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Complete List of Authors:	Zhang, Zaitian; China University of Geosciences, College of Marine Science and Technology, China University of Geosciences ; State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan) Sun, Yadong; GeoZentrum Nordbayern, Universität Erlangen-Nürnberg; Nanjing Institute of Geology and Palaeontology Chinese Academy of Sciences, State Key Laboratory of Palaeobiology and Stratigraphy Lai, Xu-Long; State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan) Wignall, Paul; University of Leeds, School of Earth and Environment
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CARNIAN (LATE TRIASSIC) CONODONT FAUNAS FROM SOUTHWESTERN CHINA AND THEIR IMPLICATIONS

by ZAITIAN ZHANG[1, 2], YADONG SUN[3, 4], XULONG LAI[2*] *and* PAUL B. WIGNALL[5]

[1] College of Marine Science and Technology, China University of Geosciences (Wuhan), Wuhan 430074, P.R. China; zhang11tian15@163.com

[2] State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan), Wuhan 430074, P.R. China; xllai@cug.edu.cn

[3] GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany; yadong.sun@fau.de

[4] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Nanjing 210008, P.R. China;

[5] School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK; p.b.wignall@leeds.ac.uk

*Corresponding author: E-mail: xllai@cug.edu.cn (X.L. Lai)

Abstract

Conodonts are important index fossils for supra-regional correlation especially in the Triassic. However, early Carnian conodonts are comparatively poorly known in South China. In this study, three sections from the Yunnan and Guizhou provinces are investigated for conodont biostratigraphy and taxonomy. Two genera and twenty-three species are identified, including four new species *Quadralella (Q.) postica* sp. nov., *Q. robusta* sp. nov., *Q. wignalli* sp. nov. and *Q. yongningensis* sp. nov. Five conodont zones are recognized. They are, in ascending order, *Paragondolella foliata* Zone, *Q. polygnathiformis* Zone, *Q. praelindae* Zone, *Q.* aff. *auriformis* Zone and *Q. robusta* sp. nov. Zone. Conodonts are reasonably diverse and abundant in the upper Zhuganpo Formation (Julian 1) but decrease sharply in both species richness and diversity towards the Wayao Formation (Julian 2 and younger). This change was most likely caused by climate warming and marine anoxia during the Carnian Humid Episode.

Key words: biostratigraphy; conodont; Middle and Late Triassic; South China

Conodonts are widely used as zone fossil to subdivide marine Triassic strata and they have been generally well documented thanks to the endeavours of several generations of researchers (e.g. Müller 1956; Clark 1959; Mosher 1968; Sweet *et al*. 1970; Clark *et al*. 1979; Kozur 1980, 1989b, 2003; Balini *et al*. 2000; Rigo *et al*. 2007; Orchard 2010, 2013, 2014; Di Stefano *et al*. 2014). However, early Carnian conodonts have received comparatively little study compared to those from other intervals of Triassic (Mosher 1968; Sweet *et al*. 1970; Orchard & Tozer 1997; Lai & Mei 2000; Kozur 1980, 2003).

Conodont faunas show a clear trend of increasing provincialism beginning in the Middle Triassic (Mosher 1968; Sweet *et al*. 1970; Budurov *et al*. 1985; Chen *et al*. 2015). Many endemic taxa appeared in the Late Triassic. By the early Carnian conodonts had achieved a considerable diversity (Martínez-Pérez *et al*. 2014; Chen *et al*. 2015), with many taxa known from North American and the European Alps (e.g. Mosher 1968; Krystyn 1980; Kozur 1989b, 2003; Orchard 1991b, 2007, 2013, 2014; Orchard & Tozer 1997; Mietto *et al*. 2012; Muttoni *et al*. 2014). However, the conodonts from these two regions are highly distinct, and have few cosmopolitan forms with the result that inter-regional correlation is difficult.

Studies of Carnian conodonts in the eastern Tethys and Panthalassa have been less thorough compared to the work on North American and European Alpine faunas. Most early studies were carried out in Japan and they established the foundation of Carnian biostratigraphic schemes (e.g. Hayashi 1968; Koike 1981, 1982; Igo 1989, Koike *et al*. 1991; Ishida & Hirsch 2001). Metcalfe *et al*.

(1979) and Metcalfe (1990, 1992) reported the occurrences of *Metapolygnathus* (*M.*) *polygnathiformis* and *M. tadpole* in the early Carnian strata in Malaysia. Studies of the Late Triassic conodonts in China only started in the 1980s. Initial work only recognized the presence of *polygnathiformis* – a very common cosmopolitan species in the Carnian. For example, Wang and Dai (1981) and Tian *et al*. (1983) identified *Neogondolella* (*N.*) *polygnathiformis* from Sichuan and Tibet, respectively. Later, more comprehensive studies established several Carnian conodont zones. Thus, Wang and Zhong (1990) erected the *N. polygnathiformis* – *Gladigondolella* assemblage zone and the *N. polygnathiformis* Zone in southwestern China while Yang *et al*. (1995) established the *N. polygnathiformis* – *N. maantangensis* assemblage zone, the *N. polygnathiformis* – *N. tadpole* assemblage zone and the *N. polygnathiformis* Zone in Guizhou. Yang *et al*. (1999) and Lai and Mei (2000) summarized the Triassic conodont zones from type areas in China and identified only three and two conodont zones for the entire Carnian stage, respectively. Subsequently, it has been shown that Carnian conodonts in South China are much more diverse than previously thought (e.g. Wang & Dai 1981; Wang 2000; Chen & Wang 2002; Yang *et al.* 2002; Sun 2006; Sun *et al*. 2016; Zhang *et al*. 2017).

In order to document the full spectrum of Carnian conodonts in southwestern China, we have carried out detailed investigations on three sections in Yunnan and Guizhou Provinces. The conodont fauna from this region is characterized by a dominance of genera *Paragondolella* (*P.*) and *Quadralella* (*Q.*)

while genera *Budurovignathus*, *Gladigondolella* and *Mosherella* are absent. A total of twenty-three species, including four new species, are identified here. In study sections, conodonts are diverse and abundant in lower Carnian strata but they become rare and small in the upper Carnian. This trend to rarity and small size, seen in the Wayao Formation, was probably caused by harsh environmental conditions during and in the aftermath of the Carnian Humid Episode.

GEOLOGICAL SETTING

Triassic strata are widely distributed in South China and can be subdivided into three regions: the Yangtze Platform, the Cathaysian Platform and the Youjiang Fold Belt (also known as the Nanpanjiang Basin) (Yin & Peng 2000). Carbonate successions were mostly developed on the Yangtze Platform and in the Nanpanjiang Basin, where they are well displayed. Our study sections come from these regions where we have sampled the Zhuganpo and Wayao formations. The former unit is characterized by a lower unit of thinly to thickly bedded limestones and an upper unit of nodular limestones or thin to medium bedded limestones. The overlying Wayao Formation is composed of black shales with interbedded marls/limestones. The studied Caizitang section is located in the suburb of Banqiao town, ~25 km NE of the Luoping city in the eastern Yunnan province (Fig. 1). The section is 120-m-thick and consists of the Zhuganpo Formation (115 m in thickness) and the lowermost 5 m of the Wayao Formation. The Tianshuo and Wolonggang sections are both located in the outskirt of

Guanling city, western Guizhou province (Fig. 1). The Tianshuo section is exposed along the road from Yongningzhen Town to the Guanling Fossil National Geopark that is located ~18 km SW of Guanling city. A total of 52 m of the upper Zhuganpo Formation is seen but the Wayao Formation is obscured. The Wolonggang section is located at Baiyun village, which is found ~2 km SE of Guanling Fossil National Geopark (Fig. 1). The section is 101 m in thickness and consists of the uppermost 4 m of the Zhuganpo Formation and an expanded succession of the Wayao Formation (97 m in thickness).

MATERIALS AND METHODS

A total of 116 samples were collected from the three sections. Twenty-two samples, each weighing ca. 4 kg, were collected from Caizitang section from which a total of 929 conodont elements were obtained. Fifty-five samples, each weighing ca. 6.5 kg, were collected from the Wolonggang section and they yielded 241 elements. Thirty-eight samples, each weighing ca. 9 kg, were collected from the Tianshuo section from which 147 elements were obtained.

All samples were crushed into 1~2 cm^3 rock chips and processed using the method described in Zhang *et al*. (2017). The specimens are all stored at the State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan). Selected specimens were imaged using a scanning electron microscope.

CONODONT BIOSTRATIGRAPHY

Ranges of taxa in the study sections are shown in figures 2 and 3. Five conodont zones are recognized. They are in ascending order:

Paragondolella foliata Zone

Lower limit: First occurrence (FO) of *P. foliata.*

Upper limit: FO of *Q. polygnathiformis.*

In the Caizitang section, the *P. foliata* Zone ranges from 30.2 m to 31 m height and contains *P. inclinata* as well as the zonal species. The *P. foliata* Zone is not recognized in the Tianshuo and Wolonggang sections because the lower Zhuganpo Formation is not exposed at these locations.

Paragondolella foliata Budurov 1975 has a global distribution (e.g. Europe, Kovács 1983; Muttoni *et al*. 2014; South China, Sun *et al*. 2016; Zhang *et al*. 2017; Japan, Koike 1982; Igo 1989; India, Chhabra & Kumar 1984), and it has been proposed as a zonal marker for the latest Ladinian (e.g. Koike 1981; Metcafle 1990). The associated *P. inclinata* (Kovács 1983) is considered to be the direct ancestor of *P. foliata* and ranges from the early Longobardian to the late Julian substage (Kovács 1983; Orchard 2007; Rigo *et al*. 2007; Chen *et al*. 2015; Lehrmann *et al*. 2015; Sun *et al*. 2016; Chen & Lukeneder 2017).

Quadralella polygnathiformis Zone

Lower limit: FO of *Q. polygnathiformis.*

Upper limit: First appearance datum (FAD) of *Q. praelindae.*

In the Caizitang section, the *Q. polygnathiformis* Zone ranges from 31 m to 42 m height and contains a relatively diverse assemblage that includes *P. foliata*, *P. inclinata, Q. intermedius*, *Q. jiangyouensis*, *Q.* aff. *polygnathiformis magna*, *Q. uniformis*, *Q. yongyueensis* and *Q.* spp. In the Tianshuo section, the *Q. polygnathiformis* Zone is defined by the first occurrence of the zonal species and it ranges from 4.2 m to 45.4 m height. Other species include *Q. jiangyouensis, Q. maantangensis*, *Q. postica* sp. nov.*, Q. wanlanensis*, *Q. wignalli* sp. nov. and *Q. yongningensis* sp. nov. This zone is not present at Wolonggang section because the section is considered to begin above this level at this location.

Quadralella polygnathiformis (Budurov & Stefanov 1965) is the most common and cosmopolitan conodont species in the Carnian (e.g. Mosher 1968; Koike 1982; Metcalfe 1990; Orchard 2007; Rigo *et al*. 2007; Mietto *et al*. 2012; Sun *et al*. 2016), and its FAD is often used to define the base of Carnian (e.g. Krystyn 1983; Sun *et al*. 2005).

The loose definition of type specimens and large ontogenetic variations of *Q. polygnathiformis* have hindered identification of the species (Koike *et al.* 1991; Orchard 2007; Chen & Lukeneder 2017). However, the abrupt step on both lateral margins is distinct and provides the key diagnostic feature. The specimen shown in the figure 3 (V-X) develops ornamentations on the anterior lateral margins – a feature that may represent part of the latest ontogenetic stage of the species (Orchard 2007). The specimens shown in figure 11 (G-I, AK-AM) share some similar features with *M. praecommunisti* but they do not have the nearly

centrally located pit that characterizes *M. praecommunisti* (Mazza *et al.* 2011).

Quadralella aff. *polygnathiformis magna* has a bifurcated keel end but not a rectangular posterior end, nor a large, elongated platform as in *Q. polygnathiformis magna* (Igo 1989).

The associated species *Q. intermedius* (Orchard 2007) has been reported from Canada (Orchard 2007), USA (Orchard & Balini 2007) and South China (Zhang *et al*. 2017). Its first appearance has been used as an accessory marker to define the Ladinian - Carnian boundary in North America, whilst the upper range extends to the *Q. tadpole* Zone (Orchard 2007, 2010). In the Caizitang section, the range of *Q. intermedius* extends to the latest Julian 1 substage. *Q. jiangyouensis* (Wang & Dai 1981) ranges from the base of Carnian to the base of Julian 2 substage (Wang & Dai 1981; Yang *et al.* 2002). *Q. yongyueensis* Zhang *et al*. 2017 was reported from the Zhenfeng area in the *Q.* aff. *praelindae* Zone (Zhang *et al*. 2017), and in the Caizitang section, it also occurs at the base of Julian 1 substage. *Q. maantangensis* (Dai & Tian in Tian *et al*. 1983) is widely reported from Sichuan, Guizhou and Yunnan provinces in South China (Tian *et al*. 1983; Yang *et al*. 1995, 2002; Wang 2000; Sun *et al*. 2005; Sun 2006), where it ranges from the base of the Julian and to possibly the Tuvalian 1/Tuvalian 2 transition (Sun *et al*. 2016; Zhang *et al*. 2017). *Q. shijiangjunensis* (Sun 2006) is known from lower Carnian strata (Zhang *et al*. 2017) with an upper range extending to the late Julian 1 substage (Sun 2006; this study). *Q. wanlanensis* co-occurs with *Q.* aff. *praelindae* in the Yongyue section (Zhang *et al*. 2017).

***Quadralella praelindae* Zone**

Lower limit: FAD of *Q. praelindae.*

Upper limit: FAD of *Q.* aff. *auriformis*.

In the Caizitang section, the *Q. praelindae* Zone ranges in height from 42.5 m to 60.5 m. *Q. polygnathiformis* is the only other species found in this interval, perhaps due to a relative low sample density. The zone was not identified in the Tianshuo and Wolonggang sections.

***Quadralella* aff. *auriformis* Zone**

Lower limit: FAD of *Q.* aff. *auriformis.*

Upper limit: FAD of *Q. robusta* sp. nov.

In the Caizitang section, the *Q.* aff. *auriformis* Zone ranges from 60.5 m to 80 m height and is associated with a diverse conodont fauna: *P. foliata*, *Q. intermedius*, *Q. jiangyouensis*, *Q. polygnathiformis*, *Q. praelindae*, *Q. tadpole*, *Q. uniformis, Q.* aff. *zonneveldi* and *Q.* spp. This zone is not recognized in the Tianshuo because of the absence of the zonal species nor at Wolonggang where the section begins above this level.

Quadralella aff. *auriformis* is most likely a local variant of *Q. auriformis* (Kovács 1977) which ranges from the upper Julian 1 to the basal of Tuvalian 1 substage (Gallet *et al*. 1994). The associated taxon *Q.* aff. *zonneveldi* was reported by Zhang *et al*. (2017) from Yongyue section in Zhenfeng area during the early Julian substage.

Quadralella aff. *zonneveldi* has a similar platform outline to that of *Q. zonneveldi*, which decreases anteriorly and posteriorly from the widest point of the platform. However, the sunken carina in our specimens is not as obvious in the specimens illustrated in Orchard (2007).

Quadralella robusta sp. nov. **Zone**

Lower limit: FAD of *Q. robusta* sp. nov.

Upper limit: not defined.

In the Caizitang section, the *Q. robusta* sp. nov. Zone ranges from 80 m height to the upper part of the section and contains a high diversity fauna dominated by *P. foliata*, *P. inclinata*, *Q. acuminatus, Q.* aff. *auriformis*, *Q. intermedius, Q. jiangyouensis*, *Q.* cf. *maantangensis, Q. polygnathiformis*, *Q. praelindae*, *Q. robusta* sp. nov., *Q. shijiangjunensis*, *Q. wignalli* sp. nov., *Q. yongyueensis*, *Q.* aff. *zonneveldi* and *Q.* spp. In the Tianshuo section, the *Q. robusta* sp. nov. Zone ranges from 45.4 m height to the top of the section and yields associated species including *Q. maantangensis*, *Q. polygnathiformis*, *Q. wanlanensis*, *Q. wignalli* sp. nov. and *Q.* spp. In the Wolonggang section, *Q. robusta* sp. nov. Zone is not recognized because of the absence of the zonal species.

The *Q. robusta* sp. nov. Zone has a good potential for region correlation in southwestern China. It occurs regionally in the upper Zhuganpo and lower Wayao formations in Zhenfeng (figures 6-14 in Sun *et al*. (2016) who identified it

as *Q*. sp. and figures 8-11 in Zhang *et al*. (2017) who identified it as *Q.* sp. B), Guanling and Luoping areas. The FO of *Q. robusta* sp. nov. occurs below the *Austrotrachyceras* ex gr. *A. austriacum* bed, indicating a late Julian 1 age (Sun *et al*. 2016; Zhang *et al.* 2017 and this study).

The associated taxon *Q. acuminatus* (Orchard 2007) was reported in Canada (Orchard 2007), USA (Orchard & Balini 2007) with a range from the latest Longobardian to the late Julian 1. At Caizitang, it appeared late in the Julian 1 substage.

DISCUSSION

1) Taxonomic notes

Conodont diversity in the Middle and Late Triassic was high (Chen *et al*. 2015). Common genera include *Budurovignathus, Carnepigondolella, Gladigondolella, Hayashiella, Kraussodontus, Mazzaella, Metapolygnathus, Neogondolella, Paragondolella, Pseudofurnishius* and *Quadralella.* Amongst these, *Metapolygnathus*, *Neogondolella*, *Paragondolella* and *Quadralella* are morphologically similar. Key diagnostic features of these genera include the outline of platform, distribution of denticles, carina characters, morphology of keel end, anterior blade, geniculation, ornamentations/nodes/denticles, cusp location and pit position.

Metapolygnathus, *Neogondolella, Paragondolella* and *Quadralella* all have gondola-shaped platforms and relatively prominent cusps. *Neogondolella* Bender

& Stoppel 1965 is characterized by having a large unornamented elongated platform, a terminally or sub-terminally located cusp, a more or less narrow posterior brim and a platform that covers the entire the element with no free blade (Koike 1982; Kozur 1989b). It occurs in Early to Middle Triassic assemblages. *Paragondolella* Mosher 1968 shares many features with *Neogondolella*, but has a high anterior blade with a short/or no free blade that decreases gradually posteriorly (Kozur 1989b, 2003; Mazza *et al*. 2012). Orchard (2013, 2014) argued that *Paragondolella* was a typical Middle Triassic genus although several long-ranging holdovers persist into the Late Triassic. *Metapolygnathus* Hayashi 1968, which flourished during the late Carnian, is characterized by possessing a centrally or anteriorly located pit (Koike 1982; Kozur 1989b, 2003; Rigo *et al*. 2007; Mazza *et al*. 2010, 2011, 2012; Kiliç *et al*. 2015). *Quadralella* Orchard 2013 is considered to be a transitional genus between *Paragondolella* and *Metapolygnathus* and has become a "waste bucket" taxon in recent years. *Quadralella* can have a large variation in platform shape, pit position and keel end.

The taxonomic classification of early Carnian conodonts is intensely debated (e.g. Koike 1982; Orchard 1991b, 2013, 2014; Kozur 1989b, 2003; Mazza *et al*. 2010, 2011, 2012; Kiliç *et al*. 2015). Based on investigations in southwestern China, some early Carnian species have a bifurcated/elongated keel end, slightly forward-shifted pit, node(s)/ornamentation(s) on the anterior lateral margin(s) and a broad posterior platform or a constriction on the posterior platform (e.g. *Q.*

langdaiensis, *Q. maantangensis*, *Q. praelindae*, *Q. wanlanensis*, *Q.* aff. *polygnathiformis magna*). These characters differ from those of *Neogondolella*, *Paragondolella* and *Metapolygnathus* and so most of our collections are assigned to *Quadralella.*

2) Palaeobiogeography

Early Carnian conodonts show strong endemism. Thus, in North American, *Mosherella*, *Paragondolella* and *Quadralella* are the dominant genera while only a few *Budurovignathus* and *Gladigondolella* elements have been reported (Mosher 1968; Kozur 1989a; Orchard *et al*. 2001; Orchard 2007, 2010; Orchard & Balini 2007). In Western Tethys, *Budurovignathus* and *Gladigondolella* are dominant in the lower Carnian whilst *Mosherella* has rarely been reported (Kozur 1989a, 2003; Balini *et al*. 2000; Orchard 2010). In southwestern China, *Budurovignathus*, *Gladigondolella* and *Mosherella* were not found during this investigation. *Budurovignathus* has been rarely reported in South China. Only Wang *et al*. (2005) documented its appearance in the Guandao section of the Nanpanjiang Basin (the same material was re-listed in Lehrmann *et al*. 2015). Only a few *Gladigondolella* elements have been found in South China to date and they are completely absent from the study sections.

3) Changes in conodont diversity during the Carnian Humid Episode

Several marine groups suffered diversity loss during the Carnian Humid Episode including the conodonts (Simms & Ruffell 1989, 1990; Rigo *et al*. 2007). A turnover of conodont species was recognized in western Tethys during the

Julian to Tuvalian transition (Kozur 1989a; Rigo *et al*. 2007), with few Julian species surviving into the lower Tuvalian (Krystyn 1980, 1983; Orchard 1991a; Rigo *et al*. 2007). Based on studies of the Zhenfeng (Yongyue and Long Chang sections), Luopin (Caizitang section) and Guanling (Tianshuo and Wolonggang sections) faunas, the diverse early Carnian conodont in the southwestern China shows a decline in number of species during the Julian 1-2 transition with only a few species remaining after the Carnian Humid Episode (Sun *et al*. 2016, Zhang *et al*. 2017 and this study). In the Luoping area, only four species occur in the Wayao Formation. In the Guanling area, only *Q.* spp. is recovered from the middle to upper Wayao Formation. The conodont fauna from the Tianshuo section also shows a decline in the upper part of the Zhuganpo Formation. A similar diversity loss is also observed in Zhenfeng area, suggesting this is a regional event (Sun *et al*. 2016; Zhang *et al*. 2017). The sharp decline in conodont diversity coincides with the Carnian Humid Episode and the associated oceanic changes (onset of anoxia/euxinia and a sharp rise of seawater temperatures) may be responsible for this crisis (Sun *et al*. 2016).

SYSTEMATIC PALEONTOLOGY

This section is the work of the three senior authors only.

Order OZARKODINIDA Dzik, 1976

Superfamily GONDOLELLOIDEA (Lindström, 1970)

Family GONDOLELLIDAE Lindström, 1970

Subfamily PARAGONDOLELLINAE Orchard, 2005

Genus *PARAGONDOLELLA* Mosher, 1968

Type species *Paragondolella excelsa* Mosher, 1968

Remark: *Paragondolella* is characterized, in upper view, by having a generally rounded or sub-quadrate posterior end. In lateral view, the carina gradually decreases in height towards the posterior end (Kozur 1989b). The cusp is sub-terminal. In lower view, the keel end is either rounded, quadrate or pointed, but never bifurcated (e.g. Mazza *et al*. 2010). Orchard (2013, 2014) and Chen *et al*. (2015) attributed most *Paragondolella* species to the Middle Triassic except for several long-ranging holdovers (e.g. *P. foliata*, *P. inclinata*).

Paragondolella foliata Budurov, 1975

Figure 5 S-U, Figure 11 AB-AD

1975 *Paragondolella foliata* n. sp. Budurov, Pl. 1, figs, 2, 9-12, 14-16, 19-22.

1982 *Neogondolella foliata* Koike, Pl. 2, figs, 11-25.

1983 *Paragondolella foliata foliata* Kovács, Pl. 2, figs. 1-2, Pl. 3, fig. 1.

1984 *Neogondolella foliata foliata* Chhabra & Kumar, Pl. 1, figs, 2-3, 19.

2000 *Paragondolella foliata* Balini *et al*., Pl. 2, fig. 8.

2016 *Paragondolella foliata* Sun *et al*., Fig. 6, figs, 1. 8.

Description: In upper view, the platform is elongated and covers all along the element, with moderately thick lateral margins that taper anteriorly, and broadest near the posterior end. Carina extends to the cusp. Cusp is

sub-terminal. One or two node-like denticle(s) may develop behind the cusp. In lateral view, the element is always straight. Basal edge is nearly straight before the pit. The lateral platform margins may extend to the anterior end with a development of a very short free blade. Geniculation on the lateral margins of the platform is absent. Denticles are discrete and highest near anterior end and gradually decrease posteriorly. The carina is higher than the lateral margins, denticles of carina stand (nearly) perpendicularly to basal edge/platform. In lower view, the pit is terminal. The keel is slightly elevated with a moderately deep furrow that extends to the anterior end.

Comparison: *P. foliata* shares many morphological features with *P. inclinata*. The key difference is that *P. foliata* has a straight basal edge before the pit.

Occurrence: Longobardian - Julian, Zhuganpo Formation, Guizhou and Yunnan provinces, South China.

Paragondolella inclinata (Kovács, 1983)

Figure 4 AT-AV, Figure 5 G-I, J-L, AH-AJ, Figure 6 M-O, V-X, Figure 10 Y-AA

1983 *Gondolella foliata inclinata* n. subsp. Kovács, Pl. 1, figs. 1-4; Pl. 3, figs. 2-4.

2000 *Paragondolella inclinata* Balini *et al*., Pl. 3, fig. 2.

2007 *Paragondolella inclinata* Orchard, Fig. 3, 1-3.

2007 *Paragondolella inclinata* Orchard & Balini, Fig. 6 & 7-11 & 24 & 25.

2010 *Paragondolella inclinata* Orchard, Fig. 11, 17-19.

2015 *Paragondolella inclinata* Lehrmann *et al*., Fig. 6, 21-22.

2016 *Paragondolella inclinata* Sun *et al*., Fig. 6, fig, 2.

Description: In upper view, the platform is moderately elongated. The platform almost covers the whole length of the element, although the first one or two denticle(s) on the blade may be free. The widest point is in the posterior two thirds of the platform. Platform margins taper anteriorly. Posterior end is rounded or sub-quadrate in outline. Carina extends to near the posterior end. The cusp is sub-terminal and surrounded by a narrow platform brim. In lateral view, the whole element is always arched, the basal edge is inclined both anteriorly and posteriorly. The anterior platform margins descend gradually to the anterior end. Geniculation is not developed. In lower view, the pit is sub-terminal, and the keel is slightly elevated with a deeply excavated furrow that extends to the anterior end.

Comparison: *P. inclinata* shares several common features with *Q. polygnathiformis*. However, the latter has more upturned platform margins and an abrupt step at an anterior geniculation.

Occurrence: Longobardian - Julian, Zhuganpo Formation, Guizhou and Yunnan provinces, South China.

Genus *QUADRALELLA* Orchard, 2013

Type species: *Quadralella lobata* Orchard, 2013

Remark: *Quadralella* was introduced to account for taxonomic uncertainties amongst Carnian – Norian conodonts. Many *Quadralella* species show

transitional features seen in *Paragondolella*, *Metapolygnathus* and *Carnepigondolella*. *Quadralella* also shows evolutionary trends: a forward shifting pit, shortening of platform and increasing platform ornament (Orchard 2014). In upper view, the platform is generally elongated and rectangular to rounded at its posterior end. Some species may exhibit a distinct constriction at the posterior of platform (e.g. *Q. praelindae* and *Q. auriformis*). Node-like ornamentations may develop on the anterior lateral platform. The cusp is prominent and located at sub-terminal or terminal positions with a development of a narrow posterior platform brim. Accessory denticles/nodes may develop around the cusp. In lateral view, the genus is generally arched before the pit. In lower view, the pit is located terminally to sub-terminally but is restricted in the posterior half. The keel end is rounded, pointed, rectangular or bifurcated.

Quadralella postica sp. nov.

Figure 11 A-C, D-F

LSID.urn:lsid:zoobank.org:act:B1293D30-16DA-4037-B8C1-1DF0AB26F4D2

Etymology: Referring to its distinctive “V-shaped” posterior end.

Holotype: Specimen (Figure 11, A-C) from sample TS-4 032, Zhuganpo Formation, Tianshuo section, South China.

Paratype: Specimen (Figure 11, D-F) from sample TS-4 033, Zhuganpo Formation,

Tianshuo section, South China.

Type locality: Middle Zhuganpo Formation, Guanling, South China.

Type interval: Early Carnian.

Material: 3 specimens (TS-4 032, 033 TS-12 040).

Diagnosis: The blade is short. Platform is moderately long and broad, asymmetric to near-symmetric with a pointed posterior end. Blade and carina consists of moderately to highly fused denticles. Pit located sub-terminally. The keel is moderately wide and may be slightly bifurcated.

Description: In upper view, the platform is moderately broad to broad and covers almost the entire element. A short free blade may develop in the anterior. The blade is low and highly fused. The carina is composed of 7-9 low and discrete denticles. The node-like cusp is indistinct and sub-terminal. Additional denticle(s) occur after the cusp. The widest point of platform is at the posterior. Posterior platform margins are symmetric to asymmetric, upturned and reduced towards the cusp from the widest point of platform, forming a pointed posterior. In lateral view, the element is slightly arched and the middle carina is relative low compared with the lateral margins. An abrupt step occurs on the anterior platform. In lower view, a pit surrounded by the loop is located sub-terminally and slightly forward shifted. Keel is broad and its termination is generally rectangular but can be weakly bifurcated. A furrow extends to the anterior end of platform.

Discussion: *Q. postica* sp. nov. and *Q. yongningensis* sp. nov. share the character of accessary node-like denticle develops behind the cusp. However, the current species is characterized by a V-shaped posterior end.

Occurrence: Julian - ?, Zhuganpo Formation, Guizhou province, South China.

Quadralella robusta sp. nov.

Figure 4 AB-AD, AH-AJ, AK-AN

2016 *Quadralella* sp. Sun *et al*., Fig. 6. fig. 14.

2017 *Quadralella* sp. B. Zhang *et al*., Fig. 8. fig. 11.

LSID.urn:lsid:zoobank.org:act:B5948C55-D3BC-4218-899C-5A7F304BE3CD

Etymology: Referring to its large platform and large cusp.

Holotype: Specimen (Figure 4, AB-AD) from sample CZ-35 016, Zhuganpo Formation, Caizitang section, South China.

Paratype: Specimen (Figure 4, AH-AJ) from sample CZ-35 011, Zhuganpo Formation, Caizitang section, South China.

Type locality: Upper Zhuganpo Formation, Luopin, South China.

Type interval: Early Carnian.

Material: 13 specimens (CZ-35 011, 012, 016, 017, 021, 023; TS-32 076; TS-40 069 and specimens from Zhang *et al*. 2017, NR-7 061, 062, 063, 067; NR-6 057).

Diagnosis: Platform covers almost entire element. Carina consists of highly fused

denticles. Robust cusp located terminally with very narrow posterior platform brim.

Description: The mature element is large and elongated. In upper view, the platform covers entire element with no free blade although juveniles may develop free blade. The lateral margins are sub-parallel to parallel and the posterior end is rounded to sub-quadrate. Adcarinal lateral grooves are relatively narrow, straight and deeply incised. In lateral view, the element is slightly arched. Anteriorly the blade is high and descends gradually towards the carina. The carina consists of highly fused denticles and may be higher than the lateral margins. A robust cusp is slightly inclined and located terminally with a very narrow posterior brim. The cusp is normally two to three times larger than the denticles. No obvious step occurs at the anterior. In lower view, a pit surrounded by a loop is terminal, but it is slightly forward shifted compared with the cusp location. Keel is relative broad. A furrow extends to the anterior end. This species has relatively thin platform that thickens with growth. During growth the denticles on the middle carina may merge together and adcarinal lateral grooves are deep.

Discussion: Compared with other *Quadralella* species, this species is characterized by having a very large cusp located terminally with a narrow posterior platform brim.

Occurrence: Julian - ?, Upper Zhuganpo Formation, Guizhou and Yunnan provinces, South China.

Quadralella wayaoensis (Wang, 2000)

Figure 10 M-O

2000 *Paragondolella wayaoensis* sp. nov. Wang, Pl. I, fig. 1.

Description: In upper view, the platform extends along the entire element. A short free blade may occur at the anterior. The widest point is in the middle of platform. Adcarinal lateral grooves are shallow. A constriction occurs in the posterior one third. The cusp is node-like and sub-terminal. The posterior end is rounded. In lateral view, the platform is straight or slightly arched. The posterior platform is relative flat. An abrupt step occurs at anterior. The carina consists of completely fused denticles. The anterior carina decreases quickly to the middle and then keeps the same height extending to posterior. The middle carina is not present. In lower view, the pit is sub-terminal and slightly forward shifted. The pit is surrounded by a small loop. The keel end is either rounded, rectangular or weakly bifurcated but not pointed. A furrow extends to the anterior end.

Comparison: *Q. wayaoensis* and *Q. praelindae* both have constrictions of their posterior platforms. However, the current species is characterized by having a broad and flat platform, a weakly bifurcated or rectangular keel end and weak constriction at the posterior one third and a “disappeared” middle carina. *Q. praelindae* is slender, intensely constricted near the posterior end and with a rounded keel end.

Occurrence: Julian - lower Tuvalian?, Zhuganpo and Wayao formations, Guizhou

province, South China.

Quadralella wignalli sp. nov.

Figure 7 Y-AA, AQ-AS, AT-AV

LSID.urn:lsid:zoobank.org:act:6AF7A068-FC36-408B-BD44-3556AE22C8E1

Etymology: Referring to Prof. Paul B. Wignall for his contribution to Permian to Triassic studies.

Holotype: Specimen (Figure 7, AQ-AS) from sample CZ-36 025, Zhuganpo Formation, Caizitang section, South China.

Paratype: Specimen (Figure 7, AT-AV) from sample CZ-36 026, Zhuganpo Formation, Caizitang section, South China.

Type locality: Middle Zhuganpo Formation, Luopin, South China.

Type interval: Early Carnian.

Material: 18 specimens (CZ-36 025, 026, 032, 040, 041; CZ-40 001, 028, 128 CZ-42 041, 095, 168; TS-11 038; TS-18 056; TS-19 051; TS-32 075; WL-02 2; WL-03 4.).

Diagnosis: Platform is moderately elongated. Posterior end is normally rectangular or near rounded. Fused blade is high. A smooth slope occurs at the junction between blade and carina. Carina consists of highly fused denticles. Cusp is big and located sub-terminally. Pit is located sub-terminally.

Description: In upper view, the platform is moderately broad and elongated and either extends the entire element or develops a short free blade at the anterior. The widest point of the platform is normally in the anterior half of the element. The lateral margins are commonly near parallel and slightly upturned. Adcarinal lateral grooves are broad in front and become narrower near the cusp. The cusp is prominent, higher than all other denticles and sub-terminal. A small node-like denticle/node may follow the cusp. The posterior end is generally rounded to rectangular. In lateral view, the element is commonly arched. The basal edge is inclined in both anterior and posterior areas. Smooth slope commonly develops at anterior lateral margin(s). However, an abrupt step may occur at the anterior in some specimens. The highest point occurs at the convex crest on the blade. The anterior blade is high and consists of highly fused denticles. A smooth slope occurs at the junction of blade and carina. The carina is low and mostly fused. In lower view, the pit is surrounded by a small loop located sub-terminally. The keel is moderately wide and extends to the anterior end where it is rounded to rectangular. A furrow extends to the anterior end.

Discussion: *P. inclinata* and the current species both have generally arched platforms with smooth slopes at the anterior. However, *Q. wignalli* sp. nov. is characterized by having a moderately broad platform, fused carina and smooth slope at the junction of carina and blade. Compared with *Q. postinclinata* (Kozur 2003), *Q. wignalli* sp. nov. has a thicker platform, a rectangular posterior end, a higher blade and a distinct cusp. Compared with *Q. polygnathiformis* and *Q.*

jiangyouensis, the current species has a convex blade, a smooth slope connecting the blade and the carina, and a thick and relatively broad platform. *Q. jiangyouensis* has a near rectangular platform which differs with that of the current species.

Occurrence: Julian - ?, Zhuganpo Formation, Guizhou and Yunnan provinces, South China.

Quadralella yongningensis sp. nov.

Figure 11 J-L, M-O, P-R

LSID.urn:lsid:zoobank.org:act:DEB04A5B-53B6-400A-BB59-4EE8D1689F08

Etymology: Referring to the town where the species is obtained

Holotype: Specimen (Figure 11, M-O) from sample TS-19 045, Zhuganpo Formation, Tianshuo section, South China.

Paratype: Specimen (Figure 11, J-L) from sample TS-11 039, Zhuganpo Formation, Tianshuo section, South China.

Type locality: Middle Zhuganpo Formation, Guanling, South China.

Type interval: Early Carnian.

Material: 4 specimens (TS-11 039; TS-19 045, 048, 050).

Diagnosis: Platform is broad. The blade and carina consist of highly fused denticles, the middle carina is normally merged. The cusp is sub-terminal and

node-like denticle(s) develops behind the cusp. Pit located sub-terminally.

Description: In upper view, the platform is broad. The platform margins are thick. Anterior blade is high. A short free blade may occur. Adcarinal lateral grooves are shallow and broad. The node-like cusp is sub-terminal and generally is followed by one to two node-like denticles. A relatively wide gap occurs between the end of carina and the cusp. The posterior end is rounded to slightly rectangular. In lateral view, the element is slightly arched. The blade consists of highly fused denticles. The carina is fused. Denticles are generally the same height as lateral margins. In lower view, the keel extends to the anterior end where it is rounded to rectangular. The pit is located sub-terminally.

Discussion: *Q. wignalli* sp. nov. and *Q. yongningensis* sp. nov. both have a highly fused blade and a fused carina. However, *Q. wignalli* sp. nov. has a big cusp and a moderately broad platform, while *Q. yongningensis* sp. nov. is characterized by the wide gap between the end of the carina and cusp as well as the presence of node(s) behind the cusp. *Q. postica* sp. nov. and *Q. yongningensis* sp. nov. both have relative wide posterior platform and node-like denticle(s) behind the cusp. However, *Q. postica* sp. nov. is characterized by the irregular or pointed posterior end of platform.

Occurrence: Julian - ?, Zhuganpo Formation, Guizhou province, South China.

Quadralella spp.

Figure 4 A-C, D-F, G-I, P-R, Figure 5 P-R, Y-AA, AE-AG, Figure 6 AK-AM, AT-AV,

Figure 7 P-R, S-U, Figure 8 J-L, Figure 9 G-I

Discussion: The specimen shown in figure 4 (A-C) has a rectangular posterior end of platform and thus differs from *P. inclinata*. The specimen shown in the figure 4 (G-I) has a highly fused blade and carina which differs from *Q. jiangyouensis*. The specimen shown in figure 5 (Y-AA) has slightly broad platform that differs from *P. inclinata*. The specimens shown in figure 5 (AE-AG) and figure 7 (P-R, S-U) are distinct from *Q. jiangyouensis* in the shapes of the platform end, position of the widest point, free blade and constriction. The specimen shown in figure 6 (AT-AV) has an expanded posterior platform that differs from *Q. tadpole*.

CONCLUSION

Conodont biostratigraphy was investigated in three sections from southwestern China in order to evaluate the full diversity of early Late Triassic conodonts. Twenty-three species, including four new species, were recognized and five conodont zones established. Based on the conodont fauna, most of Zhuganpo Formation is assigned to the early Carnian (Julian 1) whereas the Wayao Formation most likely belongs to Julian 2 to Tuvalian 2 substages. Conodont taxa show a major decline in diversity and abundance beginning in the upper Zhuganpo Formation and continuing in the Wayao Formation. This trend coincides with a lithofacies changes from limestone to shale (sometimes with interbedded sandstone). This facies changes is the regional manifestation of the Carnian Humid Episode and the associated climate warming and development of

marine anoxia is considered responsible for the nadir in conodont fortunes.

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This published work and the nomenclatural acts it contains, have been registered in ZooBank:

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REFERENCES

BALINI, M., GWEMANII, D., NICORA, A., and RIZZI, E. 2000. Ladinian/Carnian ammonoids and conodonts from the classic Schilpario-Pizzo Camino area (Lombardy): revaluation of the biostratigraphic support to chronostratigraphy and paleogeography. *Rivista Italiana di Paleontologia e Stratigrafia*, **106**, 19-58.

BENDER, H. and STOPPEL, D. 1965. Perm-conodonten. *Geologisches Jahrbuch*, **82**, 331-364.

BUDUROV, K. and STEFANOV, S. 1965. Gattung *Gondolella* aus der Trias Bulgariens. *Doklady Bolgarskoy Akademiya Nauk, Série Paléontologie*, **7**, 115-127.

—1975. *Paragondoella foliata* sp. n (Conodonta) von der Trias des Ost-Balkans. *Review of the Bulgarian Geological Society*, **36**, 79-81.

— GUPTA, V. J., SUDAR, M. N. and BURYI, G. J. 1985. Conodont zonation, biofacies and provinces in the Triassic. *Geological Society of India*, **26**, 84-94.

CHHABRA, N. and KUMAR, S. 1984. Record of Carnian conodonts from the top of Kalapani Limestone, Kumaun Himalaya, India. *Journal of the Palaeontological Society of India*, **29**, 88-92.

CHEN, L. D. and WANG, C. Y. 2002. Triassic conodonts from Zhuganpo and "Wayao" formations of Guanling, southwest China. *Acta Palaeontologica Sinica*, 41, 349-360. [In Chinese, English abstract]

CHEN, Y. L., KRYSTYN, L., ORCHARD, M. J., LAI, X. L. and RICHOZ, S. 2015. A review of the evolution, biostratigraphy, provincialism and diversity of Middle and

early Late Triassic conodonts. *Papers in Palaeontology*, **2**, 235-263.

— and LUKENEDER, A. 2017. Late Triassic (Julian) conodont biostratigraphy of a transition from reefal limestones to deep-water environments on the Cimmerian Terranes (Taurus Mountains, Southern Turkey). *Papers in Palaeontology*, **3**, 441-460.

CLARK, D. L. 1959. Conodonts from the Triassic of Nevada and Utah. *Journal of Palaeontology*, **33**, 305-312.

— PAULL, R. K., SOLIEN, M. A. and MORGAN, W. A. 1979. Triassic conodont biostratigraphy in the Great Basin. *Conodont biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young University Geology Studies*, **26**, 179-186.

DI STEFANO, P., RIGO, M., TRIPODO, A., TODARO, S. and ZARCONE, G. 2014. New biostratigraphic data from the Ladinian pelagic limestones of Pizzo Di Sant'Otiero-Madonie mountains, Sicily. *Rivista Italiana di Paleontologia e Stratigrafia*, **120**, 61-70.

DZIK, J. 1976. Remarks on the evolution of Ordovician conodonts. *Acta Palaeontology Polonica*, **21**, 395-455.

GALLET, Y., BESSE, J., KRYSTYN, L., THÉVENIAUT, H. and MARCOUX, J. 1994. Magnetostratigraphy of the Mayerling section (Austria) and Erenkolu Mezarlik (Turkey) section: Improvement of the Carnian (late Triassic) magnetic polarity time scale. *Earth Planetary Science Letters*, **125**, 173-191.

HAYASHI, S. 1968. The Permian conodonts in chert of the Adoyama Formation,

Ashio Mountains, Central Japan. *Earth Science*, **22**, 63-77.

IGO, H. 1989. Mixed conodont elements from Hachiman Town, Mino terrane, central Japan. *Nihon Koseibutsu Gakkai hokoku, kiji*, **156**, 270-285.

ISHIDA, K. and HIRSCH, F. 2001. Taxonomy and faunal affinity of late Carnian Rhaetian conodonts in the southern Chichibu belt, Shikoku, SW Japan. *Rivista Italiana di Paleontologia e Stratigrafia*, **107**, 227-250.

KILIÇ, A. M., PLASENCIA, P., ISHIDA, K. and HIRSCH, F. 2015. The case of the Carnian (Triassic) conodont genus *Metapolygnathus* Hayashi. *Journal of Earth Science*, **26**, 219-223.

KOIKE, T. 1981. Biostratigraphy of Triassic conodonts in Japan. *Science Reptorts. Yokohama Nation University Section II*, **28**, 9-42.

— 1982. Review of some platform conodonts of the Middle and Late Triassic in Japan. Yokohama National University science summary. *The second category, biology, earth science*, **29**, 15-34.

— KODACHI, Y., MATSUNO, T. and BABA, H. 1991. Triassic conodonts from exotic blocks of limestone in northern Kuzuu, the Ashio Mountains. *Science Reptorts. Yokohama Nation University Section II*, **38**, 53-69.

KOVÁCS, S. 1977. New conodonts from the north Hungarian Triassic. *Acta Mineral Petrology*, **23**, 77-90.

— 1983. On the evolution of *excelsa*-stock in the Upper Ladinian - Carnian (Conodonta, genus Gondolella, Triassic). *Schriftenreihe der Erdwissenschaftlichen Kommissionen*, **5**, 107-120.

KOZUR, H. W. 1980. The main events in the Upper Permian and Triassic conodont evolution and its bearing to the Upper Permian and Triassic stratigraphy. *Rivista Italiana di Paleontologia e Stratigrafia*, **85**, 741-766.

— 1989a. Significance of events in conodont evolution for the Permian and Triassic stratigraphy. *Courier Forschungsinstitut Senckenberg*, **117**, 385–408.

— 1989b. The taxonomy of the gondolellid conodonts in the Permian and Triassic. *Courier Forschungsinstitut Senckenberg*, **117**, 409–469.

— 2003. Integrated ammonoid, conodont and radiolarian zonation of the Triassic. *Hellesches Jahrbuch Geowissenschaften*, **B25**, 49-79.

KRYSTYN, L. 1980. Stratigraphy of the Hallstatt region. *Abhandlungen Geologischen Bundesanstalt Wien*, **35**, 69-98.

— 1983. Das Epidaurus-Profil (Griechenland) - ein Beitrag zur Conodonten-Standardzonierung des tethyalen Ladin und Unterkarn. Neue Beiträge zur Biostratigraphie der Tethys-Trias. *Schriftenreihe der Erdwissenschaftlichen Kommissionen*, **5**, 231-258.

LAI, X. L. and MEI, S. L. 2000. On zonation and evolution of Permian and Triassic conodonts. *Developments in Palaeontology and Stratigraphy*, **18**, 371-392.

LEHRMANN, D. J., STEPCHINSKI, L., ALTINER, D., ORCHARD, M. J., MONTGOMERY, P., ENOS, P., ELLWOOD, B. B., BOWRING, S. A., RAMEZANI, J., WANG, H. M., WEI, J. Y., YU, M. Y., GRIFFITHS, J. D., MINZONI, M., SCHAAL, E. K., LI, X. W., MEYER, K. M. and PAYNE, J. L. 2015. An integrated biostratigraphy (conodonts and foraminifers) and chronostratigraphy (paleomagnetic

reversals, magnetic susceptibility, elemental chemistry, carbon isotopes and geochronology) for the Permian–Upper Triassic strata of Guandao section, Nanpanjiang Basin, South China. *Journal of Asian Earth Sciences*, **108**, 117-135.

LINDSTRÖM, M. 1970. A suprageneric taxonomy of the conodonts. *Lethaia*, **3**, 427–445.

MARTÍNEZ-PÉREZ, C., PLASENCIA, P., CASCALES-MIÑANA, B., MAZZA, M. and BOTELLA, H. 2014. New insights into the diversity dynamics of Triassic conodonts. *Historical Biology*, **26**, 591-602.

MAZZA, M., FURIN, S., SPÖTL, C. and RIGO, M. 2010. Generic turnovers of Carnian/Norian conodonts: Climatic control or competition? *Palaeogeography, Palaeoclimatology, Palaeoecology*, **290**, 120-137.

— RIGO, M. and NICORA, A. 2011. A new *Metapolygnathus* platform conodont species and its implications for Upper Carnian global correlations. *Acta Palaeontologica Polonica*, **56**, 121-131.

— RIGO, M. and GULLO. M. 2012. Taxonomy and biostratigraphic record of the Upper Triassic conodonts of the Pizzo Mondello section (western Sicily, Italy), GSSP candidate for the base of the Norian. *Rivista Italiana di Paleontologia e Stratigrafia*, **118**, 85-130.

METCALFE, I. 1990. Triassic conodont biostratigraphy in the Malay Peninsula. *Geological Society of Malaysia Bulletin*, **26**, 133-45.

— 1992. Upper Triassic conodonts from the Kodiang Limestone, Kedah,

Peninsular Malaysia. *Journal of Southeast Asian Earth Sciences*, **7**, 131-138.

— KOIKE, T., RAFEK, M. B. and HAILE, N. S. 1979. Triassic conodonts from Sumatra. *Palaeontology*, **22**, 737-746.

MIETTO, P., MANFRIN, S., PRETO, N., RIGO, M., ROGJI, G., FURIN, S., GIANOLLA, P., POSENATO, R., MUTTONI, G., NICORA, A., BURATTI, N., CIRILLI, S., SPÖTL, C., RAMEZANI, J. and BOWRING, S. A. 2012. The Global boundary Stratotype Section and Point (GSSP) of the Carnian stage (Late Triassic) at Prati di Stuores/Stuores Wiesen section (Southern Alps, NE Italy). *Episodes*, **35**, 414-430.

MOSHER, L. C. 1968. Triassic conodonts from western North America and Europe and their correlation. *Journal of Paleontology*, **42**, 895-946.

MÜLLER, K. J. 1956. Triassic conodonts from Nevada. *Journal of Paleontology*, **30**, 818-830.

MUTTONI, G., MAZZA, M., MOSHER, D., KATZ, M. E., KENT, D. V. and BALINI, M. 2014. A Middle–Late Triassic (Ladinian–Rhaetian) carbon and oxygen isotope record from the Tethyan Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **399**, 246-259.

ORCHARD, M. J. 1991a. Late Triassic conodont biochronology and biostratigraphy of Kunga Group, Queen Charlotte Islands, British Columbia. *Geological Survey of Canada Bulletin*, ***90***, 173-193.

—1991b. Upper Triassic conodont biochronology and new index species from the Canadian Cordillera. *Geological Survey of Canada Bulletin*, **417**, 229-339.

—2005. Multielement conodont apparatuses of Triassic Gondolelloidea. *Special Papers in Palaeontology*, **73**, 73–101

— and TOZER, E. T. 1997. Triassic conodont biochronology, its calibration with the ammonoid standard, and a biostratigraphic summary for the Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology*, **45**, 675-692.

— CORDEY, F., RUI, L., BAMBER, E. W., MAMET, B., STRUIK, L. C., SANO, H. and TAYLOR, H. J. 2001. Biostratigraphic and biogeographic constraints on the Carboniferous to Jurassic Cache Creek Terrane in central British Columbia. *Canadian Journal of Earth Sciences*, **38**, 551-578.

— 2007. New conodonts and zonation, Ladinian–Carnian boundary beds, British Columbia, Canada. *New Mexico Museum of Natural History and Science Bulletin*, **41**, 321-330.

— and BALINI, M. 2007. Conodonts from the Ladinian–Carnian boundary beds of South Canyon, New Pass Range, Nevada, USA. *The Global Triassic. New Mexico Museum of Natural History and Science Bulletin*, **41**, 333-340.

— 2010. Triassic conodonts and their role in stage boundary definition. *Geological Society, London, Special Publications*, **33**, 139-161.

— 2013. Five new genera of conodonts from the Carnian-Norian boundary beds of Black Bear Ridge, northeast British Columbia, Canada. The Triassic System. *New Mexico Museum of Natural History and Science*, **61**, 445-437.

— 2014. Conodonts from the Carnian-Norian Boundary (Upper Triassic) of Black

Bear Ridge, north-eastern British Columbia, Canada. *New Mexico Museum of Natural History and Science Bulletin*, **64**, 1-139.

RIGO, M., PRETO N., ROGHI, G., TATEO, F. and MIETTO, P. 2007. A rise in the carbonate compensation depth of western Tethys in the Carnian (Late Triassic): deep-water evidence for the Carnian Pluvial Event. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **246**, 188-205.

SIMMS, M. J. and RUFFELL, A. H. 1989. Synchroneity of climatic change and extinctions in the Late Triassic. *Geology*, **17**, 265-268.

— 1990. Climatic and biotic change in the Late Triassic. *Journal of the Geological Society*, 147, 321-327.

SUN, Z. Y., HAO, W. C. and JIANG, D. Y. 2005. Conodont biostratigraphy near the Ladinain-Carnian boundary interval in Guanling of Guizhou. *Journal of Stratigraphy*, **29**, 257-263. [In Chinese, English abstract]

— 2006. The Middle and Upper Triassic biostratigraphy in western Guizhou and eastern Yunnan. Ph. D. Thesis, Peking University. China. 1-141 pp. [In Chinese, English abstract]

SUN, Y. D., WIGNALL, P. B., JOACHIMSKI, M. M., BOND, D. P. G., GRASBY, S. E., LAI, X. L., WANG, L. N., ZHANG, Z. T. and SUN, S. 2016. Climate warming, euxinia and carbon isotope perturbations during the Carnian (Triassic) Crisis in South China. *Earth and Planetary Science Letters*, **444**, 88-100.

SWEET, W. C., MOSHER, L. C., CLARK, D. L., COLLINSON, J. W. and HASENMUELLER, W. A. 1970. Conodont biostratigraphy of the Triassic.

Geological Society of America Memoirs, **127**, 441-466.

TIAN, C. R., DAI, J. and TIAN, S. G. 1983. Triassic conodonts. Paleontological atlas of Southwest China, volume of microfossils. Geological Publishing House, Beijing. pp. 345–398. [In Chinese]

WANG, Z. H. and DAI, J. Y. 1981. Triassic conodonts from the Jiangyou-Beichuan area, Sichuan province. *Acta Palaeotologica Sinica*, **20**, 138-152. [In Chinese, English abstract]

— and ZHONG, D. 1990. Triassic conodont biostratigraphic from eastern Yunnan, western Guizhou and northern Guangxi. *Journal of stratigraphy*, **14**, 15-34. [In Chinese, English abstract]

WANG, H. M. 2000. Discussion on the age of Guanling Fauna by conodonts. *Guizhou Geology*, **17**, 219-225. [In Chinese, English abstract]

— WANG, X. L., LI, R. X. and WEI, J. Y. 2005. Triassic conodont succession and stage subdivision of the Guandao section, Bianyang, Luodian, Guizhou. *Acta Palaeontologica Sinica*, **44**, 611-626. [In Chinese, English abstract]

YANG, S. R., LIU, J. and ZHANG, M. F. 1995. Conodonts from the Falang Formation of Southwestern Guizhou and their age. *Journal of Stratigraphy*, **19**, 161-170. [In Chinese, English abstract]

— HAO, W. C. and WANG, X. P. 1999. Triassic conodont sequences from different facies in China. *Biotic and Geological Development of Paleo-Tethys in China*, p, 97-112. [In Chinese, English abstract]

— HAO, W. C. and JIANG, D. Y. 2002. Conodonts of the Fanglang Formation from

langdai, Liuzhi county, Guizhou Province and Their Age Significance. *Geological Review*, **48**, 586-592. [In Chinese, English abstract]

YIN, H. F. and PENG, Y. Q. 2000. The Triassic of China and its interregional correlation. *Developments in Palaeontology and Stratigraphy*, **18**, 197-220.

ZHANG, Z. T., SUN, Y. D., LAI, X. L., JOACHIMSKI, M. M. and WIGNALL, P. B. 2017. Early Carnian conodont fauna at Yongyue, Zhenfeng area and its implication for Ladinian-Carnian subdivision in Guizhou, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology.* **486,** 142-157**.**

Figure captions

Fig. 1 Location map of study sections at Caizitang (NO. 1), Tianshuo (NO. 2) and Wolonggang (NO. 3) from Yunnan and Guizhou provinces, South China.

Fig. 2 Log of the Caizitang section, showing sampling positions and conodont ranges.

Fig. 3 Logs of the Tianshuo (left) and Wolonggang (right) sections, showing sampling positions and conodont ranges. In the Wolonggang Section, the Julian1-Julian 2 boundary is marked by a dashed line while the Tuvalian substage cannot be defined due to the paucity of conodont.

Fig. 4 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang Section, all in upper, lateral and lower views respectively. A-C, *Quadralella* spp. CZ-19 060. D-F, *Quadralella* spp. CZ-19 061. G-I, *Quadralella* spp. CZ- 42 159. J-L, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ- 42 166. M-O,

Quadralella polygnathiformis (Budurov & Stefanov, 1965) CZ-42 173. P-R, *Quadralella* spp. CZ-19 065. S-U, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-40 005. V-X, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-40 007. Y-AA, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-40 017. AB-AD, *Quadralella robusta* sp. nov. CZ-35 016. AE-AG, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-42 004. AH-AJ, *Quadralella robusta* sp. nov. CZ-35 011. AK-AM, *Quadralella robusta* sp. nov. CZ-35 021. AN-AP, *Quadralella praelindae* (Kozur, 2003) CZ-35 022. AQ-AS, *Paragondolella inclinata* (Kovács, 1983) CZ-42 069. AT-AV, *Quadralella shijiangjunensis* (Sun, 2006) CZ-36 036. Scale bar represents 300μm.

Fig. 5 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang Section, all in upper, lateral and lower views respectively. A-C, *Quadralella intermedius* (Orchard, 2007) CZ-40 012. D-F, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 015. G-I, *Paragondolella inclinata* (Kovács, 1983) CZ-40 021. J-L, *Paragondolella inclinata* (Kovács, 1983) CZ-40 023. M-O, *Quadralella acuminatus* (Orchard, 2007) CZ-42 067. P-R, *Quadralella* spp. CZ-42 158. S-U, *Paragondolella foliata* Budurov, 1975 CZ-42 088. V-X, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 093. Y-AA, *Quadralella* spp. CZ-42 043. AB-AD, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 044. AE-AG, *Quadralella* spp. CZ-42 020. AH-AJ, *Paragondolella inclinata* (Kovács, 1983) CZ-42 015. Scale bar represents 300μm.

Fig. 6 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang

Section, all in upper, lateral and lower views respectively. A-C, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 162. D-F, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 017. G-I, *Quadralella intermedius* (Orchard, 2007) CZ-19 055. J-L, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-19 051. M-O, *Quadralella inclinata* (Kovács, 1983) CZ-19 050. P-R, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-19 053. S-U, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-19 054. V-X, *Paragondolella inclinata* (Kovács, 1983) CZ-40 123. Y-AA, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-31 091. AB-AD, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 004. AE-AG, *Quadralella praelindae* (Kozur, 2003) CZ-40 124. AH-AJ, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 129. AK-AM, *Quadralella* spp. CZ-35 020. AN-AP, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 051. AQ-AS, *Quadralella praelindae* (Kozur, 2003) CZ-42 049. AT-AV, *Quadralella* spp. CZ-31 031. Scale bar represents 300μm.

Fig. 7 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang Section, all in upper, lateral and lower views respectively. A-C, *Quadralella yongyueensis* Zhang, Sun & Lai, 2017 CZ-19 072. D-F, *Quadralella* aff. *polygnathiformis magna* (Igo, 1989) CZ-19 075. G-I, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-25 007. J-L, *Quadralella shijiangjunensis* (Sun, 2006) CZ-40 122. M-O, *Quadralella cf. maantangensis* (Dai & Tian in Tian *et al*. 1983) CZ-40 127. P-R, *Quadralella* spp. CZ-40 125. S-U, *Quadralella* spp. CZ-40

131. V-X, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 134. Y-AA, *Quadralella wignalli* sp. nov. CZ-40 001. AB-AD, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 002. AE-AG, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-36 029. AH-AJ, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-36 031. AK-AM, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-40 008. AN-AP, *Quadralella uniformis* (Sun, 2006) CZ-31 039. AQ-AS, *Quadralella wignalli* sp. nov. CZ-36 026. AT-AV, *Quadralella wignalli* sp. nov. CZ-36 025. Scale bar represents 300μm.

Fig. 8 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang Section, all in upper, lateral and lower views respectively. A-C, *Quadralella intermedius* (Orchard, 2007) CZ-42 161. D-F, *Quadralella intermedius* (Orchard, 2007) CZ-42 171. G-I, *Quadralella* aff. *zonneveldi* (Orchard, 2007) CZ-42 172. J-L, *Quadralella* spp. CZ-43 116. M-O, *Quadralella praelindae* (Kozur, 2003) CZ-42 174. P-R, *Quadralella intermedius* (Orchard, 2007) CZ-42 176. S-U, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 092. V-X, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 115. Y-AA, *Quadralella intermedius* (Orchard, 2007) CZ-19 064. AB-AD, *Quadralella praelindae* (Kozur, 2003) CZ-42 100. Scale bar represents 200μm.

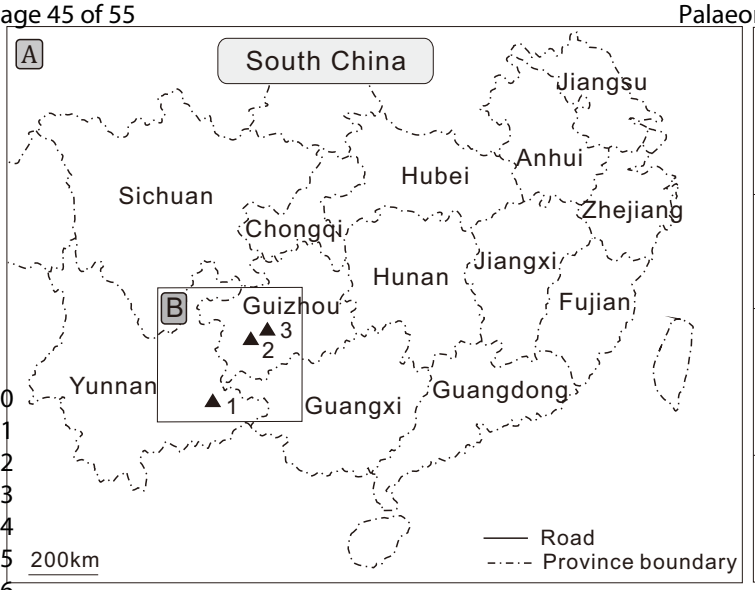
Fig. 9 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang Section, all in upper, lateral and lower views respectively. A-C, *Quadralella* aff. *auriformis* (Kovács, 1977) CZ-31 036. D-F, *Quadralella tadpole* (Hayashi, 1968) CZ-31 060. G-I, *Quadralella* spp. CZ-31 061. J-L, *Quadralella intermedius* (Orchard,

2007) CZ-31 065. M-O, *Quadralella praelindae* (Kozur, 2003) CZ-31 076. P-R, *Quadralella* aff. *zonneveldi* (Orchard, 2007) CZ-31 087. S-U, *Quadralella tadpole* (Hayashi, 1968) CZ-31 040. V-X, *Quadralella praelindae* (Kozur, 2003) CZ-31 034. Y-AA, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-31 049. Scale bar represents 200μm.

Fig. 10 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang and Wolonggang Sections. A, all in upper, lateral and lower views respectively. Scale bars represents 200μm (A-L); A-C, *Quadralella intermedius* (Orchard, 2007) CZ-31 057. D-F, *Quadralella praelindae* (Kozur, 2003) CZ-31 054. G-I, *Quadralella praelindae* (Kozur, 2003) CZ-31 052. J-L, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-31 056. Scale bars represents 300μm (M-AA). M-O, *Quadralella wayaoensis* (Wang, 2000) WL-2 001. P-R, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) WL-4 003. S-U, *Quadralella maantangensis* (Dai & Tian in Tian *et al*. 1983) WL-7.5 001. V-X, *Quadralella* aff. *polygnathiformis magna* (Igo, 1989) WL-4 002. Y-AA, *Paragondolella inclinata* (Kovács, 1983) WL-10 003.

Fig. 11 SEM photos of conodonts from the Carnian strata of Tianshuo Section , all in upper, lateral and lower views respectively. A-C, *Quadralella postica* sp. nov. TS-4 032. D-F, *Quadralella postica* sp. nov. TS-4 033. G-I, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) TS-4 034. J-L, *Quadralella yongningensis* sp. nov. TS-11 039. M-O, *Quadralella yongningensis* sp. nov. TS-19 045. P-R, *Quadralella yongningensis* sp. nov. TS-19 048. S-U, *Quadralella*

polygnathiformis (Budurov & Stefanov, 1965) TS-19 047. V-X, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) TS-19 052. Y-AA, *Quadralella wanlanensis* Zhang, Sun & Lai, 2017 TS-20 062. AB-AD, *Paragondolella foliata* Budurov, 1975 TS-32 074. AE-AG, *Quadralella wanlanensis* Zhang, Sun & Lai, 2017 TS-21 068. AH-AJ, *Quadralella wanlanensis* Zhang, Sun & Lai, 2017 TS-20 062. AK-AM, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) TS-19 060. Scale bar represents 400μm.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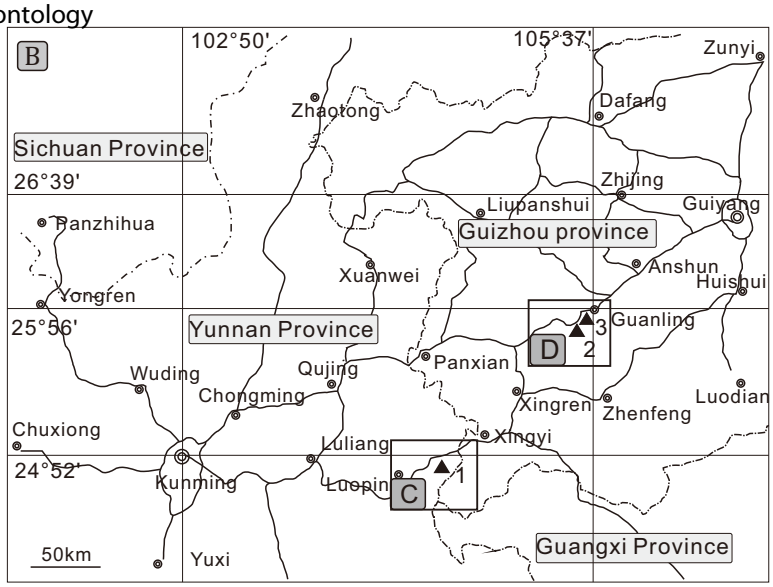
Province boundary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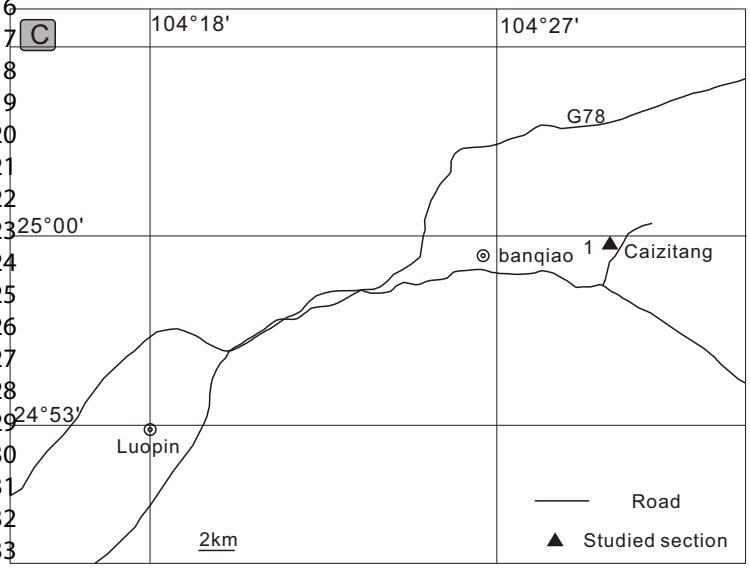
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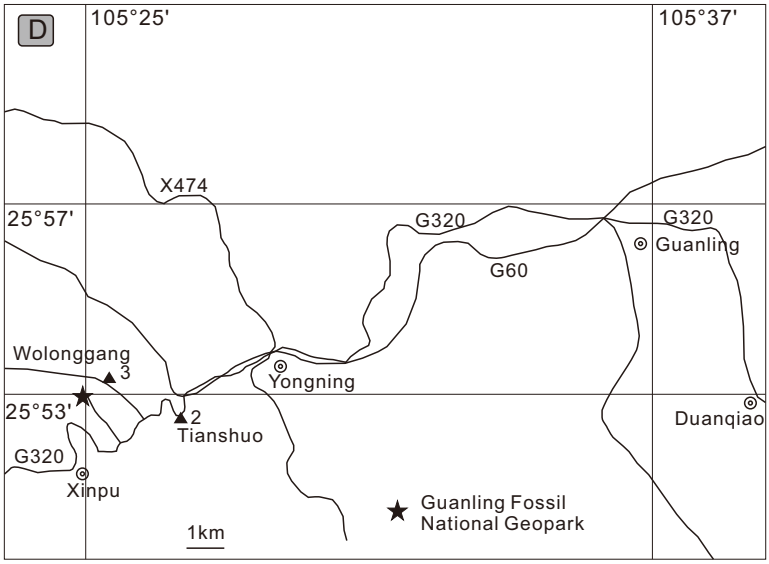
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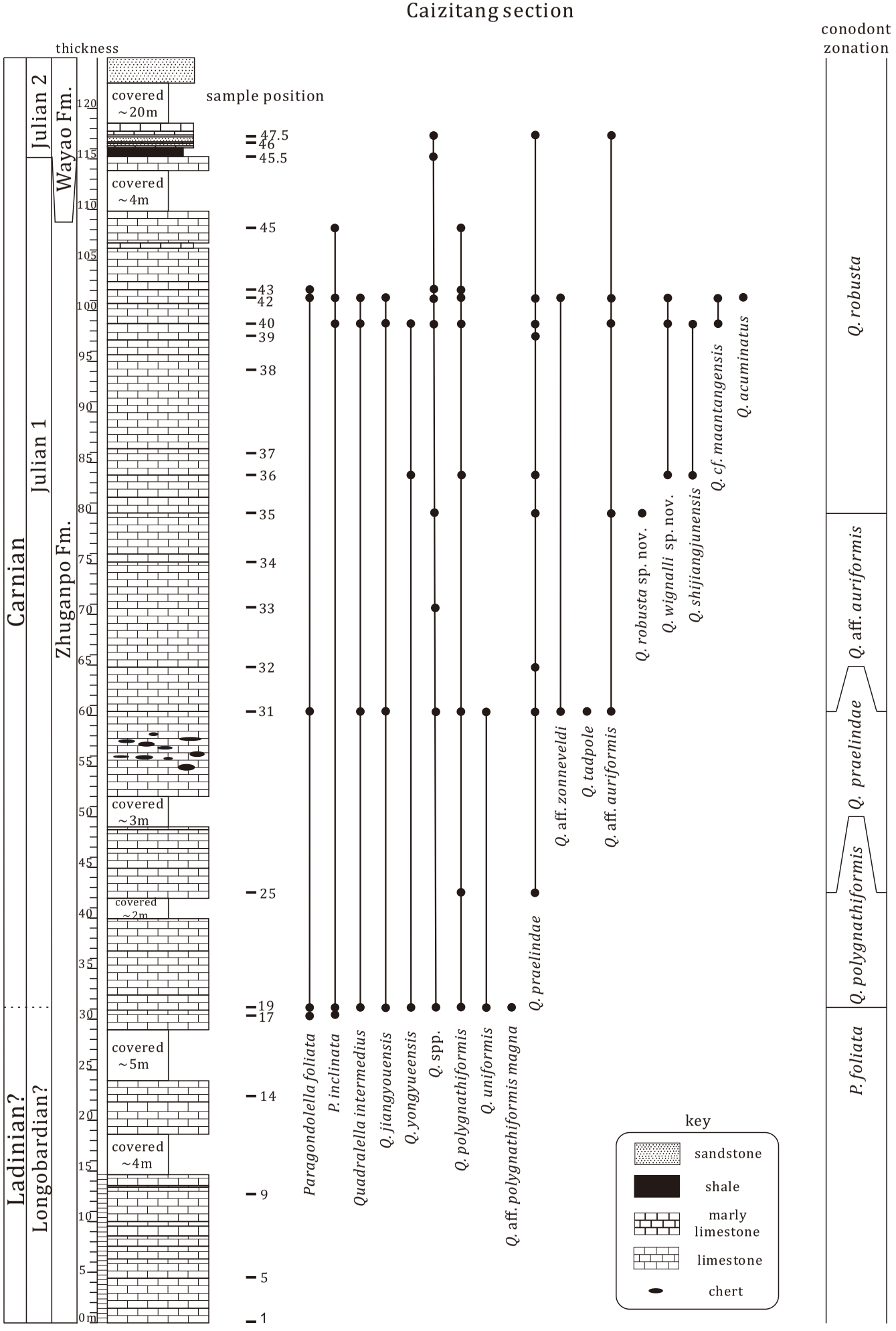
Caizitang section
thickness
sample position
conodont zonation
Carnian
Ladinian?
Longobardian?
Julian 1
Julian 2
Zhuganpo Fm.
Wayao Fm.
covered ~20m
covered ~4m
covered ~3m
covered ~2m
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Paragondolella foliata
P. inclinata
Quadralella intermedius
Q. jiangyouensis
Q. yongyueensis
Q. spp.
Q. polygnathiformis
Q. uniformis
Q. aff. polygnathiformis magna
Q. praelindae
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Q. tadpole
Q. aff. auriformis
Q. robusta sp. nov.
Q. wignalli sp. nov.
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Q. cf. maantangensis
Q. acuminatus
key
sandstone
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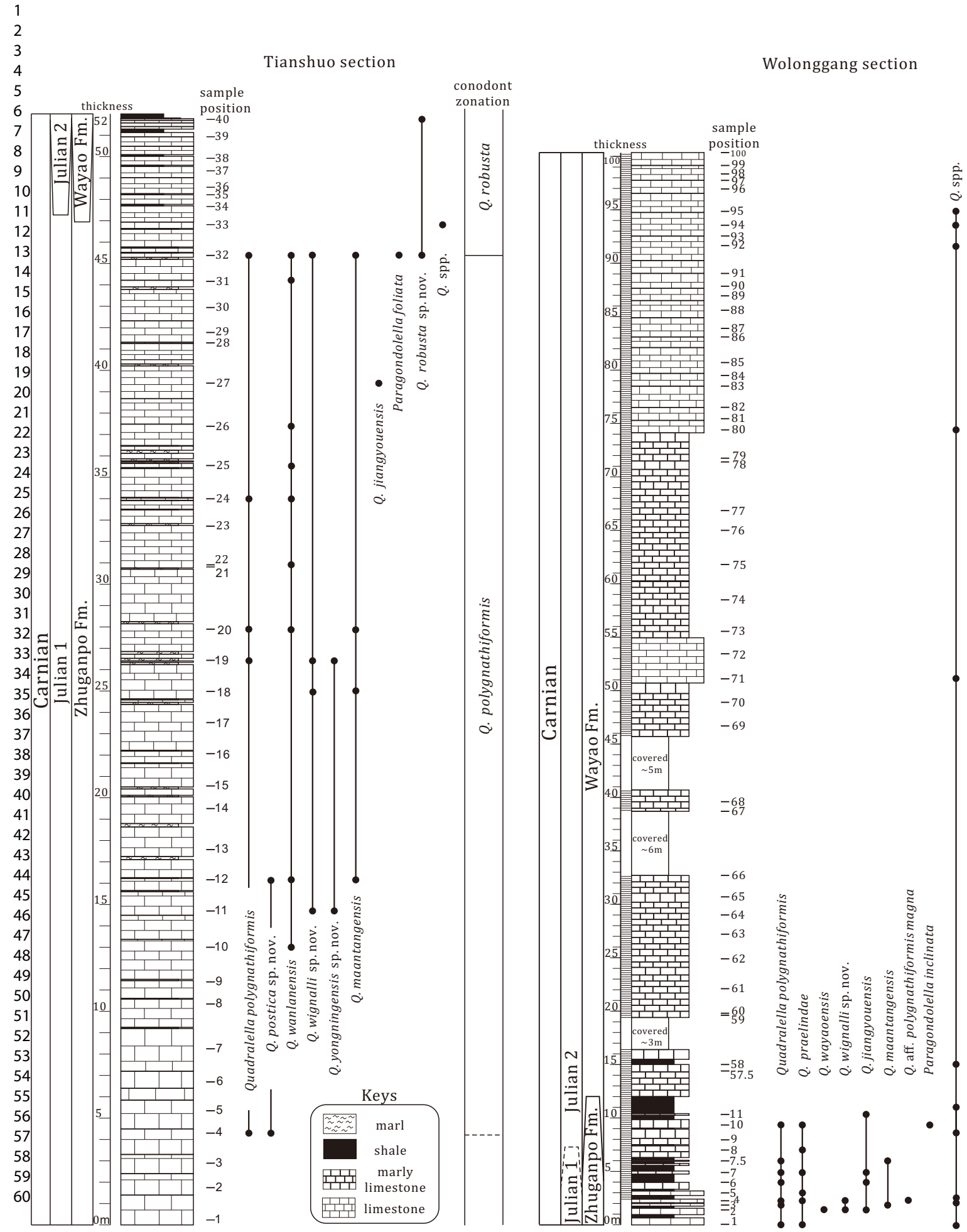
Q. robusta
Q. aff. auriformis
Q. praelindae
Q. polygnathiformis
P. foliata


Tianshuo section
Wolonggang section
thickness
sample position
conodont zonation
Carnian
Julian 2
Julian 1
Zhuganpo Fm.
Wayao Fm.
Q. robusta
Q. polygnathiformis
Quadralella polygnathiformis
Q. postica sp. nov.
Q. wanlanensis
Q. wignalli sp. nov.
Q. yongningensis sp. nov.
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Q. jiangyouensis
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covered ~5m
covered ~6m
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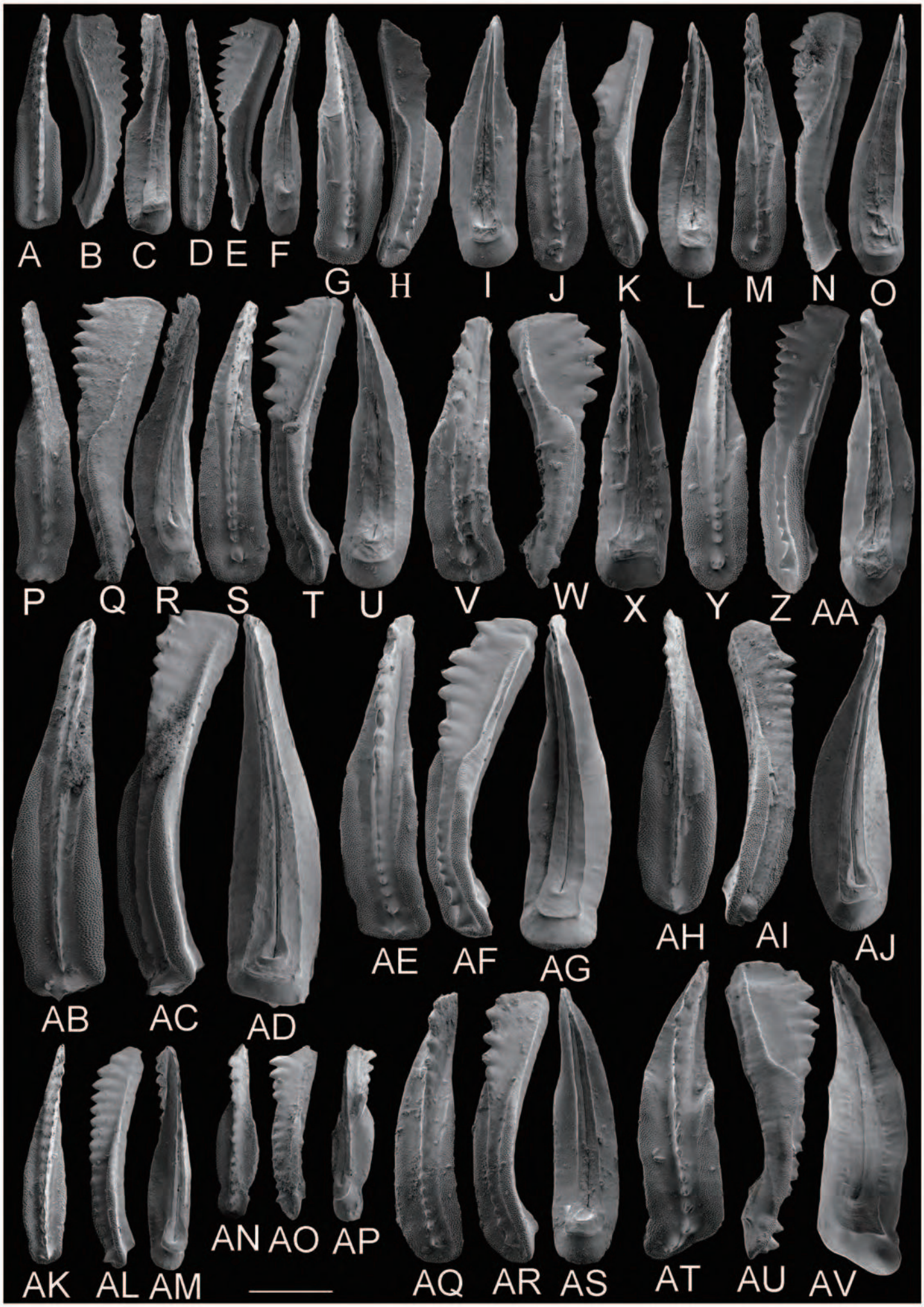
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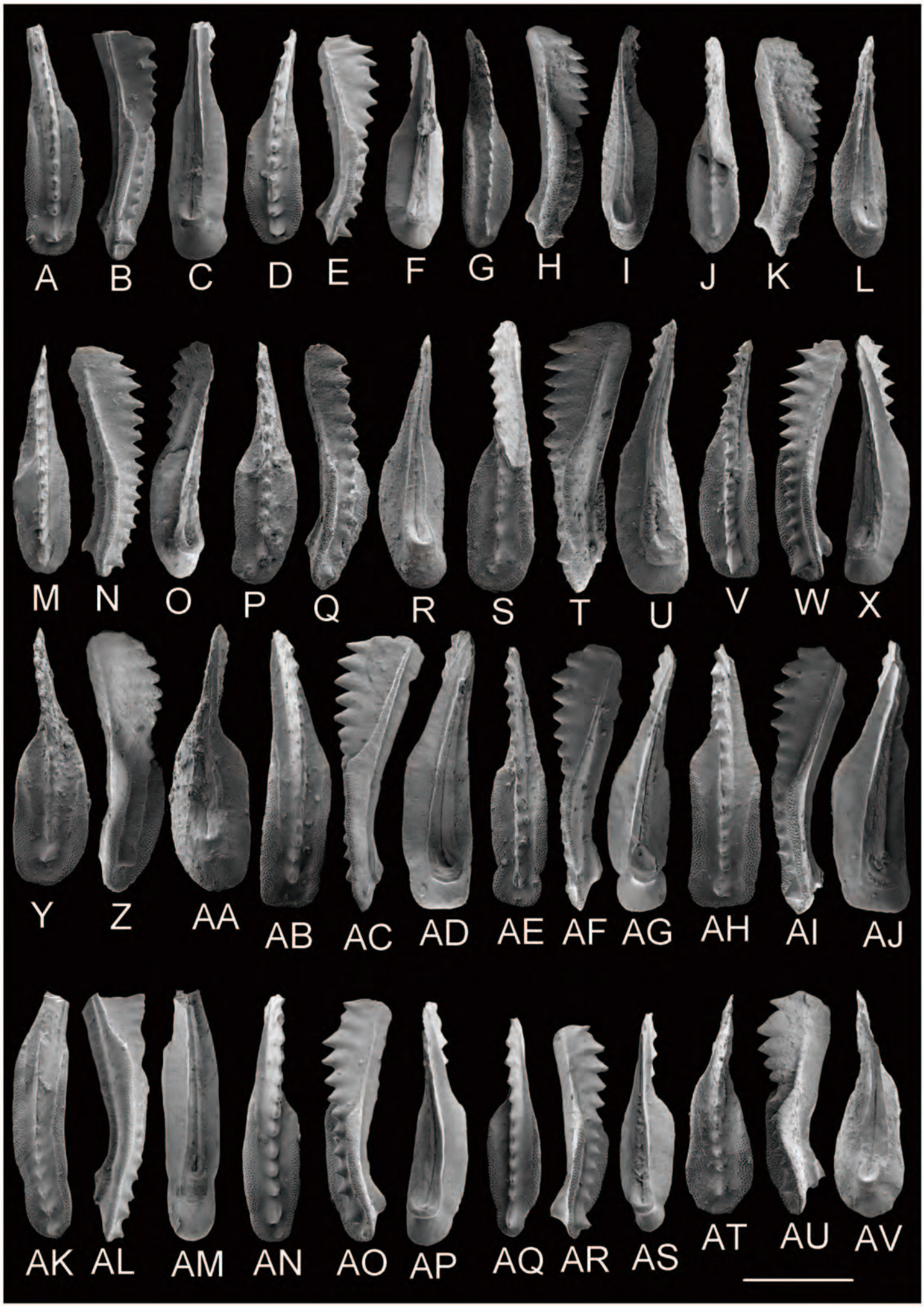
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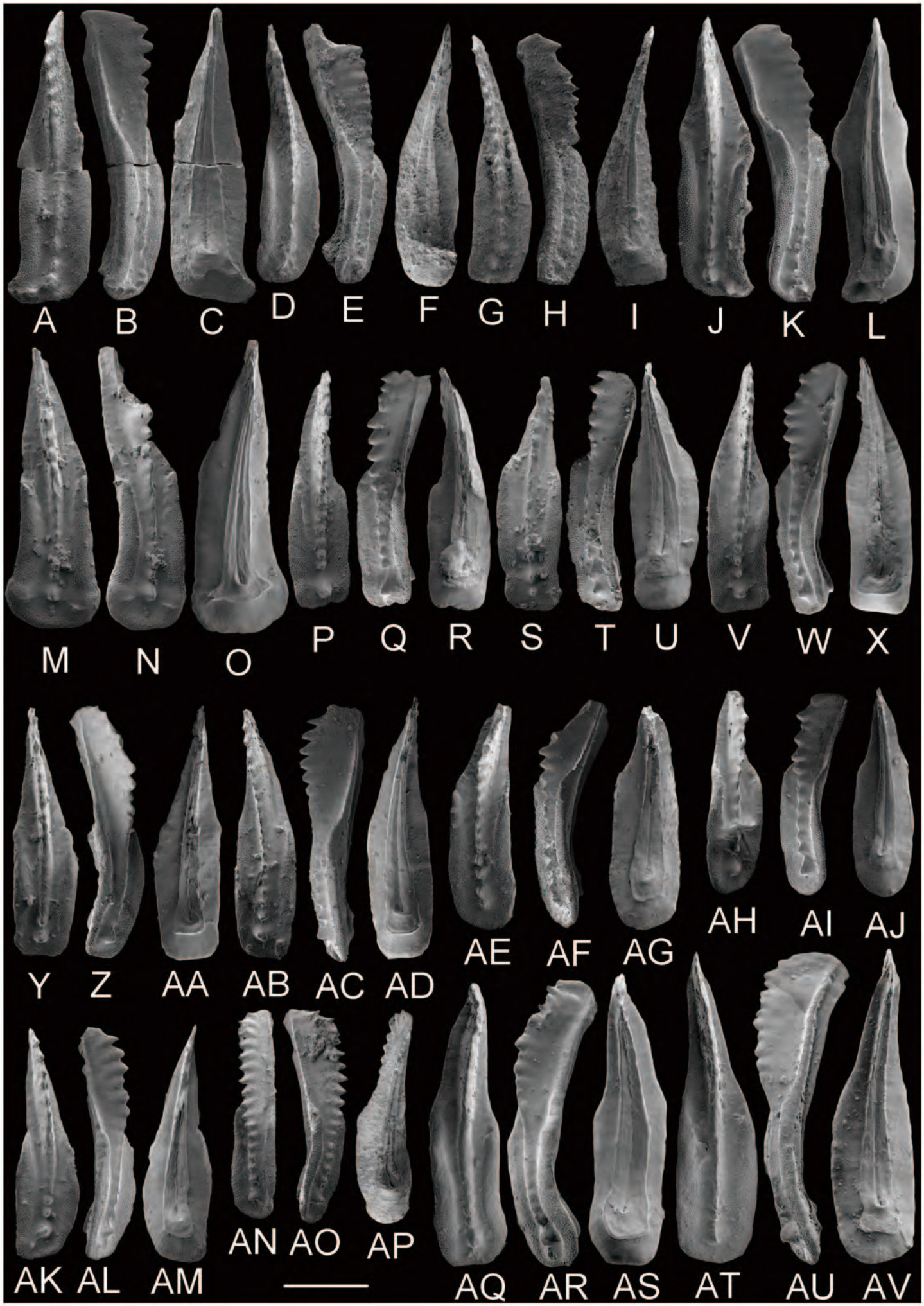
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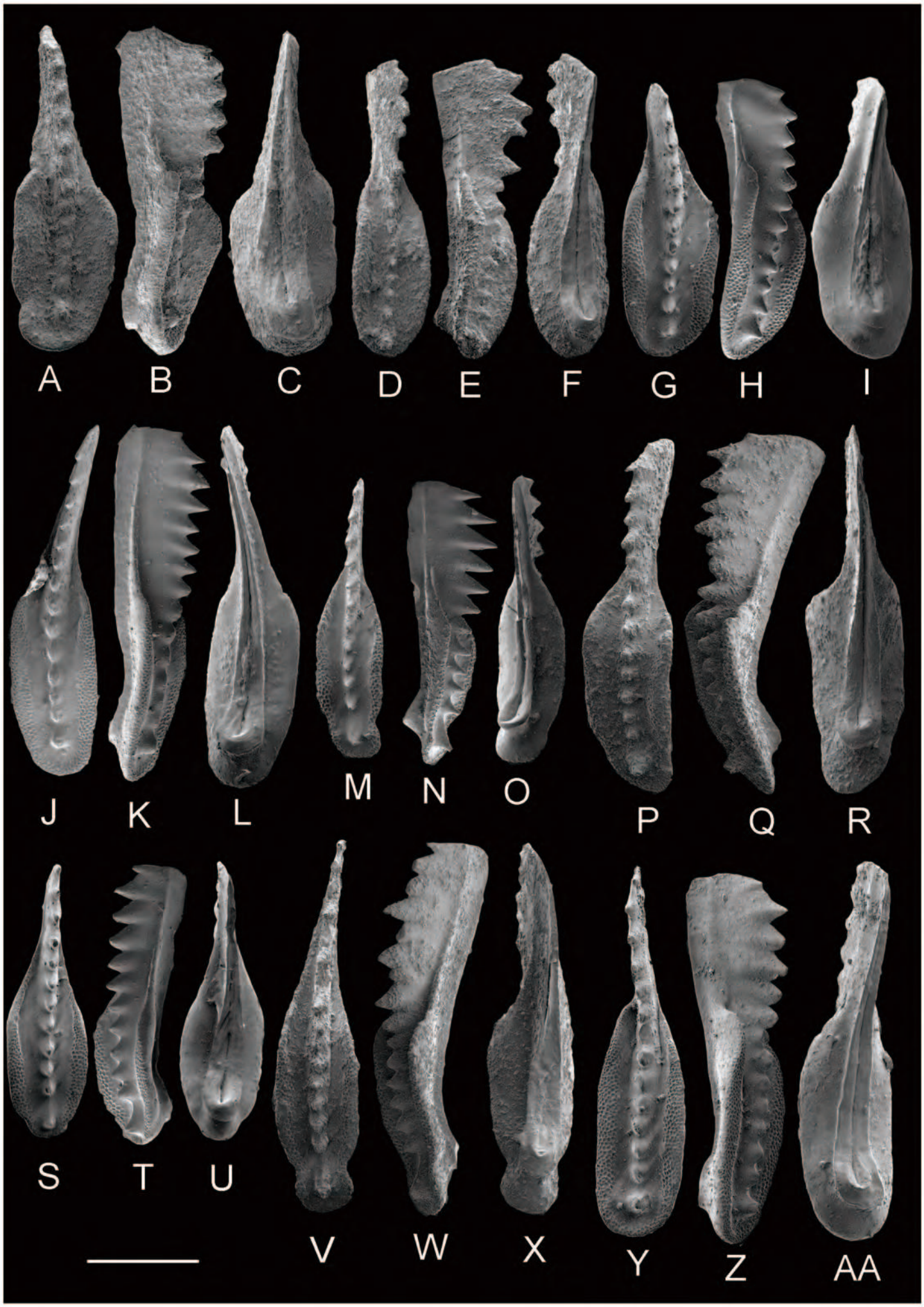
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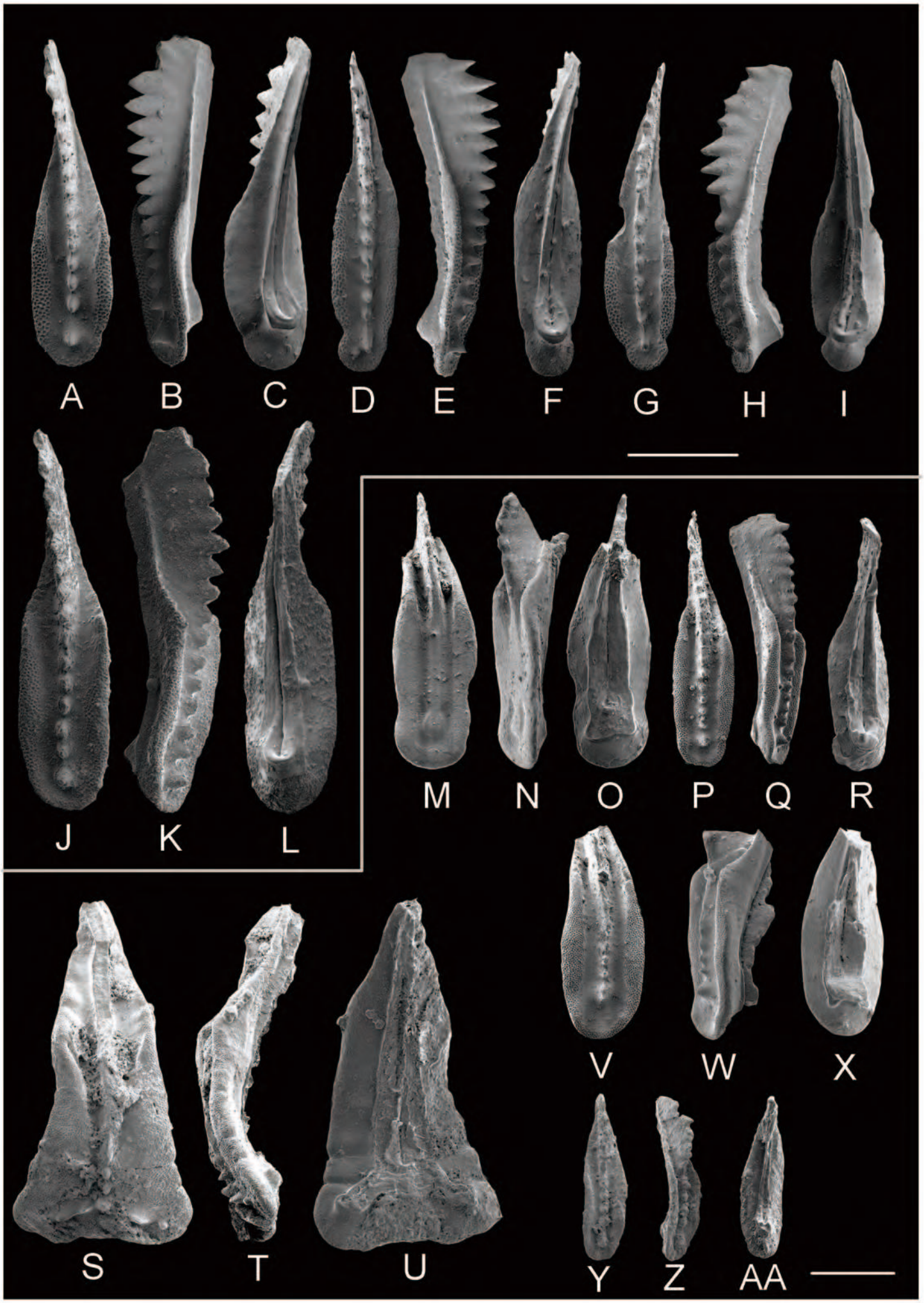
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