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Carnian (Late Triassic) conodont faunas from southwestern China and their implications

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

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4 1 CARNIAN (LATE TRIASSIC) CONODONT FAUNAS FROM
5
6 2 SOUTHWESTERN CHINA AND THEIR IMPLICATIONS
7

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3 19 **Abstract**

4 20 Conodonts are important index fossils for supra-regional correlation especially in
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6
7 21 the Triassic. However, early Carnian conodonts are comparatively poorly known
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9
10 22 in South China. In this study, three sections from the Yunnan and Guizhou
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12 23 provinces are investigated for conodont biostratigraphy and taxonomy. Two
13
14 24 genera and twenty-three species are identified, including four new species
15
16
17 25 *Quadralella (Q.) postica* sp. nov., *Q. robusta* sp. nov., *Q. wignalli* sp. nov. and *Q.*
18
19 26 *yongningensis* sp. nov. Five conodont zones are recognized. They are, in
20
21
22 27 ascending order, *Paragondolella foliata* Zone, *Q. polygnathiformis* Zone, *Q.*
23
24 28 *praelindae* Zone, *Q. aff. auriformis* Zone and *Q. robusta* sp. nov. Zone. Conodonts
25
26
27 29 are reasonably diverse and abundant in the upper Zhuganpo Formation (Julian 1)
28
29 30 but decrease sharply in both species richness and diversity towards the Wayao
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32 31 Formation (Julian 2 and younger). This change was most likely caused by climate
33
34 32 warming and marine anoxia during the Carnian Humid Episode.

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46 37 **Key words:** biostratigraphy; conodont; Middle and Late Triassic; South China

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4 42 Conodonts are widely used as zone fossil to subdivide marine Triassic strata
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6 43 and they have been generally well documented thanks to the endeavours of
7
8 44 several generations of researchers (e.g. Müller 1956; Clark 1959; Mosher 1968;
9
10 45 Sweet *et al.* 1970; Clark *et al.* 1979; Kozur 1980, 1989b, 2003; Balini *et al.* 2000;
11
12 46 Rigo *et al.* 2007; Orchard 2010, 2013, 2014; Di Stefano *et al.* 2014). However,
13
14 47 early Carnian conodonts have received comparatively little study compared to
15
16 48 those from other intervals of Triassic (Mosher 1968; Sweet *et al.* 1970; Orchard &
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18 49 Tozer 1997; Lai & Mei 2000; Kozur 1980, 2003).

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22
23 50 Conodont faunas show a clear trend of increasing provincialism beginning in
24
25 51 the Middle Triassic (Mosher 1968; Sweet *et al.* 1970; Budurov *et al.* 1985; Chen *et*
26
27 52 *al.* 2015). Many endemic taxa appeared in the Late Triassic. By the early Carnian
28
29 53 conodonts had achieved a considerable diversity (Martínez-Pérez *et al.* 2014;
30
31 54 Chen *et al.* 2015), with many taxa known from North American and the European
32
33 55 Alps (e.g. Mosher 1968; Krystyn 1980; Kozur 1989b, 2003; Orchard 1991b, 2007,
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35 56 2013, 2014; Orchard & Tozer 1997; Mietto *et al.* 2012; Muttoni *et al.* 2014).
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37 57 However, the conodonts from these two regions are highly distinct, and have few
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39 58 cosmopolitan forms with the result that inter-regional correlation is difficult.

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45 59 Studies of Carnian conodonts in the eastern Tethys and Panthalassa have
46
47 60 been less thorough compared to the work on North American and European
48
49 61 Alpine faunas. Most early studies were carried out in Japan and they established
50
51 62 the foundation of Carnian biostratigraphic schemes (e.g. Hayashi 1968; Koike
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53 63 1981, 1982; Igo 1989, Koike *et al.* 1991; Ishida & Hirsch 2001). Metcalfe *et al.*
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4 64 (1979) and Metcalfe (1990, 1992) reported the occurrences of *Metapolygnathus*
5
6 65 (*M.*) *polygnathiformis* and *M. tadpole* in the early Carnian strata in Malaysia.
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8 66 Studies of the Late Triassic conodonts in China only started in the 1980s. Initial
9
10 67 work only recognized the presence of *polygnathiformis* – a very common
11
12 68 cosmopolitan species in the Carnian. For example, Wang and Dai (1981) and Tian
13
14 69 *et al.* (1983) identified *Neogondolella (N.) polygnathiformis* from Sichuan and
15
16 70 Tibet, respectively. Later, more comprehensive studies established several
17
18 71 Carnian conodont zones. Thus, Wang and Zhong (1990) erected the *N.*
19
20 72 *polygnathiformis* – *Gladigondolella* assemblage zone and the *N. polygnathiformis*
21
22 73 Zone in southwestern China while Yang *et al.* (1995) established the *N.*
23
24 74 *polygnathiformis* – *N. maantangensis* assemblage zone, the *N. polygnathiformis* –
25
26 75 *N. tadpole* assemblage zone and the *N. polygnathiformis* Zone in Guizhou. Yang *et*
27
28 76 *al.* (1999) and Lai and Mei (2000) summarized the Triassic conodont zones from
29
30 77 type areas in China and identified only three and two conodont zones for the
31
32 78 entire Carnian stage, respectively. Subsequently, it has been shown that Carnian
33
34 79 conodonts in South China are much more diverse than previously thought (e.g.
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36 80 Wang & Dai 1981; Wang 2000; Chen & Wang 2002; Yang *et al.* 2002; Sun 2006;
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38 81 Sun *et al.* 2016; Zhang *et al.* 2017).

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41 82 In order to document the full spectrum of Carnian conodonts in
42
43 83 southwestern China, we have carried out detailed investigations on three
44
45 84 sections in Yunnan and Guizhou Provinces. The conodont fauna from this region
46
47 85 is characterized by a dominance of genera *Paragondolella (P.)* and *Quadralella (Q.)*
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4 86 while genera *Budurovignathus*, *Gladigondolella* and *Mosherella* are absent. A total
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6 87 of twenty-three species, including four new species, are identified here. In study
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8 88 sections, conodonts are diverse and abundant in lower Carnian strata but they
9
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11 89 become rare and small in the upper Carnian. This trend to rarity and small size,
12
13 90 seen in the Wayao Formation, was probably caused by harsh environmental
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16 91 conditions during and in the aftermath of the Carnian Humid Episode.
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22 23 93 **GEOLOGICAL SETTING**

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25 94 Triassic strata are widely distributed in South China and can be subdivided
26
27 95 into three regions: the Yangtze Platform, the Cathaysian Platform and the
28
29 96 Youjiang Fold Belt (also known as the Nanpanjiang Basin) (Yin & Peng 2000).
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31 97 Carbonate successions were mostly developed on the Yangtze Platform and in the
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33 98 Nanpanjiang Basin, where they are well displayed. Our study sections come from
34
35 99 these regions where we have sampled the Zhuganpo and Wayao formations. The
36
37
38 100 former unit is characterized by a lower unit of thinly to thickly bedded
39
40 101 limestones and an upper unit of nodular limestones or thin to medium bedded
41
42 102 limestones. The overlying Wayao Formation is composed of black shales with
43
44
45 103 interbedded marls/limestones. The studied Caizitang section is located in the
46
47 104 suburb of Banqiao town, ~25 km NE of the Luoping city in the eastern Yunnan
48
49
50 105 province (Fig. 1). The section is 120-m-thick and consists of the Zhuganpo
51
52 106 Formation (115 m in thickness) and the lowermost 5 m of the Wayao Formation.
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55 107 The Tianshuo and Wolonggang sections are both located in the outskirts of
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4 108 Guanling city, western Guizhou province (Fig. 1). The Tianshuo section is exposed
5
6 109 along the road from Yongningzhen Town to the Guanling Fossil National Geopark
7
8 110 that is located ~18 km SW of Guanling city. A total of 52 m of the upper Zhuganpo
9
10 111 Formation is seen but the Wayao Formation is obscured. The Wolonggang section
11
12 112 is located at Baiyun village, which is found ~2 km SE of Guanling Fossil National
13
14 113 Geopark (Fig. 1). The section is 101 m in thickness and consists of the uppermost
15
16 114 4 m of the Zhuganpo Formation and an expanded succession of the Wayao
17
18 115 Formation (97 m in thickness).
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24 117 **MATERIALS AND METHODS**

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28 118 A total of 116 samples were collected from the three sections. Twenty-two
29
30 119 samples, each weighing ca. 4 kg, were collected from Caizitang section from
31
32 120 which a total of 929 conodont elements were obtained. Fifty-five samples, each
33
34 121 weighing ca. 6.5 kg, were collected from the Wolonggang section and they yielded
35
36 122 241 elements. Thirty-eight samples, each weighing ca. 9 kg, were collected from
37
38 123 the Tianshuo section from which 147 elements were obtained.
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42 124 All samples were crushed into 1~2 cm³ rock chips and processed using the
43
44 125 method described in Zhang *et al.* (2017). The specimens are all stored at the
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46 126 State Key Laboratory of Biogeology and Environmental Geology, China University
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48 127 of Geosciences (Wuhan). Selected specimens were imaged using a scanning
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50 128 electron microscope.
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4 130 **CONODONT BIOSTRATIGRAPHY**

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6 131 Ranges of taxa in the study sections are shown in figures 2 and 3. Five
7
8 132 conodont zones are recognized. They are in ascending order:

9
10
11 133 ***Paragondolella foliata* Zone**

12
13 134 Lower limit: First occurrence (FO) of *P. foliata*.

14
15 135 Upper limit: FO of *Q. polygnathiformis*.

16
17
18 136 In the Caizitang section, the *P. foliata* Zone ranges from 30.2 m to 31 m height
19
20 137 and contains *P. inclinata* as well as the zonal species. The *P. foliata* Zone is not
21
22 138 recognized in the Tianshuo and Wolonggang sections because the lower
23
24 139 Zhuganpo Formation is not exposed at these locations.

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27
28 140 *Paragondolella foliata* Budurov 1975 has a global distribution (e.g. Europe,
29
30 141 Kovács 1983; Muttoni *et al.* 2014; South China, Sun *et al.* 2016; Zhang *et al.* 2017;
31
32 142 Japan, Koike 1982; Igo 1989; India, Chhabra & Kumar 1984), and it has been
33
34 143 proposed as a zonal marker for the latest Ladinian (e.g. Koike 1981; Metcalf
35
36 144 1990). The associated *P. inclinata* (Kovács 1983) is considered to be the direct
37
38 145 ancestor of *P. foliata* and ranges from the early Longobardian to the late Julian
39
40 146 substage (Kovács 1983; Orchard 2007; Rigo *et al.* 2007; Chen *et al.* 2015;
41
42 147 Lehrmann *et al.* 2015; Sun *et al.* 2016; Chen & Lukeneder 2017).

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50 149 ***Quadralella polygnathiformis* Zone**

51
52 150 Lower limit: FO of *Q. polygnathiformis*.

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55 151 Upper limit: First appearance datum (FAD) of *Q. praelindae*.

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4 152 In the Caizitang section, the *Q. polygnathiformis* Zone ranges from 31 m to 42
5
6 153 m height and contains a relatively diverse assemblage that includes *P. foliata*, *P.*
7
8 154 *inclinata*, *Q. intermedius*, *Q. jiangyouensis*, *Q. aff. polygnathiformis magna*, *Q.*
9
10 155 *uniformis*, *Q. yongyueensis* and *Q. spp.* In the Tianshuo section, the *Q.*
11
12 156 *polygnathiformis* Zone is defined by the first occurrence of the zonal species and
13
14 157 it ranges from 4.2 m to 45.4 m height. Other species include *Q. jiangyouensis*, *Q.*
15
16 158 *maantangensis*, *Q. postica* sp. nov., *Q. wanlanensis*, *Q. wignalli* sp. nov. and *Q.*
17
18 159 *yongningensis* sp. nov. This zone is not present at Wolonggang section because
19
20 160 the section is considered to begin above this level at this location.
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24

25 161 *Quadralella polygnathiformis* (Budurov & Stefanov 1965) is the most
26
27 162 common and cosmopolitan conodont species in the Carnian (e.g. Mosher 1968;
28
29 163 Koike 1982; Metcalfe 1990; Orchard 2007; Rigo *et al.* 2007; Mietto *et al.* 2012;
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31 164 Sun *et al.* 2016), and its FAD is often used to define the base of Carnian (e.g.
32
33 165 Krystyn 1983; Sun *et al.* 2005).
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38 166 The loose definition of type specimens and large ontogenetic variations of *Q.*
39
40 167 *polygnathiformis* have hindered identification of the species (Koike *et al.* 1991;
41
42 168 Orchard 2007; Chen & Lukeneder 2017). However, the abrupt step on both
43
44 169 lateral margins is distinct and provides the key diagnostic feature. The specimen
45
46 170 shown in the figure 3 (V-X) develops ornamentations on the anterior lateral
47
48 171 margins – a feature that may represent part of the latest ontogenetic stage of the
49
50 172 species (Orchard 2007). The specimens shown in figure 11 (G-I, AK-AM) share
51
52 173 some similar features with *M. praecommunisti* but they do not have the nearly
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4 174 centrally located pit that characterizes *M. praecommunisti* (Mazza *et al.* 2011).

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6 175 *Quadralella* aff. *polygnathiformis magna* has a bifurcated keel end but not a
7
8 176 rectangular posterior end, nor a large, elongated platform as in *Q.*
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10
11 177 *polygnathiformis magna* (Igo 1989).

12
13 178 The associated species *Q. intermedius* (Orchard 2007) has been reported
14
15 179 from Canada (Orchard 2007), USA (Orchard & Balini 2007) and South China
16
17
18 180 (Zhang *et al.* 2017). Its first appearance has been used as an accessory marker to
19
20
21 181 define the Ladinian - Carnian boundary in North America, whilst the upper range
22
23 182 extends to the *Q. tadpole* Zone (Orchard 2007, 2010). In the Caizitang section, the
24
25 183 range of *Q. intermedius* extends to the latest Julian 1 substage. *Q. jiangyouensis*
26
27
28 184 (Wang & Dai 1981) ranges from the base of Carnian to the base of Julian 2
29
30 185 substage (Wang & Dai 1981; Yang *et al.* 2002). *Q. yongyueensis* Zhang *et al.* 2017
31
32
33 186 was reported from the Zhenfeng area in the *Q. aff. praelindae* Zone (Zhang *et al.*
34
35 187 2017), and in the Caizitang section, it also occurs at the base of Julian 1 substage.
36
37
38 188 *Q. maantangensis* (Dai & Tian in Tian *et al.* 1983) is widely reported from
39
40 189 Sichuan, Guizhou and Yunnan provinces in South China (Tian *et al.* 1983; Yang *et*
41
42
43 190 *al.* 1995, 2002; Wang 2000; Sun *et al.* 2005; Sun 2006), where it ranges from the
44
45 191 base of the Julian and to possibly the Tuvallian 1/Tuvallian 2 transition (Sun *et al.*
46
47
48 192 2016; Zhang *et al.* 2017). *Q. shijiangjunensis* (Sun 2006) is known from lower
49
50 193 Carnian strata (Zhang *et al.* 2017) with an upper range extending to the late
51
52 194 Julian 1 substage (Sun 2006; this study). *Q. wanlanensis* co-occurs with *Q. aff.*
53
54
55 195 *praelindae* in the Yongyue section (Zhang *et al.* 2017).
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4 196 ***Quadralella praelindae* Zone**

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6 197 Lower limit: FAD of *Q. praelindae*.

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8 198 Upper limit: FAD of *Q. aff. auriformis*.

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10
11 199 In the Caizitang section, the *Q. praelindae* Zone ranges in height from 42.5 m
12
13 200 to 60.5 m. *Q. polygnathiformis* is the only other species found in this interval,
14
15 201 perhaps due to a relative low sample density. The zone was not identified in the
16
17
18 202 Tianshuo and Wolonggang sections.

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23 204 ***Quadralella aff. auriformis* Zone**

24
25 205 Lower limit: FAD of *Q. aff. auriformis*.

26
27
28 206 Upper limit: FAD of *Q. robusta* sp. nov.

29
30 207 In the Caizitang section, the *Q. aff. auriformis* Zone ranges from 60.5 m to 80
31
32 208 m height and is associated with a diverse conodont fauna: *P. foliata*, *Q.*
33
34 209 *intermedius*, *Q. jiangyouensis*, *Q. polygnathiformis*, *Q. praelindae*, *Q. tadpole*, *Q.*
35
36 210 *uniformis*, *Q. aff. zonneveldi* and *Q. spp.* This zone is not recognized in the
37
38 211 Tianshuo because of the absence of the zonal species nor at Wolonggang where
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40
41
42 212 the section begins above this level.

43
44
45 213 *Quadralella aff. auriformis* is most likely a local variant of *Q. auriformis*
46
47 214 (Kovács 1977) which ranges from the upper Julian 1 to the basal of Tuvalian 1
48
49 215 substage (Gallet *et al.* 1994). The associated taxon *Q. aff. zonneveldi* was reported
50
51
52 216 by Zhang *et al.* (2017) from Yongyue section in Zhenfeng area during the early
53
54
55 217 Julian substage.

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4 218 *Quadralella* aff. *zonneveldi* has a similar platform outline to that of *Q.*
5
6 219 *zonneveldi*, which decreases anteriorly and posteriorly from the widest point of
7
8 220 the platform. However, the sunken carina in our specimens is not as obvious in
9
10
11 221 the specimens illustrated in Orchard (2007).
12
13

14 222

17 223 ***Quadralella robusta* sp. nov. Zone**

20 224 Lower limit: FAD of *Q. robusta* sp. nov.

22 225 Upper limit: not defined.

24
25 226 In the Caizitang section, the *Q. robusta* sp. nov. Zone ranges from 80 m height
26
27 227 to the upper part of the section and contains a high diversity fauna dominated by
28
29
30 228 *P. foliata*, *P. inclinata*, *Q. acuminatus*, *Q. aff. auriformis*, *Q. intermedius*, *Q.*
31
32 229 *jiangyouensis*, *Q. cf. maantangensis*, *Q. polygnathiformis*, *Q. praelindae*, *Q. robusta*
33
34
35 230 sp. nov., *Q. shijiangjunensis*, *Q. wignalli* sp. nov., *Q. yongyueensis*, *Q. aff. zonneveldi*
36
37 231 and *Q. spp.* In the Tianshuo section, the *Q. robusta* sp. nov. Zone ranges from 45.4
38
39
40 232 m height to the top of the section and yields associated species including *Q.*
41
42 233 *maantangensis*, *Q. polygnathiformis*, *Q. wanlanensis*, *Q. wignalli* sp. nov. and *Q. spp.*
43
44
45 234 In the Wolonggang section, *Q. robusta* sp. nov. Zone is not recognized because of
46
47 235 the absence of the zonal species.
48

49 236 The *Q. robusta* sp. nov. Zone has a good potential for region correlation in
50
51
52 237 southwestern China. It occurs regionally in the upper Zhuganpo and lower
53
54 238 Wayao formations in Zhenfeng (figures 6-14 in Sun *et al.* (2016) who identified it
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4 239 as *Q.* sp. and figures 8-11 in Zhang *et al.* (2017) who identified it as *Q.* sp. B),
5
6 240 Guanling and Luoping areas. The FO of *Q. robusta* sp. nov. occurs below the
7
8 241 *Austrotrachyceras* ex gr. *A. austriacum* bed, indicating a late Julian 1 age (Sun *et al.*
9
10
11 242 2016; Zhang *et al.* 2017 and this study).

12
13 243 The associated taxon *Q. acuminatus* (Orchard 2007) was reported in Canada
14
15 244 (Orchard 2007), USA (Orchard & Balini 2007) with a range from the latest
16
17
18 245 Longobardian to the late Julian 1. At Caizitang, it appeared late in the Julian 1
19
20
21 246 substage.

22
23 247

24 248 **DISCUSSION**

25 249 1) Taxonomic notes

26
27
28 250 Conodont diversity in the Middle and Late Triassic was high (Chen *et al.*
29
30
31 251 2015). Common genera include *Budurovignathus*, *Carnepigondolella*,
32
33 252 *Gladigondolella*, *Hayashiella*, *Kraussodontus*, *Mazzaella*, *Metapolygnathus*,
34
35 253 *Neogondolella*, *Paragondolella*, *Pseudofurnishius* and *Quadralella*. Amongst these,
36
37
38 254 *Metapolygnathus*, *Neogondolella*, *Paragondolella* and *Quadralella* are
39
40
41 255 morphologically similar. Key diagnostic features of these genera include the
42
43
44 256 outline of platform, distribution of denticles, carina characters, morphology of
45
46
47 257 keel end, anterior blade, geniculation, ornamentations/nodes/denticles, cusp
48
49
50 258 location and pit position.

51
52 259 *Metapolygnathus*, *Neogondolella*, *Paragondolella* and *Quadralella* all have
53
54
55 260 gondola-shaped platforms and relatively prominent cusps. *Neogondolella* Bender

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4 261 & Stoppel 1965 is characterized by having a large unornamented elongated
5
6 262 platform, a terminally or sub-terminally located cusp, a more or less narrow
7
8 263 posterior brim and a platform that covers the entire the element with no free
9
10
11 264 blade (Koike 1982; Kozur 1989b). It occurs in Early to Middle Triassic
12
13 265 assemblages. *Paragondolella* Mosher 1968 shares many features with
14
15 266 *Neogondolella*, but has a high anterior blade with a short/or no free blade that
16
17
18 267 decreases gradually posteriorly (Kozur 1989b, 2003; Mazza *et al.* 2012).
19
20
21 268 Orchard (2013, 2014) argued that *Paragondolella* was a typical Middle Triassic
22
23 269 genus although several long-ranging holdovers persist into the Late Triassic.
24
25 270 *Metapolygnathus* Hayashi 1968, which flourished during the late Carnian, is
26
27
28 271 characterized by possessing a centrally or anteriorly located pit (Koike 1982;
29
30
31 272 Kozur 1989b, 2003; Rigo *et al.* 2007; Mazza *et al.* 2010, 2011, 2012; Kiliç *et al.*
32
33 273 2015). *Quadralella* Orchard 2013 is considered to be a transitional genus
34
35 274 between *Paragondolella* and *Metapolygnathus* and has become a “waste bucket”
36
37
38 275 taxon in recent years. *Quadralella* can have a large variation in platform shape,
39
40 276 pit position and keel end.

41
42 277 The taxonomic classification of early Carnian conodonts is intensely debated
43
44
45 278 (e.g. Koike 1982; Orchard 1991b, 2013, 2014; Kozur 1989b, 2003; Mazza *et al.*
46
47 279 2010, 2011, 2012; Kiliç *et al.* 2015). Based on investigations in southwestern
48
49
50 280 China, some early Carnian species have a bifurcated/elongated keel end, slightly
51
52 281 forward-shifted pit, node(s)/ornamentation(s) on the anterior lateral margin(s)
53
54
55 282 and a broad posterior platform or a constriction on the posterior platform (e.g. *Q.*

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3
4 283 *langdaiensis*, *Q. maantangensis*, *Q. praelindae*, *Q. wanlanensis*, *Q. aff.*
5
6 284 *polygnathiformis magna*). These characters differ from those of *Neogondolella*,
7
8 285 *Paragondolella* and *Metapolygnathus* and so most of our collections are assigned
9
10
11 286 to *Quadralella*.

12 13 287 2) Palaeobiogeography

14
15 288 Early Carnian conodonts show strong endemism. Thus, in North American,
16
17
18 289 *Mosherella*, *Paragondolella* and *Quadralella* are the dominant genera while only a
19
20
21 290 few *Budurovignathus* and *Gladigondolella* elements have been reported (Mosher
22
23 291 1968; Kozur 1989a; Orchard *et al.* 2001; Orchard 2007, 2010; Orchard & Balini
24
25 292 2007). In Western Tethys, *Budurovignathus* and *Gladigondolella* are dominant in
26
27
28 293 the lower Carnian whilst *Mosherella* has rarely been reported (Kozur 1989a,
29
30 294 2003; Balini *et al.* 2000; Orchard 2010). In southwestern China, *Budurovignathus*,
31
32 295 *Gladigondolella* and *Mosherella* were not found during this investigation.
33
34
35 296 *Budurovignathus* has been rarely reported in South China. Only Wang *et al.* (2005)
36
37
38 297 documented its appearance in the Guandao section of the Nanpanjiang Basin (the
39
40 298 same material was re-listed in Lehrmann *et al.* 2015). Only a few *Gladigondolella*
41
42 299 elements have been found in South China to date and they are completely absent
43
44
45 300 from the study sections.

46 47 301 3) Changes in conodont diversity during the Carnian Humid Episode

48
49
50 302 Several marine groups suffered diversity loss during the Carnian Humid
51
52 303 Episode including the conodonts (Simms & Ruffell 1989, 1990; Rigo *et al.* 2007).
53
54
55 304 A turnover of conodont species was recognized in western Tethys during the
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4 305 Julian to Tuvalian transition (Kozur 1989a; Rigo *et al.* 2007), with few Julian
5
6 306 species surviving into the lower Tuvalian (Krystyn 1980, 1983; Orchard 1991a;
7
8 307 Rigo *et al.* 2007). Based on studies of the Zhenfeng (Yongyue and Long Chang
9
10 308 sections), Luopin (Caizitang section) and Guanling (Tianshuo and Wolonggang
11
12 309 sections) faunas, the diverse early Carnian conodont in the southwestern China
13
14 310 shows a decline in number of species during the Julian 1-2 transition with only a
15
16 311 few species remaining after the Carnian Humid Episode (Sun *et al.* 2016, Zhang *et*
17
18 312 *al.* 2017 and this study). In the Luoping area, only four species occur in the
19
20 313 Wayao Formation. In the Guanling area, only *Q. spp.* is recovered from the middle
21
22 314 to upper Wayao Formation. The conodont fauna from the Tianshuo section also
23
24 315 shows a decline in the upper part of the Zhuganpo Formation. A similar diversity
25
26 316 loss is also observed in Zhenfeng area, suggesting this is a regional event (Sun *et*
27
28 317 *al.* 2016; Zhang *et al.* 2017). The sharp decline in conodont diversity coincides
29
30 318 with the Carnian Humid Episode and the associated oceanic changes (onset of
31
32 319 anoxia/euxinia and a sharp rise of seawater temperatures) may be responsible
33
34 320 for this crisis (Sun *et al.* 2016).
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322 **SYSTEMATIC PALEONTOLOGY**

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

324 Order OZARKODINIDA Dzik, 1976

325 Superfamily GONDOLELLOIDEA (Lindström, 1970)

326 Family GONDOLELLIDAE Lindström, 1970

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2
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4 327 Subfamily PARAGONDOLELLINAE Orchard, 2005

5
6 328 Genus *PARAGONDOLELLA* Mosher, 1968

7
8 329 Type species *Paragondolella excelsa* Mosher, 1968

9
10
11 330 Remark: *Paragondolella* is characterized, in upper view, by having a generally
12
13 331 rounded or sub-quadrate posterior end. In lateral view, the carina gradually
14
15 332 decreases in height towards the posterior end (Kozur 1989b). The cusp is
16
17 333 sub-terminal. In lower view, the keel end is either rounded, quadrate or pointed,
18
19 334 but never bifurcated (e.g. Mazza *et al.* 2010). Orchard (2013, 2014) and Chen *et*
20
21 335 *al.* (2015) attributed most *Paragondolella* species to the Middle Triassic except
22
23 336 for several long-ranging holdovers (e.g. *P. foliata*, *P. inclinata*).
24
25
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28 337

29
30 338 *Paragondolella foliata* Budurov, 1975

31
32
33 339 Figure 5 S-U, Figure 11 AB-AD

34
35 340 1975 *Paragondolella foliata* n. sp. Budurov, Pl. 1, figs, 2, 9-12, 14-16, 19-22.

36
37 341 1982 *Neogondolella foliata* Koike, Pl. 2, figs, 11-25.

38
39 342 1983 *Paragondolella foliata foliata* Kovács, Pl. 2, figs. 1-2, Pl. 3, fig. 1.

40
41 343 1984 *Neogondolella foliata foliata* Chhabra & Kumar, Pl. 1, figs, 2-3, 19.

42
43 344 2000 *Paragondolella foliata* Balini *et al.*, Pl. 2, fig. 8.

44
45 345 2016 *Paragondolella foliata* Sun *et al.*, Fig. 6, figs, 1. 8.

46
47
48 346 Description: In upper view, the platform is elongated and covers all along the
49
50 347 element, with moderately thick lateral margins that taper anteriorly, and
51
52 348 broadest near the posterior end. Carina extends to the cusp. Cusp is
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1
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3
4 349 sub-terminal. One or two node-like denticle(s) may develop behind the cusp. In
5
6 350 lateral view, the element is always straight. Basal edge is nearly straight before
7
8 351 the pit. The lateral platform margins may extend to the anterior end with a
9
10
11 352 development of a very short free blade. Genuculatation on the lateral margins of
12
13 353 the platform is absent. Denticles are discrete and highest near anterior end and
14
15 354 gradually decrease posteriorly. The carina is higher than the lateral margins,
16
17
18 355 denticles of carina stand (nearly) perpendicularly to basal edge/platform. In
19
20
21 356 lower view, the pit is terminal. The keel is slightly elevated with a moderately
22
23 357 deep furrow that extends to the anterior end.

24
25 358 Comparison: *P. foliata* shares many morphological features with *P. inclinata*. The
26
27
28 359 key difference is that *P. foliata* has a straight basal edge before the pit.

29
30 360 Occurrence: Longobardian - Julian, Zhuganpo Formation, Guizhou and Yunnan
31
32
33 361 provinces, South China.

34
35 362

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37
38 363 *Paragondolella inclinata* (Kovács, 1983)

39
40 364 Figure 4 AT-AV, Figure 5 G-I, J-L, AH-AJ, Figure 6 M-O, V-X, Figure 10 Y-AA

41
42 365 1983 *Gondolella foliata inclinata* n. subsp. Kovács, Pl. 1, figs. 1-4; Pl. 3, figs. 2-4.

43
44 366 2000 *Paragondolella inclinata* Balini *et al.*, Pl. 3, fig. 2.

45
46 367 2007 *Paragondolella inclinata* Orchard, Fig. 3, 1-3.

47
48 368 2007 *Paragondolella inclinata* Orchard & Balini, Fig. 6 & 7-11 & 24 & 25.

49
50 369 2010 *Paragondolella inclinata* Orchard, Fig. 11, 17-19.

51
52 370 2015 *Paragondolella inclinata* Lehrmann *et al.*, Fig. 6, 21-22.

1
2
3 371 2016 *Paragondolella inclinata* Sun *et al.*, Fig. 6, fig. 2.
4
5

6 372 Description: In upper view, the platform is moderately elongated. The platform
7
8 373 almost covers the whole length of the element, although the first one or two
9
10 374 denticle(s) on the blade may be free. The widest point is in the posterior two
11
12 375 thirds of the platform. Platform margins taper anteriorly. Posterior end is
13
14 376 rounded or sub-quadrate in outline. Carina extends to near the posterior end.
15
16 377 The cusp is sub-terminal and surrounded by a narrow platform brim. In lateral
17
18 378 view, the whole element is always arched, the basal edge is inclined both
19
20 379 anteriorly and posteriorly. The anterior platform margins descend gradually to
21
22 380 the anterior end. Geniculation is not developed. In lower view, the pit is
23
24 381 sub-terminal, and the keel is slightly elevated with a deeply excavated furrow
25
26 382 that extends to the anterior end.
27
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31

32 383 Comparison: *P. inclinata* shares several common features with *Q.*
33
34 384 *polygnathiformis*. However, the latter has more upturned platform margins and
35
36 385 an abrupt step at an anterior geniculation.
37
38
39

40 386 Occurrence: Longobardian - Julian, Zhuganpo Formation, Guizhou and Yunnan
41
42 387 provinces, South China.
43
44

45 388

46
47 389 Genus *QUADRALELLA* Orchard, 2013

48
49 390 Type species: *Quadralella lobata* Orchard, 2013

50
51 391 Remark: *Quadralella* was introduced to account for taxonomic uncertainties
52
53 392 amongst Carnian – Norian conodonts. Many *Quadralella* species show
54
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2
3
4 393 transitional features seen in *Paragondolella*, *Metapolygnathus* and
5
6 394 *Carnepigondolella*. *Quadralella* also shows evolutionary trends: a forward
7
8 395 shifting pit, shortening of platform and increasing platform ornament (Orchard
9
10
11 396 2014). In upper view, the platform is generally elongated and rectangular to
12
13 397 rounded at its posterior end. Some species may exhibit a distinct constriction at
14
15 398 the posterior of platform (e.g. *Q. praelindae* and *Q. auriformis*). Node-like
16
17 399 ornamentations may develop on the anterior lateral platform. The cusp is
18
19 400 prominent and located at sub-terminal or terminal positions with a
20
21 401 development of a narrow posterior platform brim. Accessory denticles/nodes
22
23 402 may develop around the cusp. In lateral view, the genus is generally arched
24
25 403 before the pit. In lower view, the pit is located terminally to sub-terminally but
26
27 404 is restricted in the posterior half. The keel end is rounded, pointed, rectangular
28
29 405 or bifurcated.
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37

38 *Quadralella postica* sp. nov.

39
40 Figure 11 A-C, D-F

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43 409 LSID.urn:lsid:zoobank.org:act:B1293D30-16DA-4037-B8C1-1DF0AB26F4D2
44
45

46 410 Etymology: Referring to its distinctive “V-shaped” posterior end.
47
48

49 411 Holotype: Specimen (Figure 11, A-C) from sample TS-4 032, Zhuganpo Formation,
50
51

52 412 Tianshuo section, South China.
53

54 413 Paratype: Specimen (Figure 11, D-F) from sample TS-4 033, Zhuganpo Formation,
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59
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1
2
3 414 Tianshuo section, South China.
4
5

6 415 Type locality: Middle Zhuganpo Formation, Guanling, South China.
7
8

9 416 Type interval: Early Carnian.
10
11

12 417 Material: 3 specimens (TS-4 032, 033 TS-12 040).
13
14

15 418 Diagnosis: The blade is short. Platform is moderately long and broad, asymmetric
16
17 419 to near-symmetric with a pointed posterior end. Blade and carina consists of
18
19 420 moderately to highly fused denticles. Pit located sub-terminally. The keel is
20
21 421 moderately wide and may be slightly bifurcated.
22
23

24
25 422 Description: In upper view, the platform is moderately broad to broad and covers
26
27 423 almost the entire element. A short free blade may develop in the anterior. The
28
29 424 blade is low and highly fused. The carina is composed of 7-9 low and discrete
30
31 425 denticles. The node-like cusp is indistinct and sub-terminal. Additional denticle(s)
32
33 426 occur after the cusp. The widest point of platform is at the posterior. Posterior
34
35 427 platform margins are symmetric to asymmetric, upturned and reduced towards
36
37 428 the cusp from the widest point of platform, forming a pointed posterior. In lateral
38
39 429 view, the element is slightly arched and the middle carina is relative low
40
41 430 compared with the lateral margins. An abrupt step occurs on the anterior
42
43 431 platform. In lower view, a pit surrounded by the loop is located sub-terminally
44
45 432 and slightly forward shifted. Keel is broad and its termination is generally
46
47 433 rectangular but can be weakly bifurcated. A furrow extends to the anterior end of
48
49 434 platform.
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4 435 Discussion: *Q. postica* sp. nov. and *Q. yongningensis* sp. nov. share the character of
5
6 436 accessory node-like denticle develops behind the cusp. However, the current
7
8 437 species is characterized by a V-shaped posterior end.

9
10
11 438 Occurrence: Julian - ?, Zhuganpo Formation, Guizhou province, South China.

12
13 439

14
15
16 440 *Quadralella robusta* sp. nov.

17
18 441 Figure 4 AB-AD, AH-AJ, AK-AN

19
20 442 2016 *Quadralella* sp. Sun *et al.*, Fig. 6. fig. 14.

21
22 443 2017 *Quadralella* sp. B. Zhang *et al.*, Fig. 8. fig. 11.

23
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26 444 LSID.urn:lsid:zoobank.org:act:B5948C55-D3BC-4218-899C-5A7F304BE3CD

27
28
29 445 Etymology: Referring to its large platform and large cusp.

30
31
32 446 Holotype: Specimen (Figure 4, AB-AD) from sample CZ-35 016, Zhuganpo
33
34 447 Formation, Caizitang section, South China.

35
36
37 448 Paratype: Specimen (Figure 4, AH-AJ) from sample CZ-35 011, Zhuganpo
38
39 449 Formation, Caizitang section, South China.

40
41
42 450 Type locality: Upper Zhuganpo Formation, Luopin, South China.

43
44
45 451 Type interval: Early Carnian.

46
47
48 452 Material: 13 specimens (CZ-35 011, 012, 016, 017, 021, 023; TS-32 076; TS-40
49
50 453 069 and specimens from Zhang *et al.* 2017, NR-7 061, 062, 063, 067; NR-6 057).

51
52
53
54 454 Diagnosis: Platform covers almost entire element. Carina consists of highly fused
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56
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4 455 denticles. Robust cusp located terminally with very narrow posterior platform
5
6 456 brim.

7
8
9 457 Description: The mature element is large and elongated. In upper view, the
10
11 458 platform covers entire element with no free blade although juveniles may
12
13 459 develop free blade. The lateral margins are sub-parallel to parallel and the
14
15
16 460 posterior end is rounded to sub-quadrate. Adcarinal lateral grooves are relatively
17
18 461 narrow, straight and deeply incised. In lateral view, the element is slightly arched.
19
20
21 462 Anteriorly the blade is high and descends gradually towards the carina. The
22
23 463 carina consists of highly fused denticles and may be higher than the lateral
24
25 464 margins. A robust cusp is slightly inclined and located terminally with a very
26
27
28 465 narrow posterior brim. The cusp is normally two to three times larger than the
29
30
31 466 denticles. No obvious step occurs at the anterior. In lower view, a pit surrounded
32
33 467 by a loop is terminal, but it is slightly forward shifted compared with the cusp
34
35
36 468 location. Keel is relative broad. A furrow extends to the anterior end. This species
37
38 469 has relatively thin platform that thickens with growth. During growth the
39
40
41 470 denticles on the middle carina may merge together and adcarinal lateral grooves
42
43 471 are deep.

44
45 472 Discussion: Compared with other *Quadralella* species, this species is
46
47
48 473 characterized by having a very large cusp located terminally with a narrow
49
50
51 474 posterior platform brim.

52
53 475 Occurrence: Julian - ?, Upper Zhuganpo Formation, Guizhou and Yunnan
54
55 476 provinces, South China.
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4 4775
6 478*Quadralella wayaoensis* (Wang, 2000)7
8 479

Figure 10 M-O

9
10
11 480 2000 *Paragondolella wayaoensis* sp. nov. Wang, Pl. I, fig. 1.12
13 481 Description: In upper view, the platform extends along the entire element. A14
15 482 short free blade may occur at the anterior. The widest point is in the middle of16
17 483 platform. Adcarinal lateral grooves are shallow. A constriction occurs in the18
19 484 posterior one third. The cusp is node-like and sub-terminal. The posterior end is20
21 485 rounded. In lateral view, the platform is straight or slightly arched. The posterior22
23 486 platform is relative flat. An abrupt step occurs at anterior. The carina consists of24
25 487 completely fused denticles. The anterior carina decreases quickly to the middle26
27 488 and then keeps the same height extending to posterior. The middle carina is not28
29 489 present. In lower view, the pit is sub-terminal and slightly forward shifted. The30
31 490 pit is surrounded by a small loop. The keel end is either rounded, rectangular or32
33 491 weakly bifurcated but not pointed. A furrow extends to the anterior end.34
35 492 Comparison: *Q. wayaoensis* and *Q. praelindae* both have constrictions of their36
37 493 posterior platforms. However, the current species is characterized by having a38
39 494 broad and flat platform, a weakly bifurcated or rectangular keel end and weak40
41 495 constriction at the posterior one third and a “disappeared” middle carina. *Q.*42
43 496 *praelindae* is slender, intensely constricted near the posterior end and with a44
45 497 rounded keel end.46
47 498 Occurrence: Julian - lower Tuvanian?, Zhuganpo and Wayao formations, Guizhou

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3 499 province, South China.

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8 501 *Quadralella wignalli* sp. nov.

9
10
11 502 Figure 7 Y-AA, AQ-AS, AT-AV

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14 503 LSID.urn:lsid:zoobank.org:act:6AF7A068-FC36-408B-BD44-3556AE22C8E1

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16
17 504 Etymology: Referring to Prof. Paul B. Wignall for his contribution to Permian to

18
19
20 505 Triassic studies.

21
22
23 506 Holotype: Specimen (Figure 7, AQ-AS) from sample CZ-36 025, Zhuganpo

24
25
26 507 Formation, Caizitang section, South China.

27
28
29 508 Paratype: Specimen (Figure 7, AT-AV) from sample CZ-36 026, Zhuganpo

30
31
32 509 Formation, Caizitang section, South China.

33
34
35 510 Type locality: Middle Zhuganpo Formation, Luopin, South China.

36
37
38 511 Type interval: Early Carnian.

39
40
41 512 Material: 18 specimens (CZ-36 025, 026, 032, 040, 041; CZ-40 001, 028, 128

42
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44 513 CZ-42 041, 095, 168; TS-11 038; TS-18 056; TS-19 051; TS-32 075; WL-02 2;

45
46
47 514 WL-03 4.).

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50 515 Diagnosis: Platform is moderately elongated. Posterior end is normally

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52
53 516 rectangular or near rounded. Fused blade is high. A smooth slope occurs at the

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55
56 517 junction between blade and carina. Carina consists of highly fused denticles. Cusp

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58
59 518 is big and located sub-terminally. Pit is located sub-terminally.

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4 519 Description: In upper view, the platform is moderately broad and elongated and
5
6 520 either extends the entire element or develops a short free blade at the anterior.
7
8 521 The widest point of the platform is normally in the anterior half of the element.
9
10 522 The lateral margins are commonly near parallel and slightly upturned. Adcarinal
11
12 523 lateral grooves are broad in front and become narrower near the cusp. The cusp
13
14 524 is prominent, higher than all other denticles and sub-terminal. A small node-like
15
16 525 denticle/node may follow the cusp. The posterior end is generally rounded to
17
18 526 rectangular. In lateral view, the element is commonly arched. The basal edge is
19
20 527 inclined in both anterior and posterior areas. Smooth slope commonly develops
21
22 528 at anterior lateral margin(s). However, an abrupt step may occur at the anterior
23
24 529 in some specimens. The highest point occurs at the convex crest on the blade.
25
26 530 The anterior blade is high and consists of highly fused denticles. A smooth slope
27
28 531 occurs at the junction of blade and carina. The carina is low and mostly fused. In
29
30 532 lower view, the pit is surrounded by a small loop located sub-terminally. The keel
31
32 533 is moderately wide and extends to the anterior end where it is rounded to
33
34 534 rectangular. A furrow extends to the anterior end.

35
36 535 Discussion: *P. inclinata* and the current species both have generally arched
37
38 536 platforms with smooth slopes at the anterior. However, *Q. wignalli* sp. nov. is
39
40 537 characterized by having a moderately broad platform, fused carina and smooth
41
42 538 slope at the junction of carina and blade. Compared with *Q. postinclinata* (Kozur
43
44 539 2003), *Q. wignalli* sp. nov. has a thicker platform, a rectangular posterior end, a
45
46 540 higher blade and a distinct cusp. Compared with *Q. polygnathiformis* and *Q.*
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4 541 *jiangyouensis*, the current species has a convex blade, a smooth slope connecting
5
6 542 the blade and the carina, and a thick and relatively broad platform. *Q.*
7
8 543 *jiangyouensis* has a near rectangular platform which differs with that of the
9
10
11 544 current species.

12
13 545 Occurrence: Julian - ?, Zhuganpo Formation, Guizhou and Yunnan provinces,
14
15 546 South China.

16
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18 547

19
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21 548 *Quadralella yongningensis* sp. nov.

22
23 549 Figure 11 J-L, M-O, P-R

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25
26 550 LSID.urn:lsid:zoobank.org:act:DEB04A5B-53B6-400A-BB59-4EE8D1689F08

27
28
29 551 Etymology: Referring to the town where the species is obtained

30
31
32 552 Holotype: Specimen (Figure 11, M-O) from sample TS-19 045, Zhuganpo
33
34 553 Formation, Tianshuo section, South China.

35
36
37 554 Paratype: Specimen (Figure 11, J-L) from sample TS-11 039, Zhuganpo
38
39 555 Formation, Tianshuo section, South China.

40
41
42 556 Type locality: Middle Zhuganpo Formation, Guanling, South China.

43
44
45 557 Type interval: Early Carnian.

46
47
48 558 Material: 4 specimens (TS-11 039; TS-19 045, 048, 050).

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52 559 Diagnosis: Platform is broad. The blade and carina consist of highly fused
53
54 560 denticles, the middle carina is normally merged. The cusp is sub-terminal and

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4 561 node-like denticle(s) develops behind the cusp. Pit located sub-terminally.
5

6
7 562 Description: In upper view, the platform is broad. The platform margins are thick.

8
9 563 Anterior blade is high. A short free blade may occur. Adcarinal lateral grooves are

10
11 564 shallow and broad. The node-like cusp is sub-terminal and generally is followed

12
13 565 by one to two node-like denticles. A relatively wide gap occurs between the end

14
15 566 of carina and the cusp. The posterior end is rounded to slightly rectangular. In

16
17 567 lateral view, the element is slightly arched. The blade consists of highly fused

18
19 568 denticles. The carina is fused. Denticles are generally the same height as lateral

20
21 569 margins. In lower view, the keel extends to the anterior end where it is rounded

22
23 570 to rectangular. The pit is located sub-terminally.

24
25 571 Discussion: *Q. wignalli* sp. nov. and *Q. yongningensis* sp. nov. both have a highly

26
27 572 fused blade and a fused carina. However, *Q. wignalli* sp. nov. has a big cusp and a

28
29 573 moderately broad platform, while *Q. yongningensis* sp. nov. is characterized by

30
31 574 the wide gap between the end of the carina and cusp as well as the presence of

32
33 575 node(s) behind the cusp. *Q. postica* sp. nov. and *Q. yongningensis* sp. nov. both

34
35 576 have relative wide posterior platform and node-like denticle(s) behind the cusp.

36
37 577 However, *Q. postica* sp. nov. is characterized by the irregular or pointed posterior

38
39 578 end of platform.

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41 579 Occurrence: Julian - ?, Zhuganpo Formation, Guizhou province, South China.

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45 581 *Quadralella* spp.

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47 582 Figure 4 A-C, D-F, G-I, P-R, Figure 5 P-R, Y-AA, AE-AG, Figure 6 AK-AM, AT-AV,

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4 583 Figure 7 P-R, S-U, Figure 8 J-L, Figure 9 G-I
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6 584 Discussion: The specimen shown in figure 4 (A-C) has a rectangular posterior
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8 585 end of platform and thus differs from *P. inclinata*. The specimen shown in the
9
10 586 figure 4 (G-I) has a highly fused blade and carina which differs from *Q.*
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13 587 *jiangyouensis*. The specimen shown in figure 5 (Y-AA) has slightly broad platform
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15 588 that differs from *P. inclinata*. The specimens shown in figure 5 (AE-AG) and figure
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18 589 7 (P-R, S-U) are distinct from *Q. jiangyouensis* in the shapes of the platform end,
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20 590 position of the widest point, free blade and constriction. The specimen shown in
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23 591 figure 6 (AT-AV) has an expanded posterior platform that differs from *Q. tadpole*.
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28 593 **CONCLUSION**

29
30 594 Conodont biostratigraphy was investigated in three sections from
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32 595 southwestern China in order to evaluate the full diversity of early Late Triassic
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34 596 conodonts. Twenty-three species, including four new species, were recognized
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36 597 and five conodont zones established. Based on the conodont fauna, most of
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38 598 Zhuganpo Formation is assigned to the early Carnian (Julian 1) whereas the
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40 599 Wayao Formation most likely belongs to Julian 2 to Tuvanian 2 substages.
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43 600 Conodont taxa show a major decline in diversity and abundance beginning in the
44
45 601 upper Zhuganpo Formation and continuing in the Wayao Formation. This trend
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47 602 coincides with a lithofacies changes from limestone to shale (sometimes with
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49 603 interbedded sandstone). This facies changes is the regional manifestation of the
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51 604 Carnian Humid Episode and the associated climate warming and development of
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4 605 marine anoxia is considered responsible for the nadir in conodont fortunes.
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9

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11
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40 620 **DATA ARCHIVING STATEMENT**
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42 621 This published work and the nomenclatural acts it contains, have been registered
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44 622 in ZooBank:

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47 624 <http://www.zoobank.org/References/0C1E2F81-1B34-4B19-B3BE-259199212>
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25 834 Figure captions

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27 835 Fig. 1 Location map of study sections at Caizitang (NO. 1), Tianshuo (NO. 2) and

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29 836 Wolonggang (NO. 3) from Yunnan and Guizhou provinces, South China.

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31 837 Fig. 2 Log of the Caizitang section, showing sampling positions and conodont

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33 838 ranges.

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35 839 Fig. 3 Logs of the Tianshuo (left) and Wolonggang (right) sections, showing

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37 840 sampling positions and conodont ranges. In the Wolonggang Section, the Julian1-

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39 841 Julian 2 boundary is marked by a dashed line while the Tuvalian substage cannot

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41 842 be defined due to the paucity of conodont.

42
43 843 Fig. 4 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang

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45 844 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella* spp.

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47 845 CZ-19 060. D-F, *Quadralella* spp. CZ-19 061. G-I, *Quadralella* spp. CZ- 42 159. J-L,

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49 846 *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ- 42 166. M-O,

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4 847 *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 173. P-R,
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6 848 *Quadralella* spp. CZ-19 065. S-U, *Quadralella polygnathiformis* (Budurov &
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8 849 Stefanov, 1965) CZ-40 005. V-X, *Quadralella polygnathiformis* (Budurov &
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10 850 Stefanov, 1965) CZ-40 007. Y-AA, *Quadralella polygnathiformis* (Budurov &
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12 851 Stefanov, 1965) CZ-40 017. AB-AD, *Quadralella robusta* sp. nov. CZ-35 016. AE-AG,
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14 852 *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-42 004. AH-AJ, *Quadralella*
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16 853 *robusta* sp. nov. CZ-35 011. AK-AM, *Quadralella robusta* sp. nov. CZ-35 021.
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18 854 AN-AP, *Quadralella praelindae* (Kozur, 2003) CZ-35 022. AQ-AS, *Paragondolella*
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20 855 *inclinata* (Kovács, 1983) CZ-42 069. AT-AV, *Quadralella shijiangjunensis* (Sun,
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22 856 2006) CZ-36 036. Scale bar represents 300µm.
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28 857 Fig. 5 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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30 858 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella*
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32 859 *intermedius* (Orchard, 2007) CZ-40 012. D-F, *Quadralella jiangyouensis* (Wang &
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34 860 Dai, 1983) CZ-40 015. G-I, *Paragondolella inclinata* (Kovács, 1983) CZ-40 021. J-L,
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36 861 *Paragondolella inclinata* (Kovács, 1983) CZ-40 023. M-O, *Quadralella acuminatus*
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38 862 (Orchard, 2007) CZ-42 067. P-R, *Quadralella* spp. CZ-42 158. S-U, *Paragondolella*
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40 863 *foliata* Budurov, 1975 CZ-42 088. V-X, *Quadralella polygnathiformis* (Budurov &
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42 864 Stefanov, 1965) CZ-42 093. Y-AA, *Quadralella* spp. CZ-42 043. AB-AD, *Quadralella*
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44 865 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 044. AE-AG, *Quadralella* spp.
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46 866 CZ-42 020. AH-AJ, *Paragondolella inclinata* (Kovács, 1983) CZ-42 015. Scale bar
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48 867 represents 300µm.
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55 868 Fig. 6 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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4 869 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella*
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6 870 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 162. D-F, *Quadralella*
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8 871 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 017. G-I, *Quadralella*
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10 872 *intermedius* (Orchard, 2007) CZ-19 055. J-L, *Quadralella polygnathiformis*
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12 873 (Budurov & Stefanov, 1965) CZ-19 051. M-O, *Quadralella inclinata* (Kovács, 1983)
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14 874 CZ-19 050. P-R, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-19
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16 875 053. S-U, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-19 054.
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18 876 V-X, *Paragondolella inclinata* (Kovács, 1983) CZ-40 123. Y-AA, *Quadralella*
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20 877 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-31 091. AB-AD, *Quadralella*
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22 878 *jiangyouensis* (Wang & Dai, 1983) CZ-40 004. AE-AG, *Quadralella praelindae*
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24 879 (Kozur, 2003) CZ-40 124. AH-AJ, *Quadralella jiangyouensis* (Wang & Dai, 1983)
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26 880 CZ-40 129. AK-AM, *Quadralella* spp. CZ-35 020. AN-AP, *Quadralella*
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28 881 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 051. AQ-AS, *Quadralella*
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30 882 *praelindae* (Kozur, 2003) CZ-42 049. AT-AV, *Quadralella* spp. CZ-31 031. Scale bar
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32 883 represents 300µm.
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40 884 Fig. 7 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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43 885 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella*
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45 886 *yongyueensis* Zhang, Sun & Lai, 2017 CZ-19 072. D-F, *Quadralella* aff.
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47 887 *polygnathiformis magna* (Igo, 1989) CZ-19 075. G-I, *Quadralella polygnathiformis*
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49 888 (Budurov & Stefanov, 1965) CZ-25 007. J-L, *Quadralella shijiangjunensis* (Sun,
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51 889 2006) CZ-40 122. M-O, *Quadralella cf. maantangensis* (Dai & Tian in Tian *et al.*
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53 890 1983) CZ-40 127. P-R, *Quadralella* spp. CZ-40 125. S-U, *Quadralella* spp. CZ-40
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4 891 131. V-X, *Quadralella jiangyouensis* (Wang & Dai, 1983) CZ-40 134. Y-AA,
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6 892 *Quadralella wignalli* sp. nov. CZ-40 001. AB-AD, *Quadralella jiangyouensis* (Wang
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8 893 & Dai, 1983) CZ-40 002. AE-AG, *Quadralella polygnathiformis* (Budurov &
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10 894 Stefanov, 1965) CZ-36 029. AH-AJ, *Quadralella polygnathiformis* (Budurov &
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12 895 Stefanov, 1965) CZ-36 031. AK-AM, *Quadralella polygnathiformis* (Budurov &
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14 896 Stefanov, 1965) CZ-40 008. AN-AP, *Quadralella uniformis* (Sun, 2006) CZ-31 039.
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16 897 AQ-AS, *Quadralella wignalli* sp. nov. CZ-36 026. AT-AV, *Quadralella wignalli* sp.
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18 898 nov. CZ-36 025. Scale bar represents 300µm.

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23 899 Fig. 8 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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25 900 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella*
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27 901 *intermedius* (Orchard, 2007) CZ-42 161. D-F, *Quadralella intermedius* (Orchard,
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29 902 2007) CZ-42 171. G-I, *Quadralella aff. zonneveldi* (Orchard, 2007) CZ-42 172. J-L,
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31 903 *Quadralella* spp. CZ-43 116. M-O, *Quadralella praelindae* (Kozur, 2003) CZ-42 174.
32
33 904 P-R, *Quadralella intermedius* (Orchard, 2007) CZ-42 176. S-U, *Quadralella*
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35 905 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 092. V-X, *Quadralella*
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37 906 *polygnathiformis* (Budurov & Stefanov, 1965) CZ-42 115. Y-AA, *Quadralella*
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39 907 *intermedius* (Orchard, 2007) CZ-19 064. AB-AD, *Quadralella praelindae* (Kozur,
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41 908 2003) CZ-42 100. Scale bar represents 200µm.

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43 909 Fig. 9 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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45 910 Section, all in upper, lateral and lower views respectively. A-C, *Quadralella aff.*
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47 911 *auriformis* (Kovács, 1977) CZ-31 036. D-F, *Quadralella tadpole* (Hayashi, 1968)
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49 912 CZ-31 060. G-I, *Quadralella* spp. CZ-31 061. J-L, *Quadralella intermedius* (Orchard,
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4 913 2007) CZ-31 065. M-O, *Quadralella praelindae* (Kozur, 2003) CZ-31 076. P-R,
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6 914 *Quadralella* aff. *zonneveldi* (Orchard, 2007) CZ-31 087. S-U, *Quadralella tadpole*
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8 915 (Hayashi, 1968) CZ-31 040. V-X, *Quadralella praelindae* (Kozur, 2003) CZ-31 034.
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11 916 Y-AA, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) CZ-31 049. Scale
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13 917 bar represents 200µm.
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16 918 Fig. 10 SEM photos of conodonts from the Ladinian - Carnian strata of Caizitang
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18 919 and Wolonggang Sections. A, all in upper, lateral and lower views respectively.
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21 920 Scale bars represents 200µm (A-L); A-C, *Quadralella intermedius* (Orchard, 2007)
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23 921 CZ-31 057. D-F, *Quadralella praelindae* (Kozur, 2003) CZ-31 054. G-I, *Quadralella*
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25 922 *praelindae* (Kozur, 2003) CZ-31 052. J-L, *Quadralella polygnathiformis* (Budurov
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27 923 & Stefanov, 1965) CZ-31 056. Scale bars represents 300µm (M-AA). M-O,
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29 924 *Quadralella wayaoensis* (Wang, 2000) WL-2 001. P-R, *Quadralella*
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31 925 *polygnathiformis* (Budurov & Stefanov, 1965) WL-4 003. S-U, *Quadralella*
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33 926 *maantangensis* (Dai & Tian in Tian *et al.* 1983) WL-7.5 001. V-X, *Quadralella* aff.
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35 927 *polygnathiformis magna* (Igo, 1989) WL-4 002. Y-AA, *Paragondolella inclinata*
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37 928 (Kovács, 1983) WL-10 003.
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42 929 Fig. 11 SEM photos of conodonts from the Carnian strata of Tianshuo Section , all
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44 930 in upper, lateral and lower views respectively. A-C, *Quadralella postica* sp. nov.
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46 931 TS-4 032. D-F, *Quadralella postica* sp. nov. TS-4 033. G-I, *Quadralella*
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48 932 *polygnathiformis* (Budurov & Stefanov, 1965) TS-4 034. J-L, *Quadralella*
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50 933 *yongningensis* sp. nov. TS-11 039. M-O, *Quadralella yongningensis* sp. nov. TS-19
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52 934 045. P-R, *Quadralella yongningensis* sp. nov. TS-19 048. S-U, *Quadralella*
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4 935 *polygnathiformis* (Budurov & Stefanov, 1965) TS-19 047. V-X, *Quadralella*

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6 936 *polygnathiformis* (Budurov & Stefanov, 1965) TS-19 052. Y-AA, *Quadralella*

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8 937 *wanlanensis* Zhang, Sun & Lai, 2017 TS-20 062. AB-AD, *Paragondolella foliata*

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11 938 Budurov, 1975 TS-32 074. AE-AG, *Quadralella wanlanensis* Zhang, Sun & Lai,

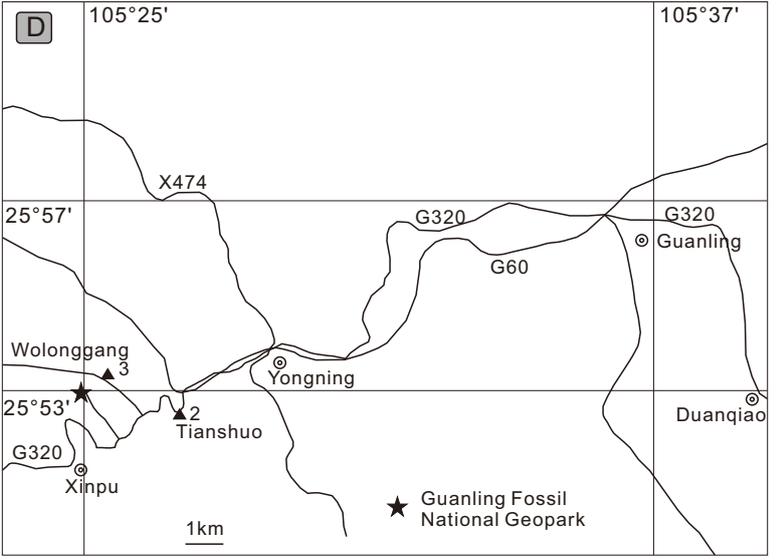
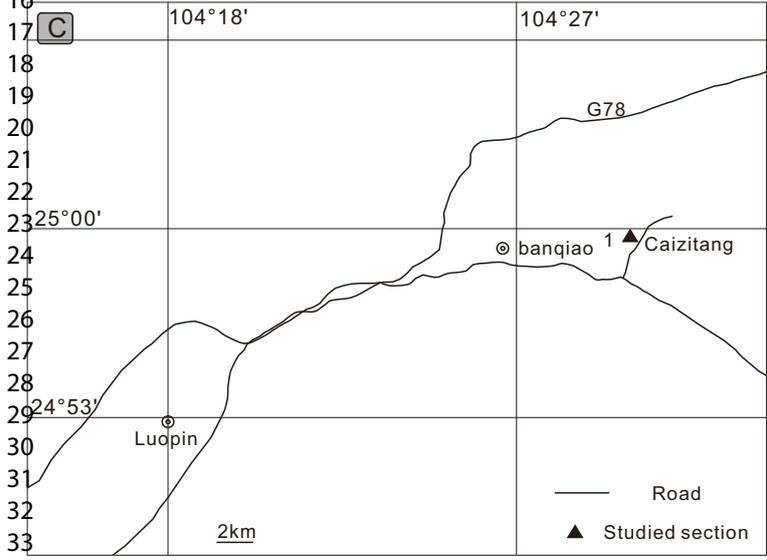
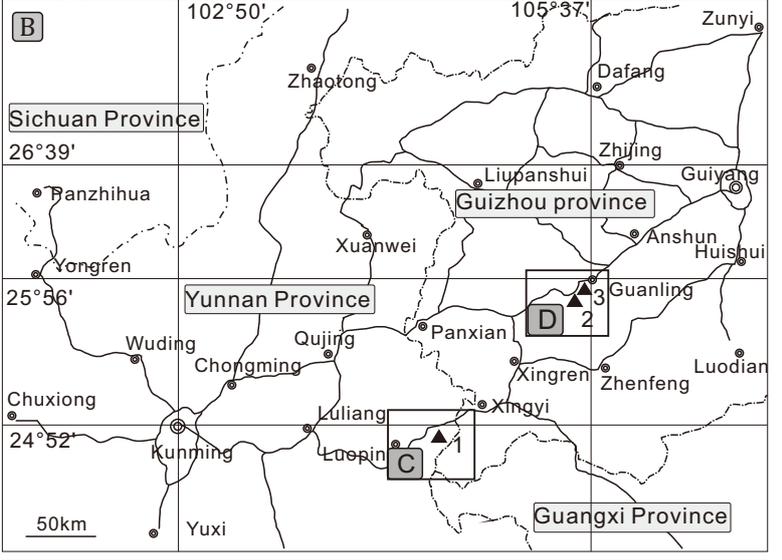
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13 939 2017 TS-21 068. AH-AJ, *Quadralella wanlanensis* Zhang, Sun & Lai, 2017 TS-20

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15 940 062. AK-AM, *Quadralella polygnathiformis* (Budurov & Stefanov, 1965) TS-19 060.

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18 941 Scale bar represents 400µm.

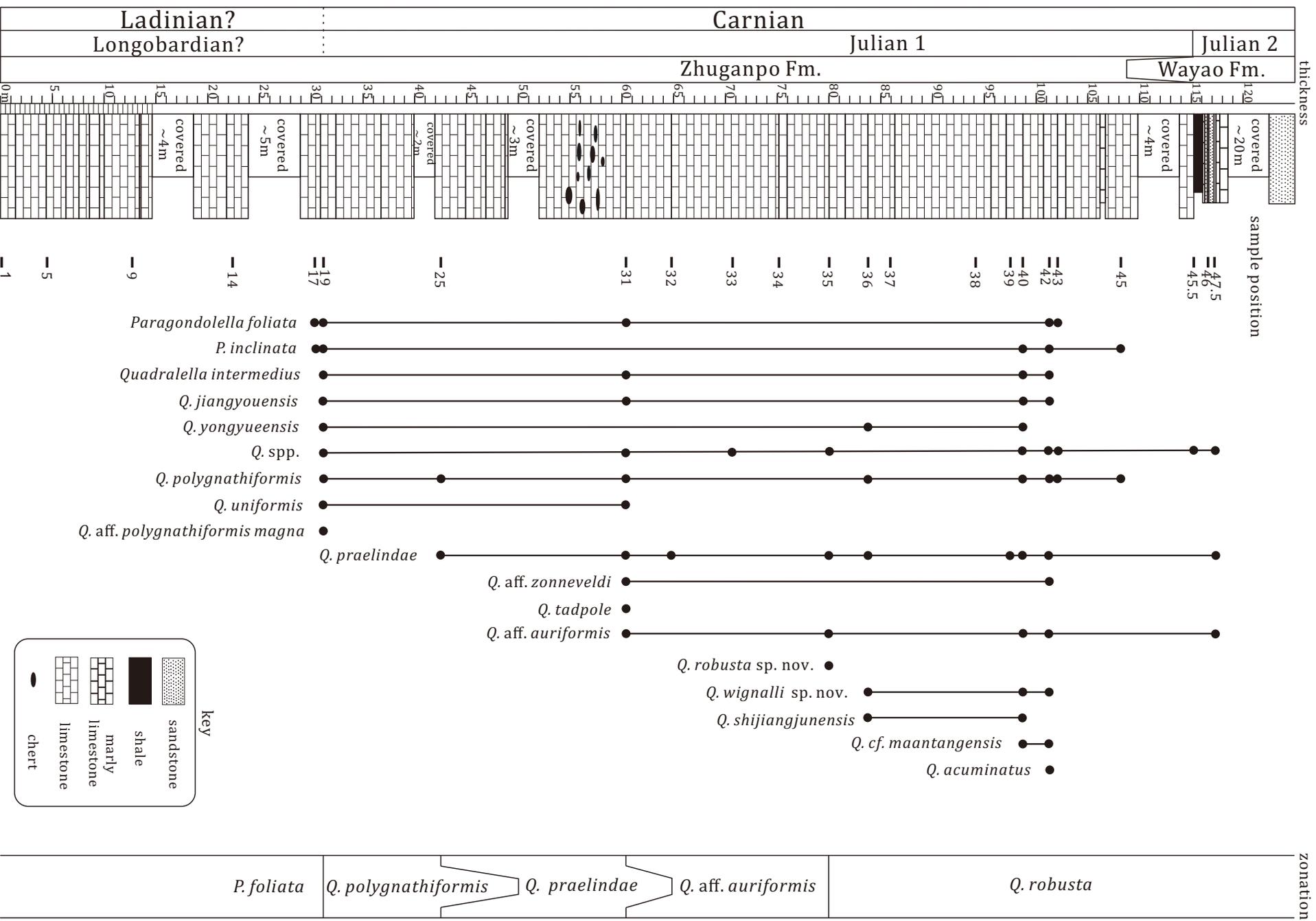
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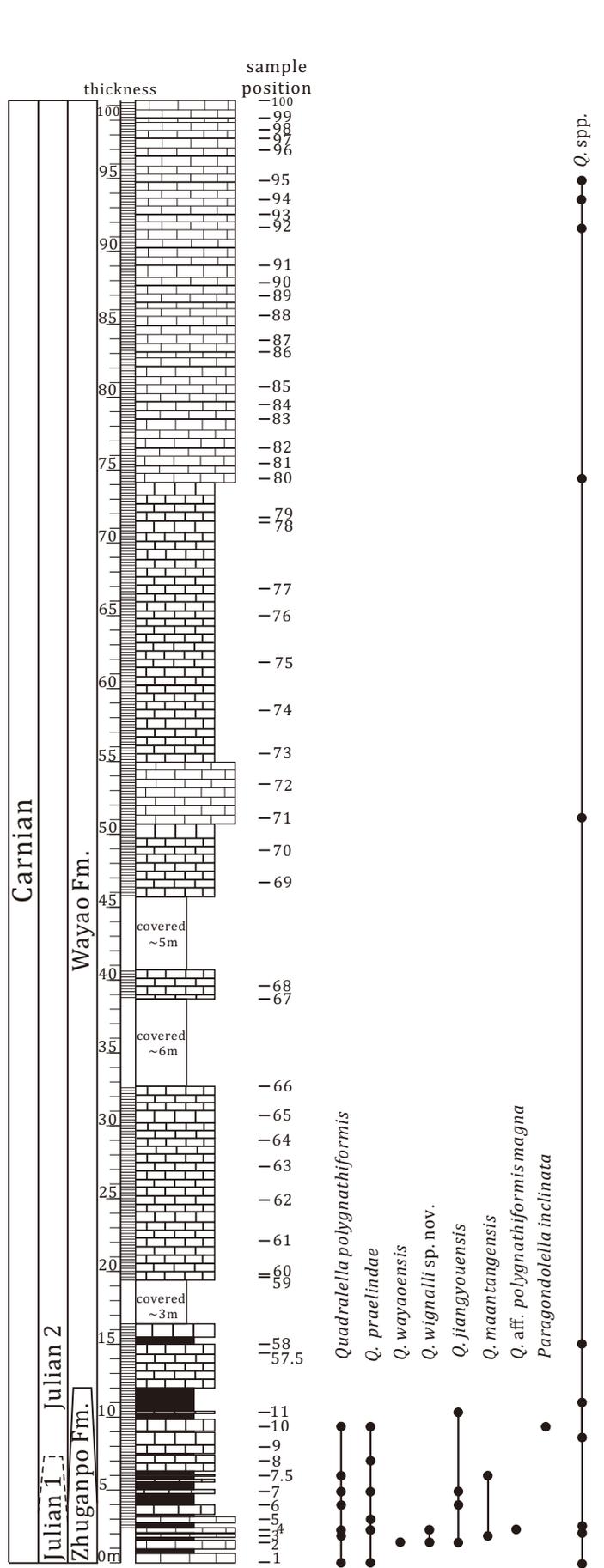
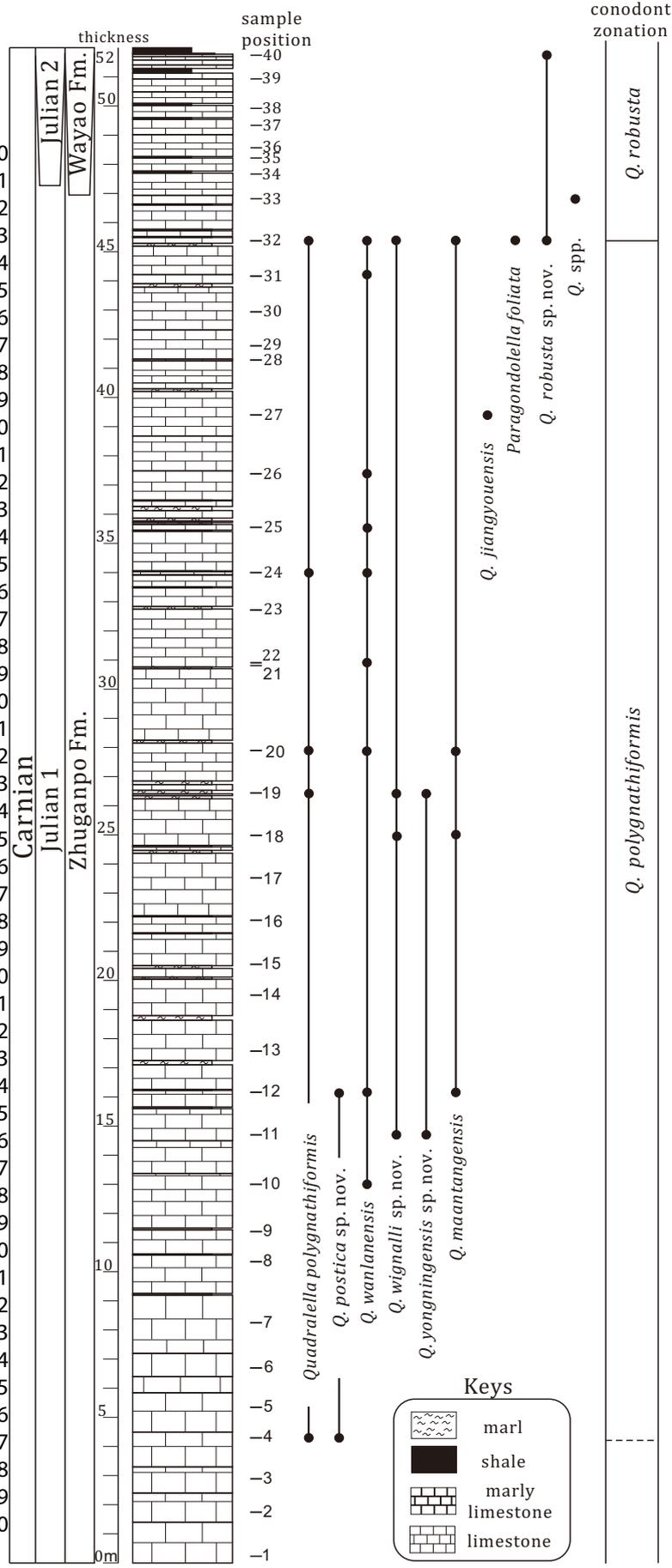
Caizitang section



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Tianshuo section

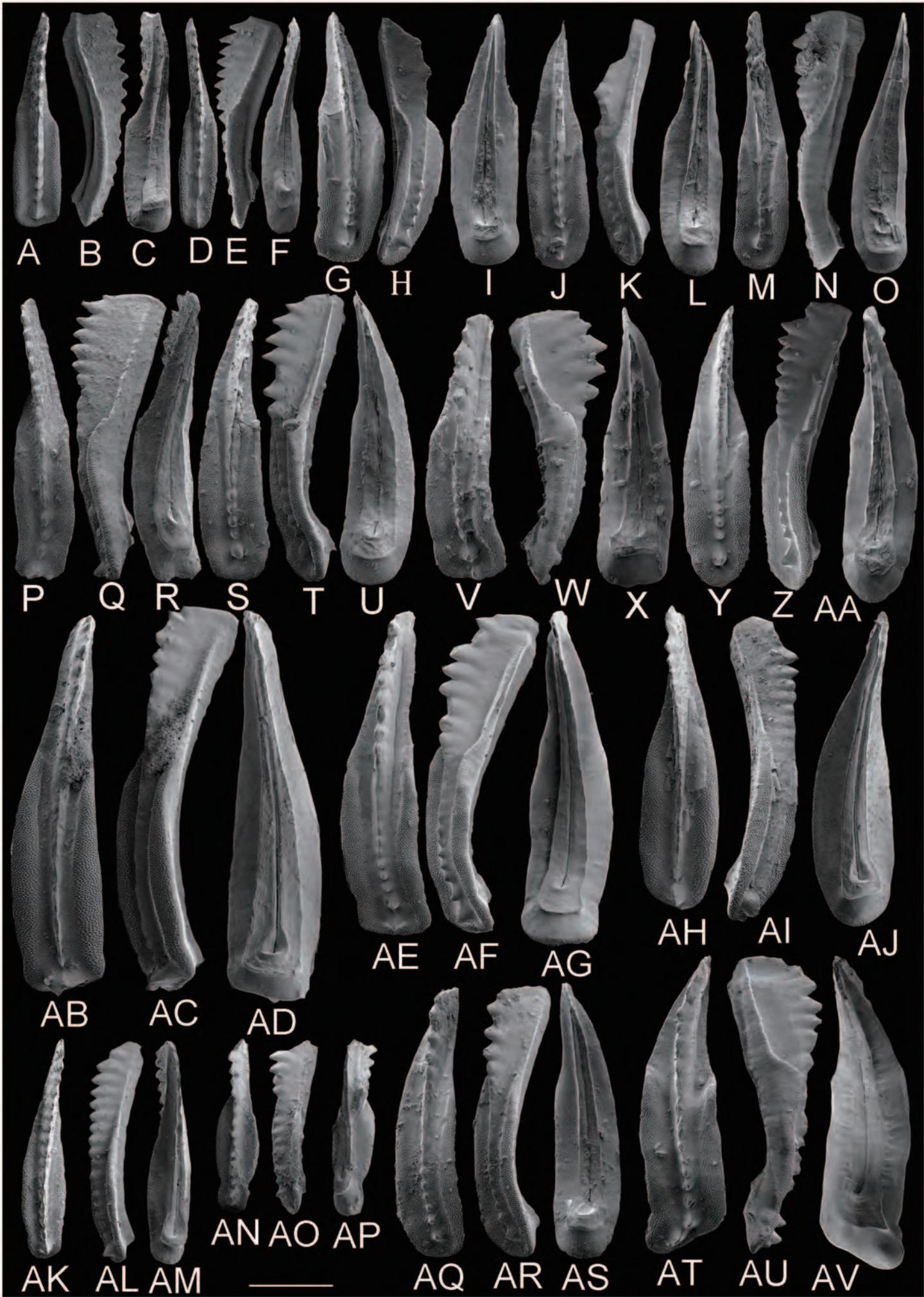
Wolonggang section



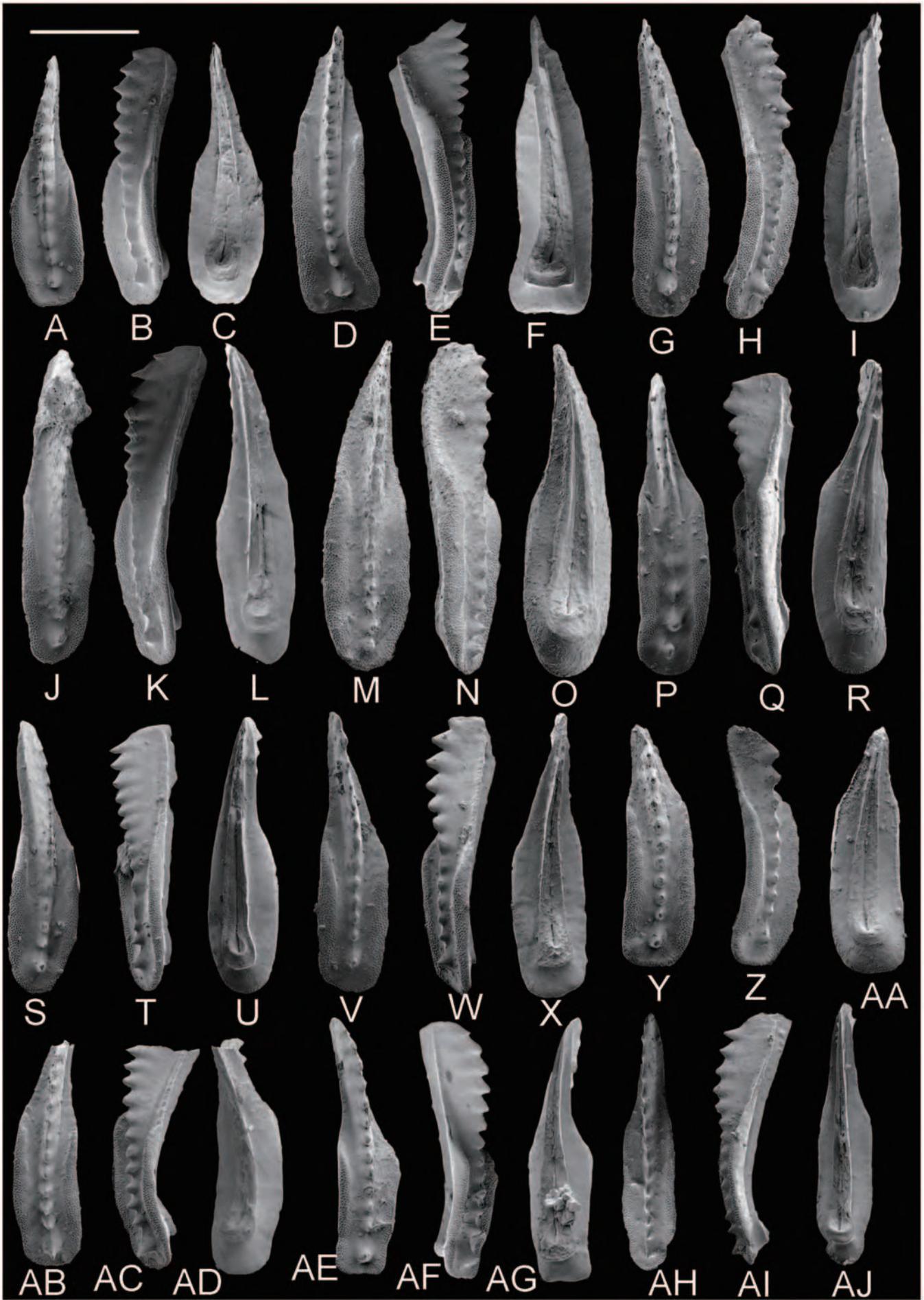
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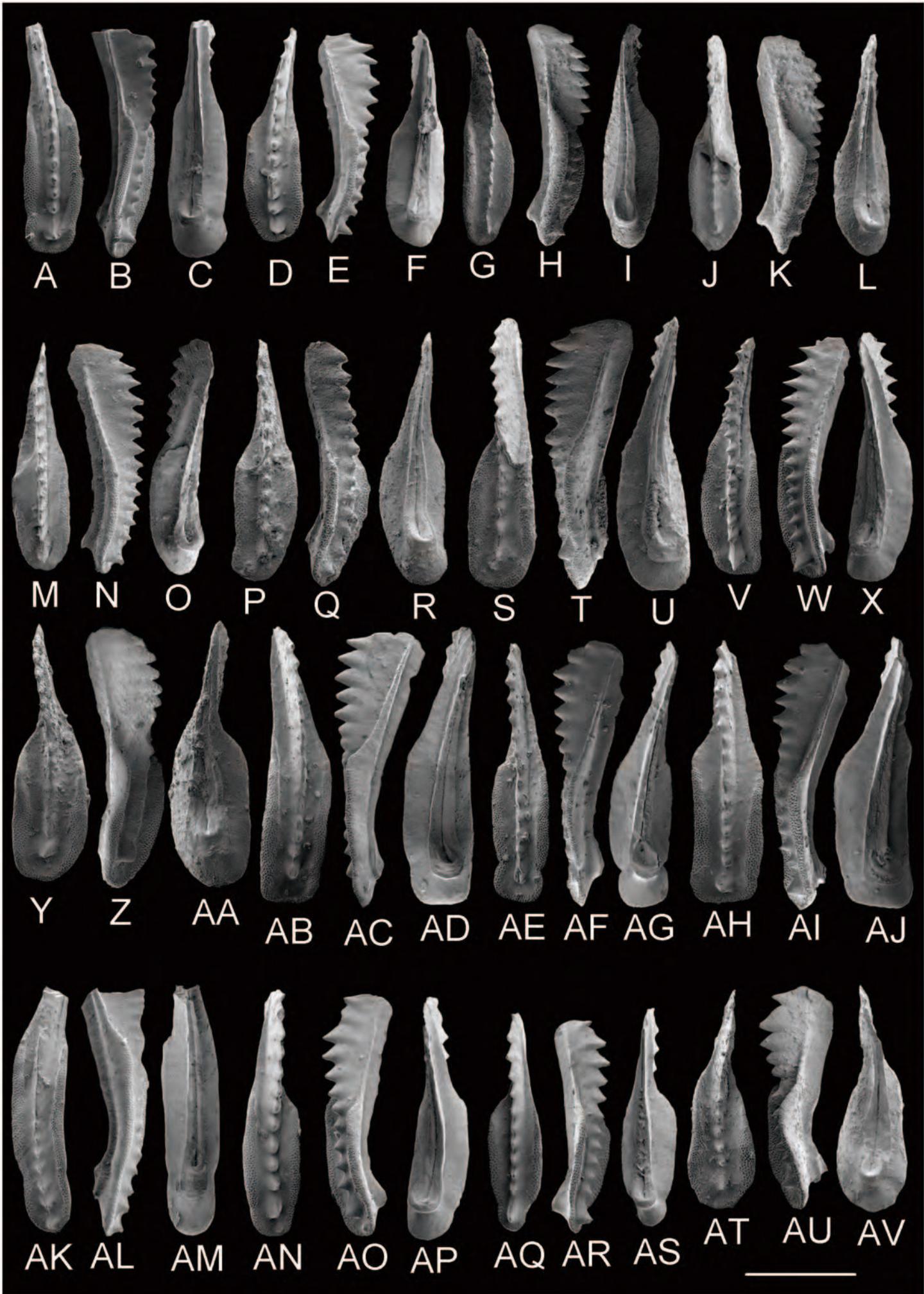
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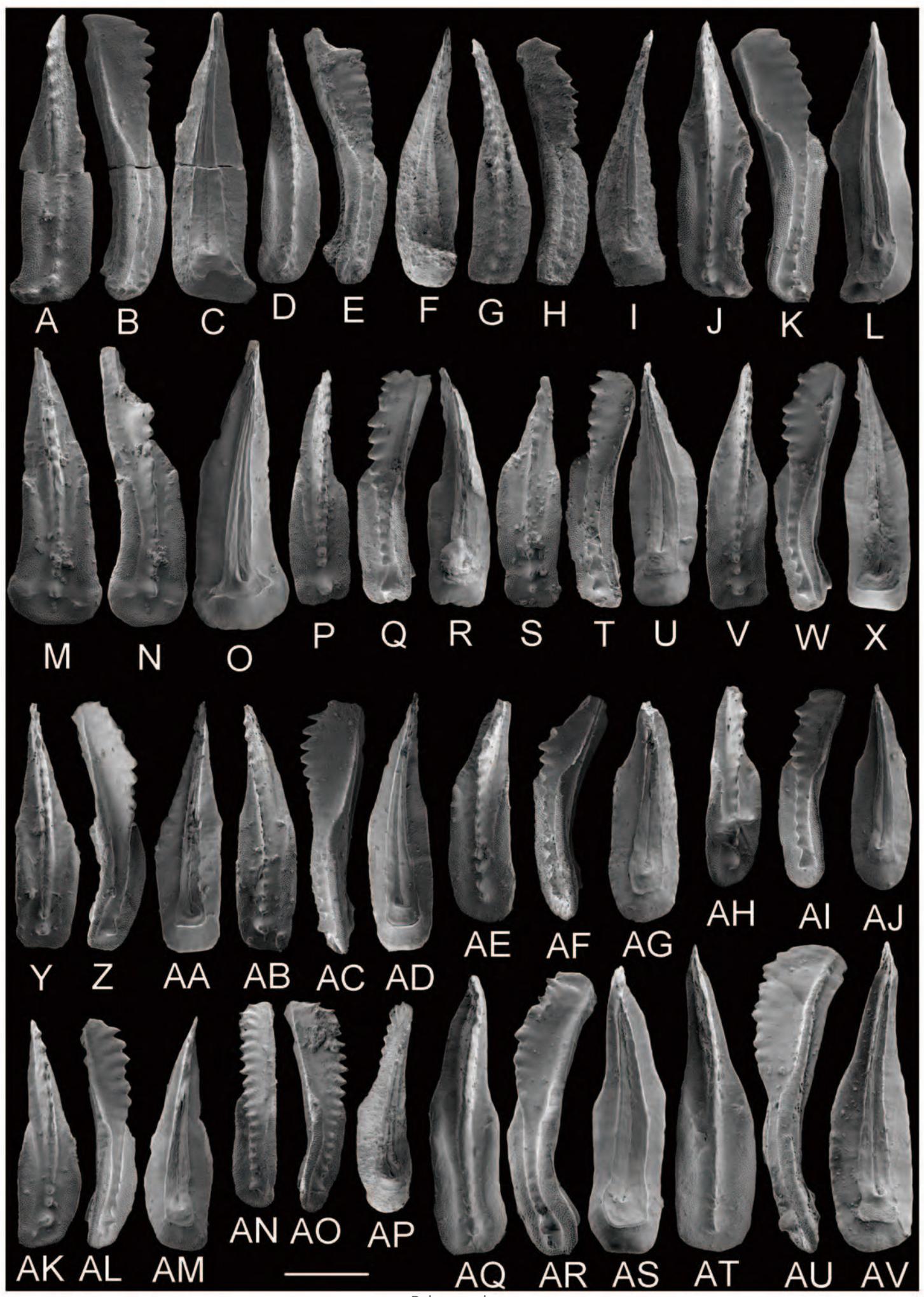
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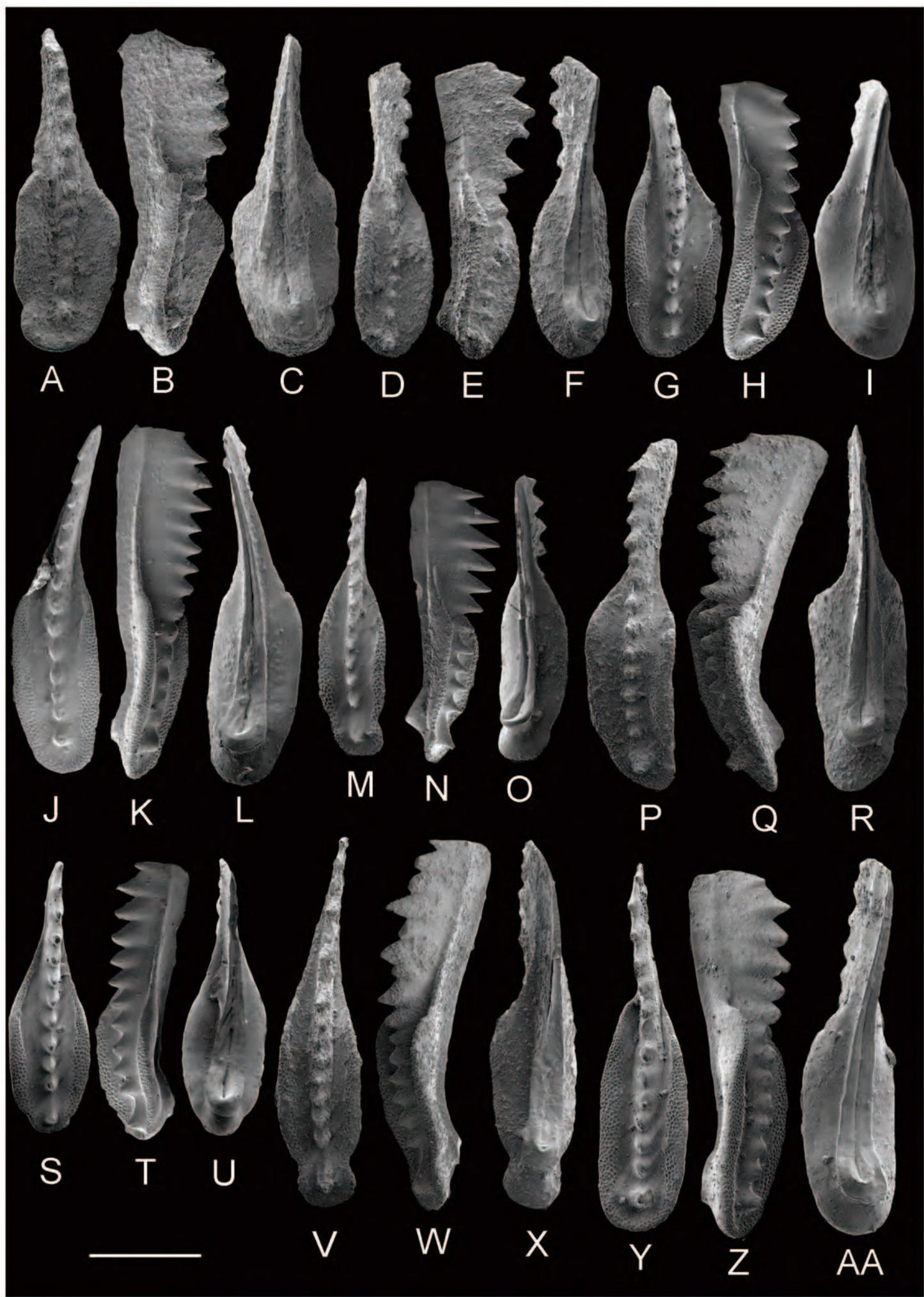
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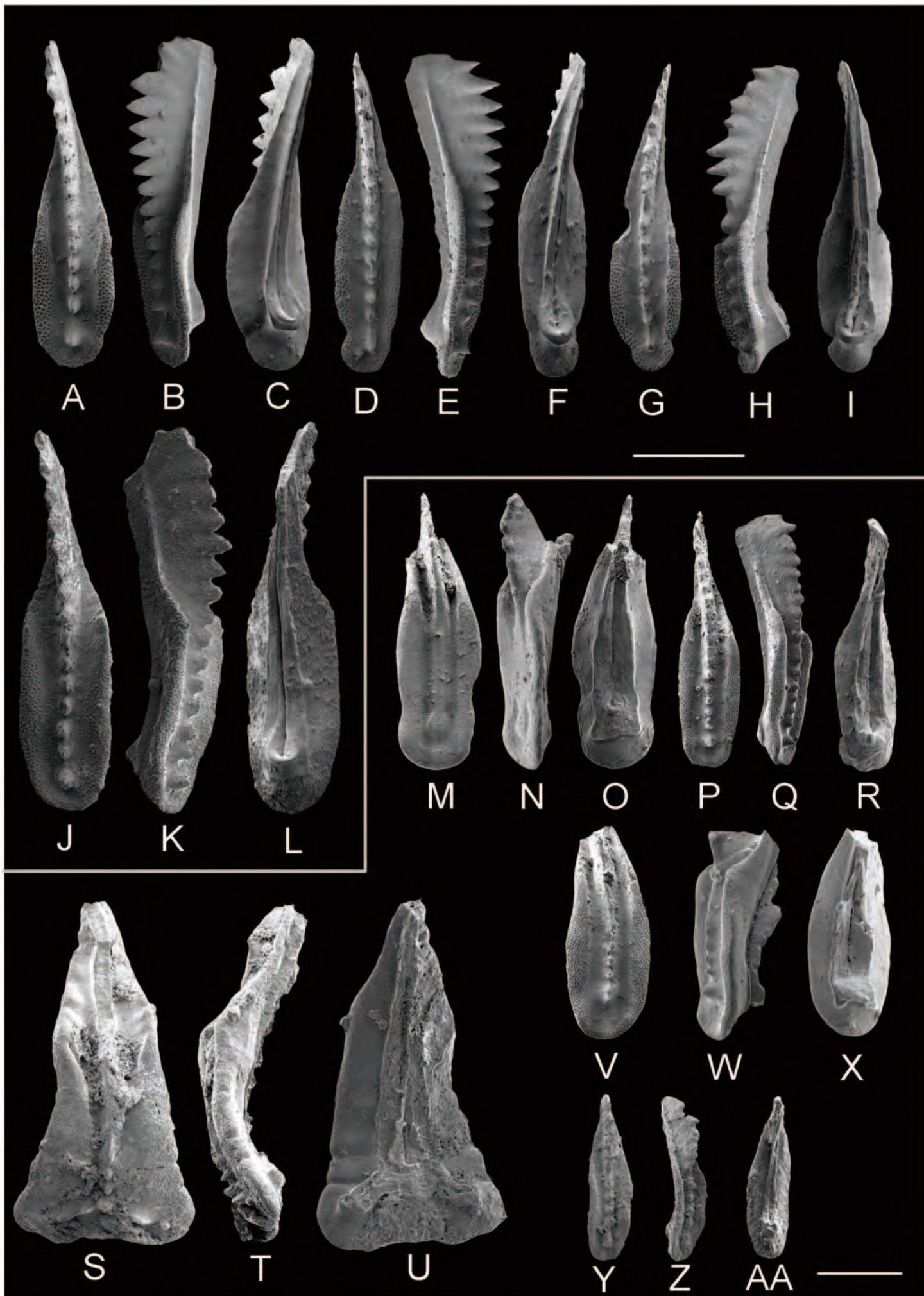
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