolella* for certain Norian species with a non-bifurcated keel. Then, Karádi (2021) combed through the evolutionary trends and morphological changes of the *Ancyrogondolella* lineage, *Ancyrogondolella*, *Epigondolella*, *Orchardella* and *Mockina*. A clearer evolutionary relationship makes *Ancyrogondolella* more acceptable. However, the problem has not been completely resolved. Some conodonts that were previously classified as *Epigondolella* in the Tethys region cannot be assigned to *Ancyrogondolella*, especially for the upper Carnian species. Thus, genus *Primatella* from the North America becomes the best current option also in Tethys. However, the definition of *Primatella* has the same problem as it was with *Epigondolella*, it is broad and ambiguous. For instance, *Primatella* species may be characterized by a variety of platform shapes: relatively long and rectangular; short and broad quadrate; short and tapered; rounded or asymmetrical posterior outlines; and platforms with a distinctive medial constriction and expanded posterior platform (Orchard, 2014). In general, apart from the ornaments on platform margins, *Primatella* exhibits variations in platform outlines, positions of pit and cusp, keel prolongation and shapes of keel end. Nevertheless, the location of pit and the shape of keel end are important features in the evolution of Carnian conodonts. *Primatella* bridges the gap between the disappearance of *Carnepigondolella* and the appearance of the *Ancyrogondolella* (Orchard, 2019), however, the ambiguous definition of *Primatella* causes scope overlapping with other genera. Therefore, *Primatella* is the best current option, but its definition needs to be made clearer and more specific, like what happened with *Ancyrogondolella* and *Epigondolella*. Similar problems arise in *Paragondolella*, *Carnepigondolella* and *Metapolyganthus* in the Tethys region as well.

4.2. Microreticulation of the Upper Triassic conodonts and its significance

Microreticulation structure is a common feature in Carnian conodonts, especially for the early Carnian species, with nearly all adult forms exhibiting microreticulation on entire platform margins, for instance the species of *Paragondolella*. Orchard (1983) described the microreticulation on platform elements of "*Epigondolella*" population and utilized it as a character in discriminating species. He also noted that the Lacian *Ancyrogondolella* has been devoid of compact microreticulation compared to *Primatella* (Orchard, 2023). However, the importance of microreticulation in conodont classification has rarely been mentioned in most cases. Microreticulation becomes a feature that is often overlooked in conodont descriptions. Although the importance of microreticulation for conodont genera and species classification have been recognized (e.g., Orchard, 1983, 2023), the trend of evolution of the Upper Triassic conodont microreticulation has not been discussed in detail.

The distribution of microreticulation on conodont platform is related to the development of the platform shape and the ornament on conodont platform margins. It is worth noting that microreticulation on the platform of some conodonts began to decrease or disappeared during the late Carnian, namely, microreticulation on the conodont platform showed a decreasing trend from early Carnian to Norian. We summarized three main ways of microreticulation reduction and disappearance on conodont platforms. First way is the occurrence of denticles on the anterior platform margins. Microreticulation is predominantly present

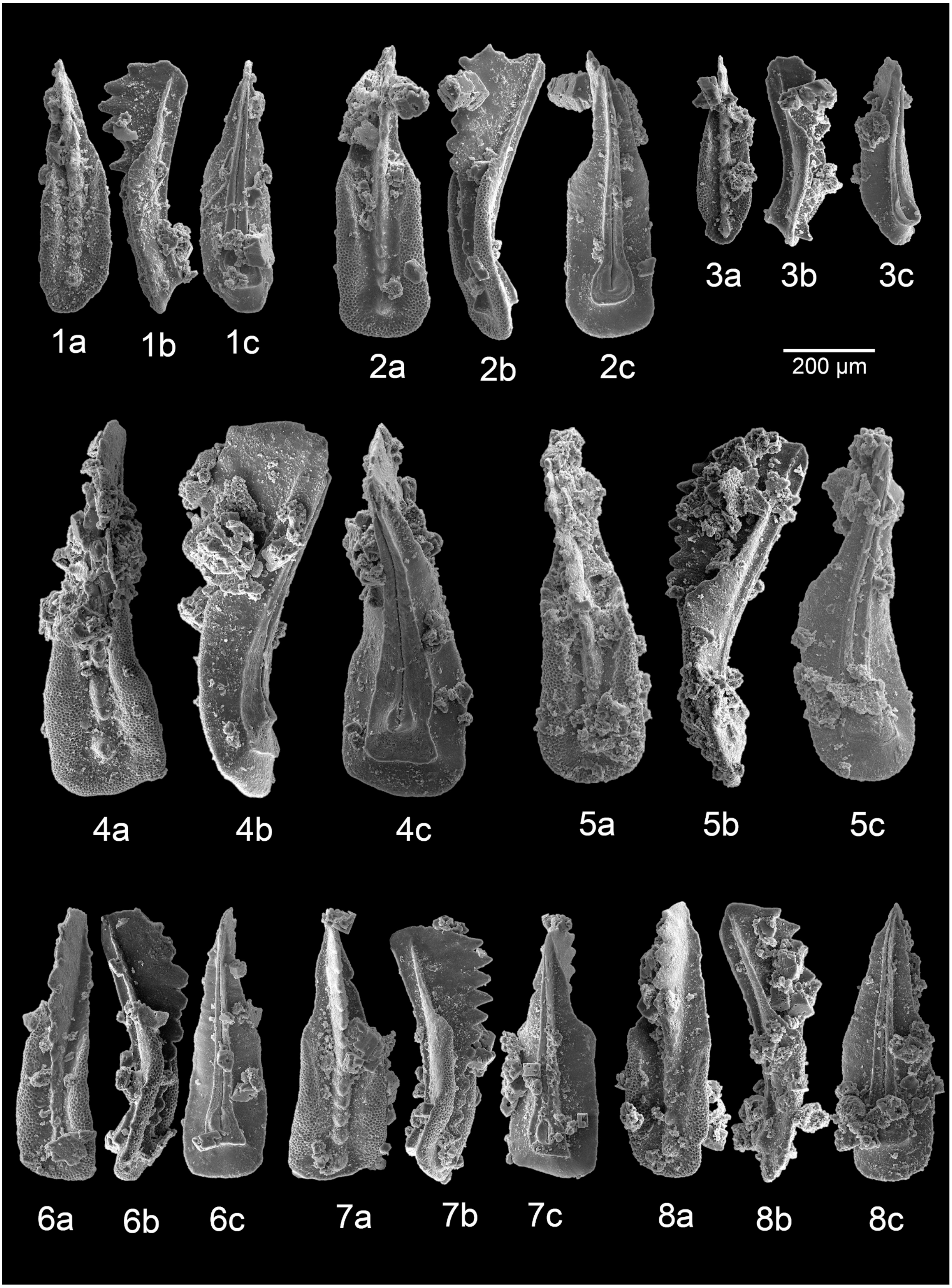

Fig. 3. SEM photos of conodonts from the JS section. Scale bar is 200 μm and all specimens are on the same scale. a: upper view, b: lateral view, c: lower view. 1–2. *Paragondolella*(=*Quadralella*) *polygnathiformis*, JS09; 3. *P. praelindae*, JS09; 4. *P. oertlii*, JS09; 5. *P. noah*, JS09; 6. *P. oertlii*, JS09; 7. *P. polygnathiformis*, JS09; 8. *P. polygnathiformis*, JS09.

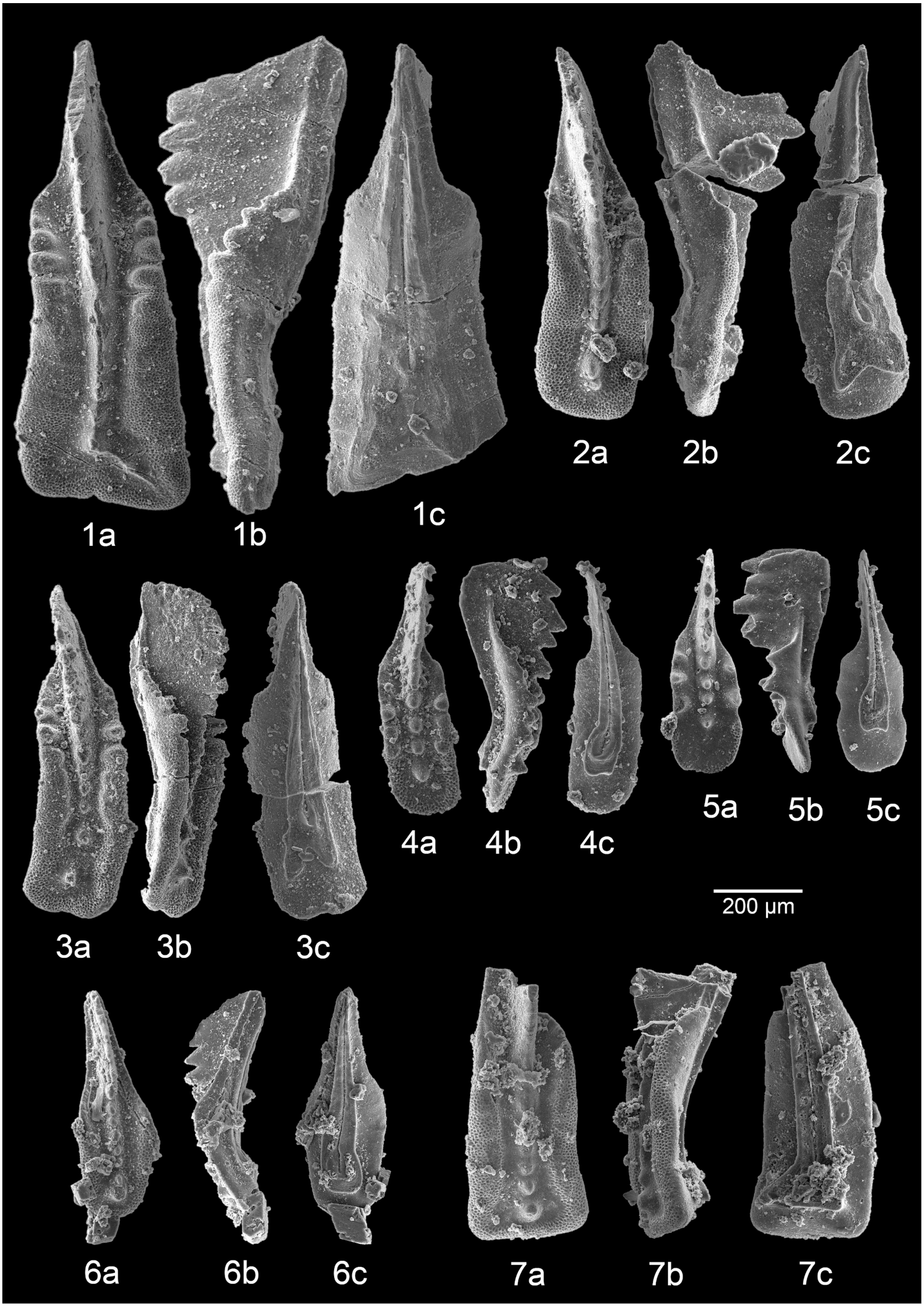

Fig. 4. SEM photos of conodonts from the JS section. Scale bar is 200 μm and all specimens are on the same scale. a: upper view, b: lateral view, c: lower view. 1. *Metapolygnathus* cf. *linguiformis*, JS89; 2. *Paragondolella*(=*Quadralella*) *noah*?, JS89; 3. *Metapolygnathus* cf. *mersinensis*, JS89; 4. *Carnepigondolella tuvalica*, JS89; 5. *C. pseudoechinata*, JS179; 6. *P. polygnathiformis*, JS09; 7. *P. noah*, JS09.

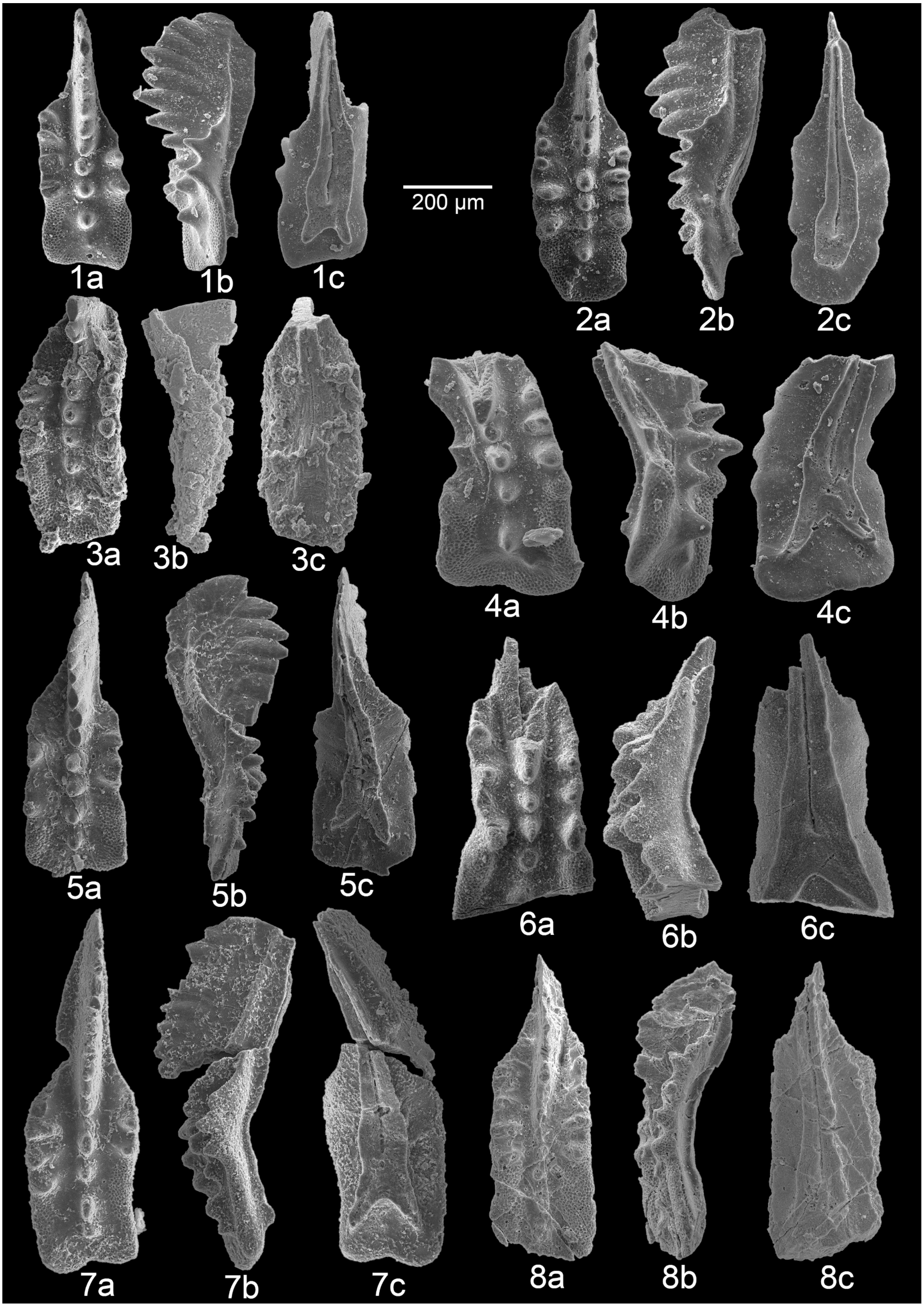

Fig. 5. SEM photos of conodonts from the JS section. Scale bar is 200 μm and all specimens are on the same scale. a: upper view, b: lateral view, c: lower view. 1. *Primatella subquadrata*, JS179; 2. *Carnepigondolella* cf. *zoae*, JS179; 3. *Metapolygnathus* cf. *mersinensis*, JS53; 4. *Pr. triangulare*, JS179; 5. *Ancyrogondolella quadrata*, JS212; 6. *Pr. triangulare*, JS106; 7. *Pr. subquadrata*, JS212; 8. *Carnepigondolella* sp., JS212.

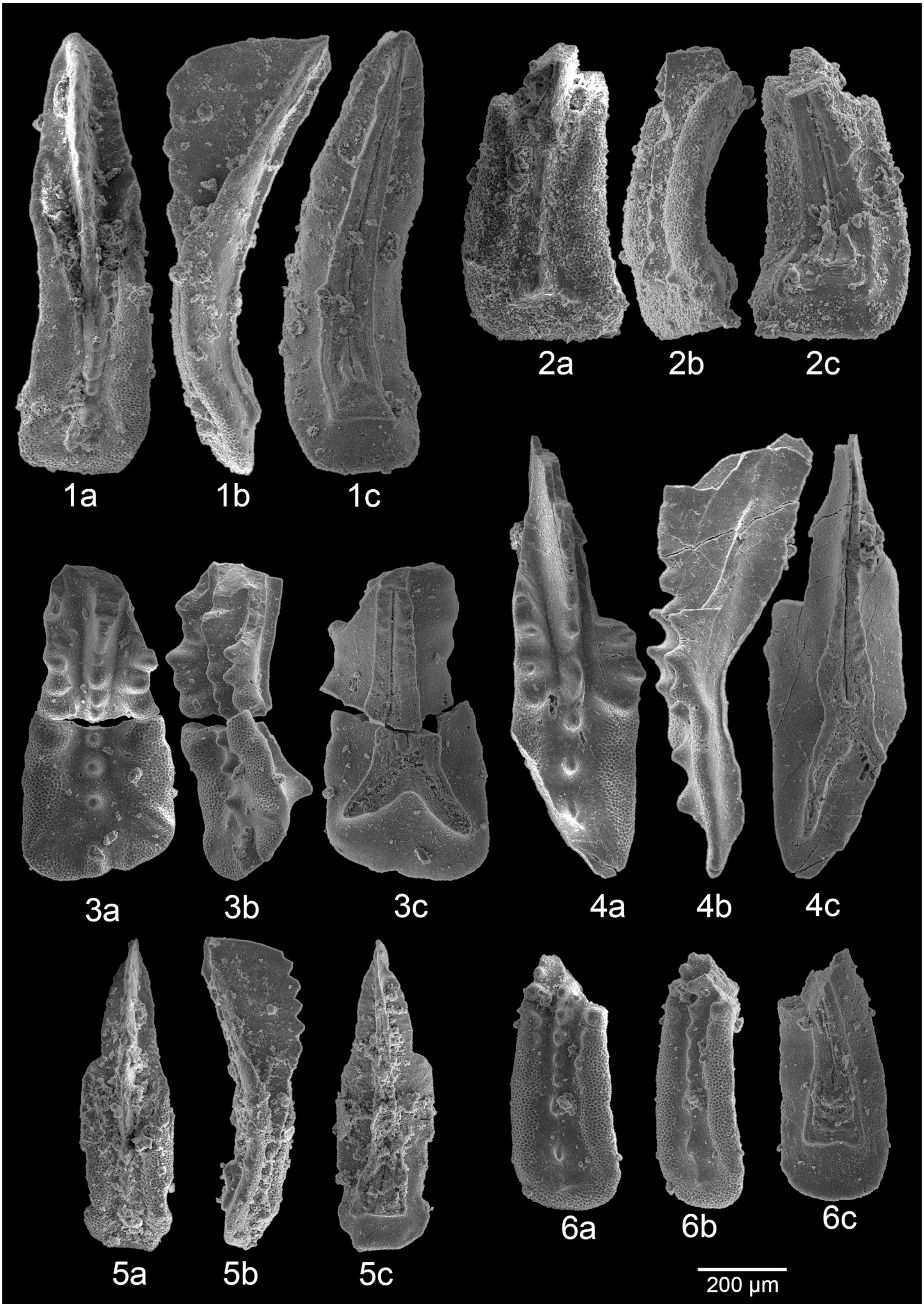

Fig. 6. SEM photos of conodonts from the JS section. Scale bar is 200 μm and all specimens are on the same scale. a: upper view, b: lateral view, c: lower view. 1. *Paragondolella*(=*Quadralella*) *noah*, JS09; 2. *P.* cf. *noah*, JS09; 3. *Pr. triangulare*, JS200; 4. *Pr.* cf. *triangulare*, JS212; 5. *P. polygnathiformis*, JS09; 6. *Metapolygnathus praecommunisti*, JS89.

on the unornamented or weakly ornamented (with low nodes) platforms rather than on those with sharp denticles. Therefore, it is common to see reduction or disappearance of microreticulation on the anterior platform denticles of the upper Carnian conodonts (Fig. 7/D, G). Second way is the occurrence of ornaments, such as nodes, denticles, ridges or swellings, on the lateral and posterior margins of the platform (Fig. 7/D). The development of ornaments usually displaces or occupy the places of microreticulation, leading to the reduction or disappearance of microreticulation, for instance some species of *Carnepigondolella*. Third way is the reduction of conodont platform, the lateral and posterior margins where microreticulation originally appeared, resulting in the area covered by microreticulation become smaller or disappear (Fig. 7/C, E). The upper Carnian conodonts with reduced platform are common in the North American region, which usually have reduced or tapered posterior platforms, for instance some species of *Acuminatella*. The two main ways by which Norian conodonts, like genus *Ancyrogondolella*, loses microreticulation on the platform are the occurrence of denticle on the anterior platform margins and the occurrence of ornaments on the lateral and posterior margins of platform (Fig. 7/I).

As shown in the Fig. 7, microreticulation is a common feature of most Carnian conodonts, however, from the appearance of *Ancyrogondolella* at the early Norian to the *Orchardella*, *Epigondolella* and *Mockina* of the middle-late Norian, it is no longer a common characteristic of these conodonts (Fig. 7/I-N). Even if microreticulation do appear occasionally, it is present only on the edges of the conodont platform (Fig. 7/L), while other conodonts wipe it off completely (Fig. 7/M, N). With the appearance of genera *Parvigondolella* and *Misikella*, the microreticulation disappeared completely by the disappearance of the platform (Fig. 7/O, P). However, there is an exception during this period, namely genus *Norigondolella*, in which the platform is always covered with dense microreticulation (Fig. 7/Q, R). It may be due to that *Norigondolella* retained the element shape of its Carnian ancestors and did not develop any ornaments on the platform margins. It is worth mentioning that microreticulation is only present on the conodont platform and the ornaments at the platform margins but does not develop on blade and carina (also see in Orchard, 1983). Even though the carina of some species is composed of low nodes, microreticulation does not appear on them, which is pretty different from the nodes on the platform margins.

The microreticulation may have the potential to serve as one of the distinguishing characteristics between Carnian and Norian conodonts because of the different distributions. For instance, the decrease or disappearance of microreticulation could be a useful diagnostic characteristic in the definition of the genus *Ancyrogondolella*. Most of the *Ancyrogondolella* has no or less microreticulation structure while *Primatella* and some other Carnian conodonts usually has intensive microreticulation on platform or nodes. Orchard (2014) emphasized the compact microreticulation on the platform margins and nodes in the definition of genus *Primatella*. He also mentioned that the Lacian *Ancyrogondolella* has been devoid of compact microreticulation (Orchard, 2023). We tend to support the devoid of compact microreticulation as one of the diagnostic characteristics of genus *Ancyrogondolella* to distinguish it from similar conodont genera. However, there's a debate from *A. rigoi*, in the published pictures, some *A. rigoi* contain dense microreticulation (Fig. 7/H) and some do not (see Fig. 1A in Karádi, 2021). This contradiction comes from the neglect of the importance of microreticulation in the conodont classification and definition. Therefore, further studies on genus *Ancyrogondolella* and the species *A. rigoi* are needed. Conodonts of the same genus, or at least for the same species, should have the similar/same characteristic of microreticulation. Meanwhile, the role of microreticulation in conodont classification and definition should be emphasized in the future.

4.3. *Conodont biostratigraphy and the correlation*

Compared to genera, there is less controversy surrounding the classification of conodont species. In the study section, all paragondolellids are found in sample JS09 which is situated in close proximity to the base of the section. The conodont fauna observed within the JS09 primarily comprises: *Paragondolella* (=*Quadraella*) *polygnathiformis*, *P. praelindae*, *P. noah*, and *P. oertlii*. *Paragondolella polygnathiformis* and *P. praelindae* has been found from the Julian (lower Carnian) substage to the Tuvalian (Rigo et al., 2007, 2018; Mazza et al., 2012; Shi et al., 2019), but the cooccurrence of *P. noah* and *P. oertlii* in the sample indicates an age corresponding to the Tuvalian substage (upper Carnian). *Paragondolella*

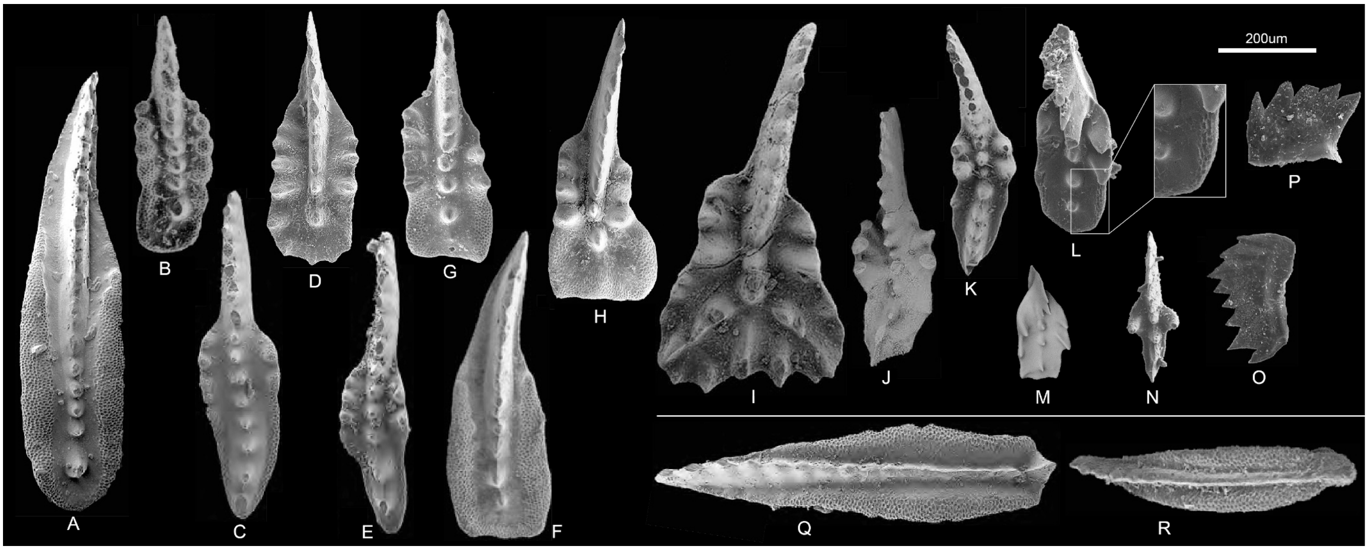

Fig. 7. Microreticulation characteristics of different Upper Triassic conodonts. Scale bar is 200 μm. A. *Paragondolella polygnathiformis* (Fig. 4/Y in Zhang et al., 2018a); B. *Carnepigondolella zoae* (pl.1, Fig. 7 in Orchard, 1991); C, E. *Acuminatella acuminata* (fig. 32/14,30 in Orchard, 2014); D. *C. samueli* (pl.3, Fig. 2 in Mazza et al., 2012); F. *Metapolygnathus praecommunisti* (Fig. 2/H in Mazza et al., 2011); G. *Primatella? subquadrata*, JS179 (this study); H. *Ancyrogondolella rigoi* (pl.6, Fig. 7 in Mazza et al., 2012); I. *A. triangularis* (pl.1, Fig. 4 in Orchard, 2018); J. *Epigondolella spiculata* (pl.4, fig. 17 in Orchard, 2018); K. *Orchardella multidentata* (pl.4, fig. 24 in Orchard, 2018); L. *Mockina slovakensis* (Fig. 6/5 in Guo et al., 2024); M. *M. slovakensis* (Fig. 3/7 in Du et al., 2021b); N. *M. bidentata* (Fig. 4/15 in Jin et al., 2022b); O. *Parvigondolella andrusovi* (Fig. 4 in Karádi et al., 2020); P. *Misikella hernsteini* (Fig. 4 in Karádi et al., 2020); Q. *Norigondolella navicula* (fig. 49/10 in Orchard, 2014); R. *N. steinbergensis* (Fig. 6/K in Karádi and Korte, 2023).

noah is typically believed to appear in the lower to middle Tuvalian, while *P. oertlii* presents more commonly in the middle to upper Tuvalian (e.g., Mazza et al., 2012; Rigo et al., 2018).

From the position of JS09 to JS179, the conodont assemblages primarily comprise: *Metapolygnathus* cf. *mersinensis*, *M.* cf. *linguiformis*, *M. praecommunisti*, *Primatella triangulare*, *Pr. subquadrata*, *Carnepigondolella* cf. *zoae*, *C. tuvalica* and *C. pseudoechinata*. The *M.* cf. *mersinensis* and *M.* cf. *linguiformis* typically extend from the upper Tuvalian (upper Carnian) to the lower Lacian (lower Norian) (e.g., Mazza et al., 2012). *Primatella triangulare* was introduced by Orchard (2014) from the *acuminata-prominens* Subzone through the *asymmetrica-Norigondolella* Subzone of the *primitia* Zone (late Tuvalian to early Lacian) at the Black Bear Ridge section. This species was recently reported from the western Tethys (Csővár, Hungary) by Karádi and Korte (2023). *Carnepigondolella pseudoechinata* is commonly found in the upper Tuvalian, sometimes in the lower Lacian in Tethys region (e.g., Mazza et al., 2012). *Pr. subquadrata* was described by Orchard (2014) at the Black Bear Ridge section, and it is common from high in the *angusta-dylani* Subzone through the *asymmetrica-Norigondolella* Subzone of the *primitia* Zone. It is indicative of an age spanning from the late Tuvalian to the early Lacian. However, *C. tuvalica* and *M. praecommunisti* in the JS89 is exclusively found in upper Tuvalian strata as reported in previous studies (e.g., Mazza et al., 2012; Rigo et al., 2018). In addition, the conodont species *C.* cf. *zoae* has been found in sample JS179. *Carnepigondolella zoae* is frequently observed only in the upper Tuvalian at both the Black Bear Ridge section and the Pizzo Mondello section (Mazza et al., 2012; Orchard, 2014), the age of the strata from the base of the section to the position of sample JS179 is restricted to middle to late Tuvalian. But it has to be mentioned that the *C.* cf. *zoae* in study section has higher denticles on anterior platform margins and weaker platform constriction than the typical *zoae*. From the position of JS179 to JS212, it is the transitional interval of Carnian-Norian boundary, only one *Pr. triangulare* has been found within this interval so far. *Ancrygondolella quadrata* were found in sample JS212, it is suggested to range from the uppermost Tuvalian to the Alaunian (middle Norian) in the Pizzo Mondello section (e.g., Mazza et al., 2012; Rigo et al., 2018), but this species in Hungary is regarded as one of the index species of the *A. rigoi-A. quadrata* Zone, indicating an age of Lacian, lower Norian (Karádi and Korte, 2023). Similarly, *A. quadrata* serves as an index species of the Lacian *quadrata* Zone, which is positioned above the *parvus* Zone in the Black Bear Ridge section (Orchard, 2014). Therefore, *A. quadrata* represents the more reliable view of the Lacian substage. Although the *Metapolygnathus parvus* has not been identified in the studied samples, the occurrence of *A. quadrata* in JS212 confirm the age of the strata as Lacian. Nevertheless, the Carnian-Norian boundary could not be defined due to the lack of *M. parvus*. For better stratigraphic correlation and subdivision, further investigation of conodont in the JS section is necessary in the future.

5. Conclusions

The investigation of conodonts was conducted in the Jiesheng section within the Tethys Himalaya, south of Tibet. The discovery of conodonts is significant for stratigraphic dating in the study area, as well as global correlations.

Conodont assemblages in the strata from the base of the section to the sample JS179 indicate an age of middle Tuvalian to late Tuvalian (late Carnian); the strata from JS179 to JS212 belongs to Carnian-Norian boundary transitional interval; the strata above JS212 belongs to the lower Lacian (lower Norian).

The classification of Carnian conodonts should be given sufficient attention. Both the North American and western Tethyan taxonomic schemes are flawed, which will hinder the study of regional and global correlations and the development of evolutionary processes of Carnian conodonts.

The microreticulation on the conodont platform showed a decreasing trend from early Carnian to Norian. We speculate that microreticulation may have the potential to serve as one of the distinguishing characteristics between Carnian and Norian conodonts.

CRediT authorship contribution statement

Yixing Du: Methodology, Conceptualization, Writing – original draft. **Zhong Han:** Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Viktor Karádi:** Conceptualization, Writing – review & editing. **Tianhao Su:** Investigation. **Junling Dong:** Investigation. **Bao Guo:** Investigation. **Yuehan Sun:** Investigation. **Manuel Rigo:** Conceptualization, Writing – review & editing. **Qiangwang Wu:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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