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# Journal of Paleontology



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**Smithian platform-bearing gondolellid conodonts from  
Yiwagou Section, northwestern China and implications for  
their geographic distribution in the Early Triassic**

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Manuscripts

1 **Smithian platform-bearing gondolellid conodonts from Yiwagou**  
2 **Section, northwestern China and implications for their geographic**  
3 **distribution in the Early Triassic**

4  
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19

20 **Abstract.**—Abundant platform-bearing gondolellid conodonts including: *Scythogondolella*

21 *mosheri* (Kozur and Mostler), *Sc. phryna* Orchard and Zonneveld, *Scythogondolella* cf. *milleri*  
22 (Müller) have been discovered from the Yiwagou Section of Tewo, together with *Novispathodus*  
23 *waageni waageni* (Sweet), *Nv. w. eowaageni* Zhao and Orchard. This is the first report of  
24 Smithian platform-bearing gondolellids from the Paleo-Tethys region. In addition,  
25 *Eurygnathodus costatus* Staesche, *E. hamadai* (Koike), *Parafurnishius xuanhanensis* Yang et al.,  
26 and the genera *Pachycladina* Staesche, *Parachirognathus* Clark, *Hadrodontina* Staesche have  
27 also been recovered from Dienerian to Smithian strata at Yiwagou Section. Three conodont zones  
28 are established, in ascending order: *Eurygnathodus costatus*-*E. hamadai* Assemblage Zone,  
29 *Novispathodus waageni*-*Scythogondolella mosheri* Assemblage Zone, and the  
30 *Pachycladina*-*Parachirognathus* Assemblage Zone.

31 The platform-bearing gondolellids were globally distributed just after the end-Permian mass  
32 extinction, but the formerly abundant *Clarkina* Kozur disappeared in the late Griesbachian.  
33 Platform-bearing gondolellids dramatically decreased to a minimum of diversity and extent in  
34 the Dienerian before recovering in the Smithian. *Scythogondolella* Kozur, probably a  
35 thermophilic and eurythermic genus, lived in all latitudes at this time whilst other genera did not  
36 cope with Smithian high temperatures and so become restricted to the high-latitude regions.  
37 However, the maximum temperature in late Smithian likely caused the extinction of almost all  
38 platform-bearing gonodlellids. Finally, the group returned to equatorial regions and achieved  
39 global distribution again in the cooler conditions of the late Spathian. We conclude that  
40 temperature (and to a lesser extent oxygen levels) exerted a strong control on the geographical

41 distribution and evolution of platform-bearing gondolellids in the Early Triassic.

42

## 43 **Introduction**

44

45 The end-Permian mass extinction was the most severe in geological history and saw the  
46 disappearance of the majority of marine organisms (e.g. Wignall, 2015). Ecosystem recovery  
47 took several million years and was hindered by the Smithian-Spathian extinction around two  
48 million years after the main crisis. Early Triassic sea surface temperatures were especially high  
49 and reached their zenith in the late Smithian (Sun et al., 2012; Romano et al., 2012). Black shales  
50 and other anoxic facies were also widespread, especially in the late Smithian, although oxic  
51 marine red beds (MRBs) became common in the early Spathian (Sun et al., 2015; Song et al.,  
52 2017). Thus, high seawater temperatures and anoxia in late Smithian may have caused the  
53 second order extinction event at this time as seen amongst conodonts (Orchard, 2007; Stanley,  
54 2009), ammonoids (Hallam and Wignall, 1997; Brayard et al., 2009; Stanley, 2009) and bivalves  
55 (Chen, 2004). The small size of organisms (the Lilliput Effect), such as conodonts (Chen et al.,  
56 2013; Maekawa and Komatsu, 2014) and gastropods (Piestch et al., 2014) may also be  
57 attributable to the high temperatures.

58 The term 'gondolellid' derives from the Family Gondolellidae and is composed of two  
59 groups, segminiplanate, platform-bearing genera (eg. *Neogondolella*, *Scythogondolella*), and  
60 segminate, platform-less genera (eg. *Neospathodus*, *Novispathodus*). The fate of

61 platform-bearing gondolellid conodonts during the vicissitudes of the Early Triassic is unclear.  
62 They were globally prosperous prior to the end-Permian mass extinction and once again  
63 successful in the Middle Triassic. However, in Early Triassic, conodonts in low latitude regions,  
64 such as South China, were mostly dominated by blade-shaped (or segminate) instead of  
65 platform-bearing gondolellids. By comparison, in northern high latitude areas and the southern  
66 margin of Neo-Tethys, the platform-bearing gondolellids become more common (e.g., Orchard  
67 and Zonneveld, 2009, Konstantinov et al., 2013; Bondarenko et al., 2015). Attempts to elucidate  
68 conodont biogeographic realms in the Early Triassic (e.g., Yang et al., 2001; Klets, 2008) are  
69 currently hampered by incomplete data from some regions. In this paper, we report newly  
70 discovered and abundant Smithian platform-bearing gondolellid conodonts from the Yiwagou  
71 Section of Tewo County, Gansu Province, northwestern China that enables us to advance  
72 discussions of the evolution of this important Triassic group. In addition a taxonomic description  
73 is provided for some of the less well known conodonts (*Parafurnishius xuanhanensis* and several  
74 *Scythogondolella* species).

75

## 76 **Geological setting and stratigraphy**

77

78 The Early Triassic Qinling Basin was a major seaway between the South China and Northern  
79 China blocks that narrowed to the east and opened to Paleo-Tethys in the west (Lai et al., 1992,  
80 1995, Yin and Peng, 1995, Feng et al., 1994). The studied Yiwagou Section was located in a

81 shallow-water, carbonate platform at the northern margin of South China Block and on the  
82 southern side of the Basin (Fig. 1). There has been little research in the region because of its  
83 inaccessibility and high altitude (but see Yin et al., 1988, 1992; Yin and Peng, 1995; Lai et al.,  
84 1992, 1994, 1995). The Yiwagou Section lies along a ravine near Zhagana village, Tewo County  
85 (start point GPS 34.256N, 103.204E, Fig. 1). The Section is about 1500 meters long, with the  
86 highest point reaching 4060 m above the sea-level, and consists of continuous strata from Upper  
87 Permian to Lower Triassic composed of the Changhsing Formation ( $P_3ch$ ), the Zhalishan  
88 Formation ( $T_1z$ ) and the Maresongduo Formation ( $T_1m$ ). The Changhsing Formation is mostly  
89 grey, thick-bedded limestone and oolitic limestone. The Zhalishan Formation (Griesbachian to  
90 Smithian) is 565.5m thick, consisting of grey to dark grey, thin to medium-bedded micritic and  
91 bioclastic limestone with intercalations of calcareous, reddish to purple-red, fine-grained sandy  
92 limestone (Fig. 2). The Maresongduo Formation (Spathian) consists of red to purple-red,  
93 thick-bedded crystallized dolomite, dolomitic limestone and micritic limestone. Overall, red beds  
94 first appear within the lower Zhalishan Formation and increase in importance upwards, until they  
95 dominate the upper part of the Zhalishan Formation and the entire Maresongduo Formation.  
96 Marine Red Beds (MRBs) are more typically found in deeper offshore environment (Song et al.,  
97 2017), but are rare in shallow-water carbonate platform settings such as the Yiwagou Section.  
98 The MRB horizons likely record fluctuating oxygen concentration and water depth in the  
99 southern Qinling Basin (Lai et al., 1992).

100 Conodont assemblages in this area are typically high diversity but low abundance (Lai,

101 1992). Six Early Triassic conodont zones have been established at the Yiwagou Section, in  
102 ascending order, they are: *Hindeodus parvus* Zone, *Neospathodus dieneri* Zone, *Neospathodus*  
103 *pakistanensis* Zone, *Pachycladina-Parachirognathus* Assemblage Zone, *Neospathodus*  
104 *triangularis* Zone, *Neospathodus homeri-Neospathodus hungaricus* Assemblage Zone (Lai, 1992,  
105 Fig. 3). Biogeographically, the assemblages at Yiwagou has been thought to have characteristics  
106 transitional between South China and North China, albeit with a greater affinity to South China  
107 faunas (Lai et al., 1992, 1995). In addition to conodonts, the section also yields many  
108 foraminifers and bivalves, such as the foraminifers *Colaniella media* and *Reichelina tenuissima*  
109 in the Changhsing Formation, the bivalves *Claraia concentrica*, *C. hubeiensis*, *C. aurita*,  
110 *Eumorphotis* sp., *Entolium* sp. and *Pteria* sp. in the Zhalishan Formation and the bivalve  
111 *Chlamys weiyuanensis* in the Maresongduo Formation (Yang et al., 1992).

112

### 113 **Materials and methods**

114

115 A total of 153 samples (each one weighting about 3–4 kg) were collected from the upper  
116 Changhsing, Zhalishan and lower Maresongduo formations at Yiwagou. All samples were  
117 crushed into 1–2 cm<sup>3</sup> fragments, then dissolved in an 8 % solution of acetic acid, followed by  
118 heavy liquid separation. A stereoscopic binocular microscope was used to find conodonts in the  
119 residues, and a scanning electron microscope (SEM) was used for photography.

120

121 *Repositories and institutional abbreviations.*—All conodonts in this study are stored in the  
122 School of Earth Science, China University of Geosciences (CUG) in Wuhan City, Hubei  
123 Province, China.

124

## 125 **Results**

126

127 A total of 2100 conodont specimens (221 P<sub>1</sub> elements) were obtained from the Yiwagou samples  
128 and this study focuses on those obtained from the upper Zhalishan Formation (Dienerian and  
129 Smithian, Figs. 4–7). Most samples were productive, including the sample no. ZLS-30 from the  
130 Zhalishan Formation which yielded abundant *Scythogondolella*, (38 P<sub>1</sub> elements in total). This  
131 conodont fauna has rarely been found in the Qinling Basin or in South China before. The sample  
132 no. ZLS-30 included 30 *Scythogondolella mosheri*, one *Sc. phryna* and one *Sc. cf. milleri*. The  
133 remaining specimens are difficult to be identified because of poor preservation. Only one  
134 segminiplanate conodont with a deformed platform, assigned to *Neogondolella cf. milleri* was  
135 found in Zhalishan Formation before this study (Lai, 1992). Other than *Scythogondolella*, 13  
136 *Novispathodus* and some ramiform elements were also recovered from this sample, including six  
137 *Novispathodus waageni waageni* and three *Novispathodus waageni eowaageni*. All specimens in  
138 this sample have a Conodont Alteration Index (CAI) around five (i.e. a black in color).

139

140 *Conodont zones at Yiwagou Section.*—In addition to *Scythogondolella mosheri*, *Sc. phryna*, *Sc.*

141 *cf. milleri* and *Novispathodus waageni* mentioned above, *Eurygnathodus costatus*, *E. hamadai*  
142 and *Parafurnishius xuanhanensis* were also discovered for the first time from the Yiwagou  
143 Section (Fig. 3). Three conodont zones are established in the Dienerian to Smithian interval, in  
144 ascending order they are: *Eurygnathodus costatus*-*Eurygnathodus hamadai* Assemblage Zone,  
145 *Novispathodus waageni*-*Scythogondolella mosheri* Assemblage Zone, and the  
146 *Pachycladina*-*Parachirognathus* Assemblage Zone.

147 *Eurygnathodus costatus*-*Eurygnathodus hamadai* Assemblage Zone.—

148 Lower limit: first occurrence of *E. costatus* and *E. hamadai*

149 Upper limit: first occurrence of *Novispathodus waageni*

150 Associated conodonts include *Pa. xuanhanensis* and some ramiform elements. At the  
151 Yiwagou Section, 31 *Eurygnathodus costatus* and 29 *E. hamadai* specimens were recovered  
152 from the sample no. ZLS-9. Both *E. costatus* and *E. hamadai* are widely distributed in the world,  
153 and are often co-occur in the late Dienerian or Smithian (e.g., Chen et al., 2016). *Parafurnishius*  
154 *xuanhanensis* was found in Induan strata from the Panlongdong Section, Sichuan Province,  
155 southwest China (Yang et al., 2014). This is the second discovery of this species, which indicates  
156 a connection between Yiwagou and northeastern Sichuan.

157 *Novispathodus waageni*-*Scythogondolella mosheri* Assemblage Zone.—

158 Lower limit: First occurrence of *Nv. waageni* and *Sc. mosheri*

159 Upper limit: First occurrence of *Pc. obliqua*

160 Associated conodonts include *Sc. phryna*, *Sc. cf. milleri* (Müller) and ramiform elements.

161 Both *Nv. w. waageni* and *Nv. w. eowaageni* occur in the sample no. ZLS-30. *Nv. waageni* is a  
162 cosmopolitan species found in diverse facies (Tong et al., 2003) [although it is not known from  
163 southern European sections (Chen et al., 2016)], and its first appearance indicates the beginning  
164 of the Smithian. Goudemand et al. (2012) re-allocated this species from *Neospathodus* to  
165 *Novispathodus* based on its multi-element apparatus. Zhao et al. (2007) differentiated *Nv. w.*  
166 *eowaageni* from *Nv. w. waageni* by its more upright denticles and subdivided the original *Nv.*  
167 *waageni* Zone into two subzones, a lower *Nv. w. eowaageni* and an upper *Nv. w. waageni*  
168 subzone. The *Nv. w. waageni* and *Nv. w. eowaageni* from Yiwagou Section have the ratio of  
169 length to width about 3:1, and their basal cavities are not developed, a typical feature of small  
170 elements (Sweet, 1970a). *Nv. w. eowaageni* has been found in South China, Malaysia, Kashmir,  
171 Spiti, Canada and Western Australia and ranges from the Smithian to the early Spathian (e.g.,  
172 Zhao et al., 2013; Chen et al., 2015).

173 *Scythogondolella* is a cosmopolitan Smithian conodont that lived in relatively deep-water  
174 environments. Kozur (1989) named the genus, later Orchard (2005, 2007, 2008), Orchard and  
175 Zonneveld (2009) reconstructed its apparatus and added some new species. Several Smithian  
176 conodont zones were established by Orchard and Zonneveld (2009) in the Wapiti Lake area of  
177 western Canada, including the *Sc. lachrymiformis* Zone, and the *Sc. mosheri* Zone which could  
178 be subdivided into the *Sc. phryna* and *Sc. milleri* subzones. Compared with segminate conodont  
179 zones (such as *Novispathodus* and *Neospathodus* zones), platform-bearing gondolellid zones  
180 could be more refined, and have great potential to improve the precision of the correlation of

181 Smithian strata worldwide. In conclusion, the *Novispathodus waageni-Scythogondolella mosheri*

182 Assemblage Zone at Yiwagou is considered to be of Smithian age.

183 *Pachycladina-Parachirognathus* Assemblage Zone.—

184 Lower limit: First occurrence of *Pc. obliqua*

185 Upper limit: undefined

186 Hundreds of ramiform elements occur in this zone, and their sizes vary substantially from

187 bed to bed (and will be subject to future study). This zone is characterized by the bloom of

188 *Pachycladina* and *Parachirognathus*, including *Pachycladina obliqua*, *Pc. qinlingensis*, *Pc. sp.*,

189 *Parachirognathus delicatulus*, *Pa. semicircnelus* and *Pa. sp.*. The conodont *Hadrodontina*

190 *anceps* also occurs. *Pachycladina* and *Parachirognathus* are widely distributed in South China

191 (Jiang et al., 2000; Wang et al., 2005; Yan et al., 2013; Chen et al., 2015), Qinling areas (Lai,

192 1992), Tibet (Xia and Zhang, 2005) and western USA (Clark et al., 1979; Solien, 1979).

193 *Pachycladina* and *Hadrodontina* are common in the Dinarides (Perri, 1991; Kolar-Jurkovšek and

194 Jurkovšek, 2015; Kolar-Jurkovšek et al., 2017), whereas *Parachirognathus* is not very frequent.

195 This zone corresponds to the *Pachycladina-Parachirognathus* Assemblage Zone in the Beibei

196 Area, Chongqing (Jiang, 1982) and the Bianyang Section, Guizhou (Yan et al., 2013), South

197 China, and is also equivalent to the *Parachirognathus-Fumishius* Assemblage Zone and upper

198 *Parachirognathus ethingtoni* Zone in the Great Basin, western USA (Clark et al., 1979; Solien,

199 1979), where they were all assigned to the Smithian Substage.

200

201 *Parafurnishius xuanhanensis* also occurs below the *Eurygnathodus costatus*-*Eurygnathodus*  
202 *hamadai* Assemblage Zone (Fig. 3), but its age could not be well constrained because of the few  
203 reports about this species. Our conodont study has not allowed us to discern the level of the  
204 Dienerian/Smithian boundary at Yiwagou Section although it is probably below the sample no.  
205 ZLS-30. Further study, including a C isotope analysis may help locate this level.

206

## 207 Discussion

208

209 *Global geographical distribution of Early Triassic platform-bearing gondolellid*  
210 *conodonts.*—Ten platform-bearing gondolellid conodont genera (*Clarkina*, *Neoclarkina*  
211 *Henderson*, *Borinella* Budurov and Sudar, *Scythogondolella*, *Neogondolella* Bender and Stoppel,  
212 *Gladigondolella* müller, *Paullella* Orchard, *Columbitella* Orchard, *Magnigondolella* Golding and  
213 Orchard, *Spathogondolella* Jiang) occur in the Early Triassic. The evolution of platform-bearing  
214 gondolellids in Early Triassic remains controversial. Klets and Kopylova (2007) suggested an  
215 evolutionary lineage consisting of: - *Mesogondolella* - *Clarkina* - *Neospathodus* - *Neogondolella*  
216 - *Scythogondolella*. However, we consider that *Neogondolella* is unlikely to have evolved from  
217 *Neospathodus*. The opinion we tentatively support is as follows: *Clarkina* survived the  
218 end-Permian mass extinction in low abundance until disappearing in the late Griesbachian. A few  
219 *Neogondolella*, *Neoclarkina* and *Borinella* species evolved from *Clarkina* during this time.  
220 *Clarkina*, *Neogondolella* and *Neoclarkina* have very similar P1 elements, but the latter two can

221 be distinguished from *Clarkina* with their different  $S_0$  elements (Henderson and Mei, 2007). In  
222 this paper, *Clarkina* is used for those conodonts that originated in the Permian and extended into  
223 Early Triassic. As for *Scythogondolella*, Orchard (2007) proposed an evolutionary lineage  
224 consisting of: - *Cl. nassichuki* - *Cl. krystyni* - *Cl. discreta* - *Sc.?* sp. A - Smithian  
225 *Scythogondolella*. *Sc.?* sp. A in the early Dienerian (Orchard, 2007, Orchard and Zonneveld,  
226 2009) and *Ng.* sp. B in the late Dienerian (Hatlberg and Clark, 1984, pl. 1, fig. 3) might be the  
227 ancestor of Smithian *Scythogondolella*. Its multielement apparatus of 15 elements differs from  
228 *Neogondolella* in both the P and S elements (Orchard, 2005, 2007; Goudemand et al., 2012).  
229 However, since the multielement apparatuses have not been completely established, the genera  
230 of some species might be corrected in the future.

231 The geographical distribution of platform-bearing gondolellids (Fig. 8), based on published  
232 records and our new findings, are discussed below.

233 Griesbachian.—Some *Clarkina* species [*Cl. carinata* (Clark), *Cl. planata* (Clark), *Cl.*  
234 *orchardi* (Mei), *Cl. kazi* (Orchard), *Cl. meishanensis* Zhang et al., *Cl. zhejiangensis* (Mei), *Cl.*  
235 *nassichuki* (Orchard), *Cl. taylorae* (Orchard), *Cl. tulongensis* (Tian), *Cl. deflecta* (Wang and  
236 Wang), *Cl. changxingensis* (Wang and Wang), *Cl. prediscreta* Wu et al., *Cl. postwangi* (Tian), *Cl.*  
237 *hauschkei* Kozur] survived the end-Permian mass extinction and lived alongside newly evolved  
238 species [*Neogondolella griesbachensis* (Orchard), *Ng. lehrmanni* (Chen et al.) and *Neoclarkina*  
239 *krystyni* (Orchard), *Nc. discreta* (Orchard and Krystyn)] in the Griesbachian. They have been  
240 reported from northern low-latitude regions: South China (e.g., Zhang et al., 2007; Jiang et al.,

241 2007, 2011; Chen et al., 2009; Zhao et al., 2013), western USA (Clark et al., 1979); northern  
242 high-latitude areas: British Columbia (Mosher, 1973; Henderson, 1997; Orchard and Zonneveld,  
243 2009; Golding et al., 2014), Canadian Arctic (Mosher, 1973; Henderson, 1997; Orchard, 2007;  
244 Orchard, 2008), Svalbard (Nakrem et al., 2008), Greenland (Teichert and Kummel, 1976); south  
245 margin of Neo-Tethys: Oman (Krystyn et al., 2003), West Pakistan (Sweet, 1970a), Kashmir  
246 (Sweet, 1970b), India (Krystyn and Orchard, 1996; Goel, 1977; Orchard and Krystyn, 1998;  
247 Krystyn et al., 2004), Nepal (Hatleberg and Clark, 1984), Tibet (Tian, 1982; Orchard et al., 1994;  
248 Wang and Wang, 1995; Orchard and Krystyn, 1998; Wu et al., 2014); Panthalassa: Japan (Igo,  
249 1989; Koike, 1996). *Borinella megacuspa* Orchard that originated in the late Griesbachian has  
250 been reported from Canadian Arctic (Orchard, 2008).

251 Overall, the distribution of platform-bearing gondolellids was still global following the  
252 end-Permian extinction but they were only common in high-latitude regions, such as Svalbard  
253 and Canadian Arctic (Klets, 2008), whilst they were no longer flourishing in the low-latitudes.  
254 However, *Clarkina* became extinct at the end of Griesbachian.

255 Dienerian.—The diversity of platform-bearing gondolellids fell to a minimum in the  
256 Dienerian and they disappeared from equatorial regions. The last appearance of *Neoclarkina*  
257 *discreta*, *Neogondolella griesbachensis* and *Borinella megacuspa* was in the Canadian Arctic  
258 (Orchard, 2008), whilst several new species of *Borinella* [*B. nepalensis* (Kozur and Mostler), *B.*  
259 *chowadensis* (Orchard), *B. sweeti* (Kozur and Mostler)] have been reported from British  
260 Columbia, West Pakistan, India (Orchard, 2007; Orchard and Krystyn, 2007) and Svalbard

261 (Hatleberg and Clark, 1984, originally assigned to *Ng. elongata*). And the new species  
262 *Neogondolella mongeri* (Orchard) was reported from British Columbia (Orchard, 2007, Orchard  
263 and Zonneveld, 2009).

264 Smithian.—Orchard et al. (2007) considered the middle Smithian to be the heyday of Early  
265 Triassic conodonts. In addition to *Borinella*, three new genera *Scythogondolella*, *Neogondolella*  
266 and *Paullella*, probably evolved in the late Dienerian or early Smithian have been found in  
267 Smithian. Amongst these, *Scythogondolella* was a dominant and cosmopolitan genus (Orchard,  
268 2008; Klets, 2008). In contrast, other platform-bearing gondolellids were rarer and less  
269 widespread. *Scythogondolella* is represented by seven species [*Sc. mosheri*, *Sc. milleri*, *Sc.*  
270 *phryna*, *Sc. lachrymiformis* Orchard, *Sc. rhomboidea* Orchard and Zonneveld, *Sc. ellesmerensis*  
271 Orchard, *Sc. crenulata* (Mosher)] and five other species in open nomenclature (*Sc.?* sp. A  
272 Orchard and *Sc. B-E* Orchard), distributed across northern high-latitude regions: Siberia (Dagis,  
273 1984; Klets and Yadrenkin, 2001; Konstantinov, 2013), Canadian Arctic (Mosher, 1973; Kozur  
274 and Mostler, 1976; Orchard, 2007, 2008 and Orchard and Zonneveld, 2009; Beranek et al., 2010),  
275 British Columbia (Mosher, 1973; Orchard, 2008; Orchard and Zonneveld, 2009; Golding et al.,  
276 2014, 2015; Henderson et al., 2018), Svalbard (Weitschat and Lehmann, 1978; Hatleberg and  
277 Clark, 1984; Nakrem et al., 2008), South Primorye (Kozur and Mostler, 1976; Buryi, 1979;  
278 Bondarenko et al., 2015), Qinghai, China (part of the Tarim Plate, Fang et al., 2013); the south  
279 margin of Neo-Tethys: Tibet (Tian, 1982; Tian et al., 1983; Zhao and Zhang, 1991; Wang and  
280 Wang, 1995; Zou et al., 2006), India (Matsuda, 1984), Timor Island (Nogami, 1968; Berry et al.,

281 1984), West Pakistan and Nepal (Kozur and Mostler, 1976; Hatleberg and Clark, 1984). Some  
282 also occurred in relatively low-latitude (about 10N°) regions: western USA (Müller, 1956; Clark  
283 and Mosher, 1966; Solien, 1979; Clark et al., 1979; Orchard, 2008), Chaohu, South China (Liang  
284 et al., 2011), Qinling Basin, northwestern China (this paper) and Panthalassa: Japan (Nogami,  
285 1968).

286 Newly evolved *Neogondolella* (*Ng. altera* Klets and Yadrenkin, *Ng. composita* Dagis, *Ng.*  
287 *jakutensis* Dagis, *Ng. sibirica* Dagis) occurred in high-latitude Siberia (Dagis, 1984; Klets and  
288 Yadrenkin, 2001) and Svalbard (Dagis and Korchinslaya, 1989). *Borinella* species (*B. buurensis*  
289 Dagis, *B. chowadensis*, *B. nepalensis*) and *Paullella meeki* (Paull) are known from high northern  
290 latitudes regions: Siberia (Dagis, 1984), Canadian Arctic (Beranek et al., 2010), British  
291 Columbia and western USA (Orchard, 2007, 2008, Orchard and Zonneveld, 2009; Golding et al.,  
292 2014, 2015; Henderson et al., 2018), Svalbard (Hatleberg and Clark, 1984, originally assigned to  
293 *Ng. elongata*; Nakrem et al., 2008), and southern Neo-Tethys: India (Orchard and Krystyn, 2007;  
294 Orchard, 2010) and Nepal (Dagis, 1984).

295 Spathian.—The bloom of *Scythogondolella* species was terminated in the late Smithian  
296 extinction along with *Borinella* and *Paullella*, leaving *Neogondolella* as the sole  
297 platform-bearing gondolellid survivor (although no species of this genus are known to have  
298 survived). The Spathian saw several new *Neogondolella* species appear [*Ng. jubata* Sweet, *Ng.*  
299 *amica* Klets, *Ng. captica* Klets, *Ng. taimyrensis* Dagis, *Ng. paragondolellaeformis* Dagis, *Ng.*  
300 *shevyrevi* (Kozur and Mostler), *Ng. dolpanae* Balini, Gavrilova and Nicora]. They were joined

301 by another four genera [*Gladigondolella* (*Gl. malayensis* Nogami, *Gl. carinata* Bender),  
302 *Columbitella* (Sweet), *Magnigondolella regalis* Golding and Orchard and *Spathogondolella*  
303 *jiarongensis* Jiang and Chen] that originated in the late Spathian and ranged into Middle Triassic.

304 By the late Spathian platform-bearing gondolellids had returned to equatorial regions and  
305 thus they re-attained a global distribution. They occurred in equatorial regions: South China  
306 (Jiang, 1982; Wang, 1982; Wang et al., 2005; Chen et al., 2015) and Transcaucasia (Orchard,  
307 2007); in the northern hemisphere: Siberia (Dagis, 1984; Klets, 1998), Canadian Arctic (Mosher,  
308 1973), Svalbard (Weitschat and Lehmann, 1978; Hatleberg and Clark, 1984), British Columbia  
309 (Mosher, 1973; Orchard and Tozer, 1997; Orchard, 2008), Western USA (Clark et al., 1979;  
310 Solien, 1979; Carey, 1984; Orchard and Tozer, 1997; Orchard, 2005), Greece (Gaetani et al.,  
311 1992), South Primorye (Buryi, 1979) and Romania (Orchard et al., 2007); in the southern  
312 hemisphere: Oman (Orchard, 1994), West Pakistan (Sweet, 1970a), India (Matsuda, 1984), Tibet  
313 (Tian, 1982, 1983; Zhao and Zhang, 1991; Wang and Wang, 1995) and Nepal (Hatleberg and  
314 Clark, 1984).

315  
316 *Controls on the evolution of Early Triassic platform-bearing gondolellid conodonts.*—Some  
317 platform-bearing gondolellids were a deep-water, nektobenthic group, such as *Clarkina* and  
318 *Neogondolella* (Lai et al., 2001), but others possibly prefer pelagic environments, such as  
319 *Borinella* and *Gladigondolella* (Orchard, 2007; Kozur et al., 2009; Zhang et al., 2017). The  
320 former are likely to have been affected by the substantial temperature and seafloor oxygenation

321 fluctuations known to have affected Early Triassic marine habitats, and the latter have probably  
322 been mainly affected by the seawater temperature. In particular, the diversity and evolution of  
323 platform-bearing gondolellids appear to have closely followed the temperature record of the time  
324 (Sun et al., 2012). The disappearance in late Griesbachian of *Clarkina* that was dominant in end  
325 Permian strata coincides with a temperature rise that began at the Permo-Triassic boundary and  
326 peaked at the late Griesbachian. The rise saw the platform-bearing gondolellids of low diversity  
327 and abundance contract to relatively high latitude regions in the Dienerian (Fig. 8). The  
328 subsequent cooling trend in the Dienerian, that peaked at the Dienerian/Smithian boundary,  
329 coincided with the appearance of new taxa including *Scythogondolella*, *Paullella* and several  
330 *Neogondolella* species. Temperature then rose again through the Smithian, peaking late in the  
331 substage. It appears that many conodonts could not cope with these high temperatures, especially  
332 in tropical latitudes, causing genera such as *Neogondolella* and *Borinella* to become restricted to  
333 high-latitude regions (Fig. 8). In contrast *Scythogondolella* was tolerant of a broad range of  
334 temperatures and was found in all latitudes. However, the latest Smithian temperature peak  
335 coincides with the extinction of all platform-bearing gondolellids, except for *Neogondolella* that  
336 saw a turnover amongst its constituent species. Finally, platform-bearing gondolellids returned to  
337 the equatorial regions and achieved global distribution again during late Spathian cooling.

338 Early Triassic marine oxygenation tracks the temperature oscillations reasonably closely  
339 with peak intensity of anoxia during the warmest intervals (Griesbachian/earliest Dienerian and  
340 late Smithian) whilst the anoxicity of the Spathian appears to have been more regionally variable

341 (Song et al., 2012; Sun et al., 2015; Wignall et al., 2016; Huang et al., 2017). Thus, the crises in  
342 platform-bearing gondolellid fortunes correspond with widespread anoxic episodes although  
343 their subsequent Spathian radiation was at a time when anoxia was reasonably widespread.  
344 However, the extent of anoxia in Spathian may not have been sufficient to hinder radiation, and it  
345 is noteworthy at Yiwagou that this interval is represented by marine red beds.

346

## 347 **Conclusions**

348

349 Smithian platform-bearing gondolellid conodonts *Scythogondolella mosheri*, *Sc. phryna* and *Sc.*  
350 *cf. milleri* have been discovered at Yiwagou, northwestern China, together with *Novispathodus*  
351 *waageni waageni*, *Nv. w. eowaageni* in the same sample. This is the first report of Smithian  
352 platform-bearing gondolellid conodonts in Paleo-Tethys. Additionally, *Eurygnathodus costatus*,  
353 *E. hamadai*, *Parafurnishius xuanhanensis* are also here reported from the Dienerian to Smithian  
354 interval at the Yiwagou Section. Three conodont zones have been established from Dienerian to  
355 Smithian, they are in ascending order: *Eurygnathodus costatus*-*Eurygnathodus hamadai*  
356 *Assemblage Zone*, *Novispathodus waageni*-*Scythogondolella mosheri* *Assemblage Zone*,  
357 *Pachycladina*-*Parachirognathus* *Assemblage Zone*.

358 The fluctuating fortunes of the platform-bearing gondolellids closely follow the seawater  
359 temperature record with low diversity related to peaks of temperature in Early Triassic seas.

360 Compilation of global platform-bearing gondolellid occurrences show that high temperatures in

361 the late Griesbachian-early Dienerian and in the Smithian saw their retreat to higher, cooler  
362 latitudes. *Scythogondolella* is shown to be both a thermophilic and eurythermic genus which was  
363 successful during the high temperatures of the Smithian, when other platform-bearing  
364 gondolellids disappeared from tropical latitudes. However, the peak temperatures late in the  
365 Smithian may have been too much for even *Scythogondolella* to survive.

366 Closely linked oxygenation trends may have also played a role in controlling diversity.  
367 However, the occurrence of marine red beds in the Smithian (and to an even greater extent in the  
368 Spathian) suggest oxygenation levels were frequently extremely good in the shallow-water  
369 carbonate platform at Yiwagou (cf. Lai and Xu, 1992).

370

## 371 **Systematic paleontology**

372

373 Class Conodonta Eichenberg, 1930

374 Order Conodontophorida Eichenberg, 1930

375 Family Ellisoniidae Clark, 1972

376 Genus *Parafurnishius* Yang et al., 2014

377

378 *Type species.*—*Parafurnishius xuanhanensis* Yang et al., 2014 from the Feixianguan Formation  
379 at the Panlongdong Section in Xuanhan County, northeastern Sichuan Province, southwest  
380 China.

381

382

*Parafurnishius xuanhanensis* Yang et al., 2014

383

Figure 4.1–4.21

384

385 2014 *Parafurnishius xuanhanensis* Yang et al., p. 269, pl. 3. figs. A–J, pl. 7. pl. A–O.

386

387 *Holotype*.—NIGP161300, from the Feixianguan Formation at the Panlongdong Section in

388 Xuanhan County, northeastern Sichuan Province, southwest China (Yang et al., 2014, pl. 3, fig.

389 J).

390

391 *Occurrence*.—from the Zhalishan Formation at the Yiwagou Section in Tewo County, Gansu

392 Province, northwestern China, in Dienerian or Smithian.

393

394 *Description*.—The P1 element has a variable shape platform with the width:length ratio about

395 1:2. In upper view, a relatively small cusp lies in the centre, surrounded by 8–10 high and strong

396 irregularly distributed denticles. Generally, it has an anterior process with 1–2 denticles and a

397 roughly triangular posterior process with 3–4 denticles, between which there is a broad platform

398 with 2–7 denticles and a cusp. In lateral view, the basal margin is almost straight, but sometimes

399 upturned posteriorly in juvenile elements. Denticles generally erect or inclined posteriorly in the

400 posterior part. In lower view, a large basal cavity is approximately diamond-shaped with a basal

401 pit located in the centre. A basal furrow extends from the basal pit to the anterior end, but always  
402 no furrow or a very shallow one to the posterior end.

403

404 *Materials.*—71 specimens.

405

406 *Remarks.*—The specimens at Yiwagou Section are much smaller than those recorded from the  
407 Panlongdong Section, Sichuan Province, southwest China (Yang et al., 2014). The juvenile  
408 individual has only one row of denticles in the anterior part that separates into two rows from  
409 middle to posterior part, which indicates that this species may develop from blade shaped  
410 conodonts.

411 Another conodont *Platyvillosus corniger* is very similar to this species, but is of Olenekian  
412 age. It is found in Spathian strata at Žiri-sortirnica 28 Section, in the Idrija–Žiri area of Slovenia  
413 (Chen, et al., 2016) and Olenekian strata in Mokrice locality, eastern Slovenia (Kolar-Jurkovšek  
414 and Jurkovšek, 2015; Kolar-Jurkovšek et al., 2017). Although Kolar-Jurkovšek and Chen et al.  
415 have highlighted the subtle morphological differences (Chen et al., 2016; Kolar-Jurkovšek et al.,  
416 2017), it is still difficult to distinguish these two species with specimens from the Yiwagou  
417 Section although they probably have different apparatuses (Yang et al., 2014; Kolar-Jurkovšek et  
418 al., 2017). Here we assign them to *Pa. xuanhanensis* because they appear in a range of samples  
419 and are accompanied by *Hindeodus postparvus* in the first few samples in Induan (not shown in  
420 Fig. 3), but this taxon needs further research.

421

422

Order Ozarkodinida Dzik, 1976

423

Family Gondolellidae Lindström, 1970

424

Subfamily Scythogondolellinae Orchard, 2007

425

Genus *Scythogondolella* Kozur, 1989

426

427 *Type species.*—*Gondolella milleri* Müller, 1956 from the Lower Triassic *Meekoceras* bed, Dinner

428 Springs Canyon, northeastern Nevada, USA.

429

430 *Remarks.*—Compared with *Neogondolella*, *Scythogondolella* is characterized by a very

431 prominent blade-carina which extends beyond the posterior end to form a free blade in most

432 cases.

433

434 *Scythogondolella mosheri* (Kozur and Mostler, 1976)

435

Figure 5.1–5.21

436

437 1973 *Neogondolella nevadensis* Clark in Mosher, p. 169, pl. 19, figs. 17, 18, 24.438 1973 *Neogondolella elongata* Sweet in Mosher, p. 166, pl. 19, fig. 19.439 1976 *Gondolella mosheri* Kozur and Mostler, p. 8, pl. 1, figs. 9–12.440 1978 *Neogondolella planata* Clark in Weitschat and Lehmann, pl. 14, figs. 1–5.

- 441 1978 *Neogondolella nevadensis* Clark in Weitschat and Lehmann, pl. 14, figs. 6–10.
- 442 1982 *Neogondolella elongatus* Sweet in Tian, pl. 1, 11.
- 443 1983 *Neogondolella elongatus*; Tian et al., pl. 94, fig. 1.
- 444 1984 *Neogondolella nevadensis*; Berry et al., pl. 1, figs. 22–25.
- 445 1984 *Neogondolella nevadensis*; Hatleberg and Clark, pl. 2, figs. 14, 15.
- 446 1991 *Neogondolella nevadensis*; Zhao and Zhang, pl. 1, figs. 17, 18.
- 447 2005 *Scythogondolella mosheri*; Orchard, p. 97–98, fig. 23A–H.
- 448 2008 *Scythogondolella mosheri*; Orchard, p. 410, pl. 5, figs. 1–4.
- 449 2008 *Scythogondolella mosheri*; Nakrem et al., pl. 5, figs. 4–6, 12, 13.
- 450 2014 *Scythogondolella mosheri*; Golding et al., p. 173, pl. 1, figs. 7–9.
- 451 2015 *Scythogondolella mosheri*; Golding et al., p. 167–168, pl. 12, figs. 19–21.
- 452 2018 *Scythogondolella mosheri*; Henderson et al., pl. 1, figs. 35–37.
- 453
- 454 *Holotype*.—from Dolpo, Nepal (Kozur and Mostler, 1976, pl. 1, figs. 9–12).
- 455
- 456 *Occurrence*.—from the Zhalishan Formation at the Yiwagou Section in Tewo County, Gansu
- 457 Province, northwestern China, in Smithian.
- 458
- 459 *Description*.—This species has a wedge-shaped platform, with the maximum width occurring
- 460 posteriorly. The posterior margin is typically constricted and indented inwards from the large

461 cusp which projects posteriorly beyond the platform margin. Consequently, some specimens  
462 have a heart-shaped plan view. The platform with smooth upturned margins tapers progressively  
463 to the anterior end, leaving a free blade of variable length. The blade-carina is typically high with  
464 relatively large, discrete denticles, of uniform height in lateral view. In lower view, the rounded  
465 expanded basal cavity loop surrounds a small basal pit. Juvenile specimens typically have a more  
466 developed carina than platform, with a very prominent cusp projecting posteriorly beyond the  
467 platform margin.

468

469 *Materials*.—30 specimens.

470

471 *Remarks*.—Mosher (1973) recovered *Neogondolella nevadensis* from the Romunduri and Tardus  
472 zones (ammonoid zones of lower and upper Smithian) and *Ng. elongata* from the Tardus Zone in  
473 the Canadian Arctic and British Columbia. However, these occurrences are reassigned to *Sc.*  
474 *mosheri* based on more recent study. Kozur and Mostler (1976) defined *Sc. mosheri* (= *Gondolella mosheri*)  
475 from the Tardus Zone (upper Jakutian) of Dolpa, Nepal. Some of the  
476 elements illustrated as *Neogondolella planata* and *Ng. nevadensis* (Weitschat and Lehmann,  
477 1978, pl. 14, figs. 1–10) clearly belong to *Sc. mosheri*. In addition, *Ng. elongatus* in Tian (1982,  
478 pl. 1, 11) and Tian et al. (1983, pl. 94, fig. 1), *Ng. nevadensis* in Berry et al. (1984, pl. 1, figs.  
479 23–25), Hatleberg and Clark (1984, pl. 2, figs. 14, 15) and Zhao and Zhang (1991, pl. 1, figs. 17,  
480 18) can also be considered reassigned to *Sc. mosheri*.

481 *Sc. mosheri* has often been confused with *Ng. nevadensis*, *Ng. planata* and *Ng. elongata*, but  
482 it can be distinguished by its relatively high bladed carina with large denticles and strong cusp.  
483 Both *Ng. nevadensis* and *Ng. planata* have lower nodular denticles and a smaller cusp. The name  
484 of *Ng. elongata* (or *elongatus*) is not used any longer, and has been changed to *Columbitella*  
485 *elongata* (Orchard, 2005) that also has a strong cusp and carina, but a more rounded and  
486 expanded loop surrounding its basal pit (Orchard, 2007). Compared with the specimens in  
487 Canadian Arctic, *Sc. mosheri* from Yiwagou are much smaller, with no more than nine denticles,  
488 and so are probably juveniles.

489  
490 *Scythogondolella* cf. *milleri* (Müller, 1956)

491 Figure 5.22–5.23

492  
493 *Holotype*.—Lower Triassic *Meekoceras* bed, Dinner Springs Canyon, northeastern Nevada, USA  
494 (Müller, 1956, p. 823, pl. 95, figs. 4–6).

495  
496 *Occurrence*.—from the Zhalishan Formation at the Yiwagou Section in Tewo County, Gansu  
497 Province, northwestern China, in Smithian.

498  
499 *Description*.—This large broken specimen has subparallel upturned platform margins  
500 ornamented with small nodes. The carina is relatively low with fused denticles. The

501 moderate-sized cusp projects posteriorly beyond the platform margin. In the lower view, the keel  
502 with basal groove is broad.

503

504 *Material*.—One specimen.

505

506 *Remarks*.—This specimen closely resembles *Sc. milleri*, but it is broken and so we assign it to *Sc.*  
507 *cf. milleri*. *Sc. milleri*, defined by Müller (1956) in the *Meekoceras* Bed of Nevada, is the most  
508 widespread and extensively studied species of its genus. Typically, it has uneven upturned  
509 platform margins ornamented with nodes or small denticles, which is thought to have evolved  
510 from older *Sc. mosheri* with slightly waved platform margins. Nogami (1968) identified  
511 numerous *Sc. milleri* ranging from juvenile to gerontic stages in Timor and Japan. The large  
512 elements have distinctive, denticulated platform margins, but the juvenile elements closely  
513 resembles *Sc. mosheri* with slightly sculptured platform margins. It seems that juvenile elements  
514 of *Sc. milleri* and *Sc. mosheri* have very similar early growth stages but become differentiated in  
515 later stages. We also note that one *Gondolella milleri* illustrated by Nogami (1968, pl. 10, fig. 11)  
516 is *Neogondolella nevadensis* rather than *Sc. milleri* because of its low carina. Additionally the  
517 specimen illustrated by Liang et al. (2011, pl. 3, fig. 10) from Chaohu, South China should be  
518 assigned to *Sc. milleri*, making it the first report of Smithian platform-bearing gondolellid  
519 conodonts in South China.

520 *Sc. milleri* is a cosmopolitan species; it has been found in Siberia (Dagis, 1984;

521 Konstantinov, 2013), Nevada (Müller, 1956; Clark and Mosher, 1966), Utah (Clark et al., 1979),  
522 Canadian Arctic (Orchard, 2008), British Columbia (Mosher, 1973, Orchard and Tozer, 1997,  
523 Solien, 1979), Dolpo, Nepal (Kozur and Mostler, 1976), Spiti, India (Orchard, 2007), Timor  
524 Island (Berry et al., 1984), Japan (Nogami, 1968), Spitzbergen (Nakrem et al., 2008) and  
525 Southern Primorye (Bondarenko et al., 2015). In China, it has been reported from Tibet (Tian,  
526 1982; Tian et al., 1983; Wang and Wang, 1995; Zou et al., 2006), Qinghai Province (Fang et al.,  
527 2013), and as noted above, Chaohu, South China (Liang et al., 2011).

528

529 *Scythogondolella phryna* Orchard and Zonneveld, 2009

530 Figure 5.24–5.26

531

532 2009 *Scythogondolella phryna* Orchard and Zonneveld, p. 786, pl. 16, figs. 10–16, 20–24.

533 2010 *Scythogondolella phryna*; Beranek et al., pl. 6, figs. 37–39.

534 2014 *Scythogondolella phryna*; Golding et al., p. 173, pl. 1, figs. 4–5.

535

536 *Holotype*.—GSC 132549 from GSC loc. no. C-103866 (213E), in the Toad Formation on Toad

537 River, northeast British Columbia (Orchard and Zonneveld, 2009, pl. 16, figs. 16, 23, 24).

538

539 *Occurrence*.—from the Zhalishan Formation at the Yiwagou Section in Tewo County, Gansu

540 Province, northwestern China, in Smithian.

541

542 *Description*.—This specimen has a narrow biconvex platform, tapering anteriorly and posteriorly  
543 uniformly, with a short free blade occurring in the anterior end. The platform is roughly  
544 symmetrical and flat, broadest around the middle. The large cusp and high blade-carina with 10  
545 large discrete denticles that all lean posteriorly. Although they are all broken, the height still  
546 apparently surpasses the platform width.

547

548 *Material*.—One specimen.

549

550 *Remarks*.—This species was originally described from the Wapiti Lake and Toad River areas in  
551 northeast British Columbia (Orchard and Zonneveld, 2009). *Sc. phryna* seems like an  
552 intermediate form between segminiplanate and segminate conodonts with an atrophic platform. It  
553 may be a cosmopolitan species, but needs more research.

554

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556

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562

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880 **Figure captions**

881

882 **Figure 1.** Geographic position of studied area. **(1)** Tectonic map of Qinling orogenic belt

883 (modified after Dong et al., 2015). Scale bar = 1000 km; **(2)** Location of the Yiwagou Section,

884 Tewo. Scale bar = 20 km; **(3)** Palaeogeography of Qinling Basin (modified after Lai et al., 1995).

885 1. National highway; 2. Main road; 3. Centre of an aulacogen; 4. Continental deposits; 5. Basinal

886 deposits; 6. Slope deposits; 7. Old land; 8. Offshore deposits.

887

888 **Figure 2.** Photographs of marine red beds in Zhalishan Formation from Dienerian to Smithian,

889 Yiwagou Section. 13–17. Bed numbers. Scale bar = 10 m.

890

891 **Figure 3.** Conodont distribution in the Lower Triassic strata at the Yiwagou Section, Tewo,

892 northwestern China. Scale bar = 10 m.

893

894 **Figure 4.** SEM photos of conodonts obtained from the Yiwagou Section. **(1–21)** *Parafurnishius*

895 *xuanhanensis* Yang et al., 2014: **(1–6)** from sample ZLS-6, registration nos.

896 ZLS17006001–17006002; **(7–12)** from sample ZLS-7, registration nos.

897 ZLS17007001–17007002; **(13–21)** from sample ZLS-13, registration nos.

898 ZLS17013001–17013003. **(22–36)** *Eurygnathodus costatus* Staesche, 1964, from sample ZLS-9,  
899 registration nos. ZLS17009001–17009005. **(37–45)** *Eurygnathodus hamadai* (Koike, 1982),  
900 from sample ZLS-9, registration nos. ZLS17009006–17009008. Scale bar = 100  $\mu\text{m}$ .

901

902 **Figure 5.** SEM photos of conodonts obtained from the Yiwagou Section. **(1–21)**

903 *Scythogondolella mosheri* (Kozur and Mostler, 1976), registration nos. ZLS17030001–17030007.

904 **(22–23)** *Scythogondolella* cf. *milleri* (Müller, 1956), registration nos. ZLS17030008. **(24–26)**

905 *Scythogondolella phryna* Orchard and Zonneveld, 2009, registration nos. ZLS17030009. All  
906 come from sample ZLS-30. Scale bar = 100  $\mu\text{m}$ .

907

908 **Figure 6.** SEM photos of conodonts obtained from the Yiwagou Section. **(1–6)** *Novispathodus*

909 *waageni waageni* (Sweet, 1970a), from sample ZLS-30, registration nos.

910 ZLS17030039–17030041. **(7–10)** *Novispathodus waageni eowaageni* (Zhao and Orchard in

911 Zhao et al., 2007), from sample ZLS-30, registration nos. ZLS17030042–17030043. **(11–12)**

912 *Parachirognathus* n. sp. A, from sample ZLS-82, registration nos. ZLS17082001–17082002. **(13)**

913 *Pachycladina obliqua* Staesche, 1964, S<sub>2</sub> element, from sample ZLS-42, registration nos.

914 ZLS17042001. **(14–19)** *Pachycladina qinlingensis* Lai, 1992: **(14)** P<sub>2</sub> element, from sample

915 ZLS-88, registration nos. ZLS17088001; **(15)** P<sub>2</sub> element, from sample ZLS-85, registration nos.

916 ZLS17085001; **(16)** P<sub>2</sub> element, from sample ZLS-74, registration nos. ZLS17074001; **(17)** P<sub>2</sub>

917 element, from sample ZLS-53, registration nos. ZLS17053001; **(18)** S<sub>1</sub> element, from sample

918 ZLS-98, registration nos. ZLS17098001; **(19)** S<sub>2</sub> element, from sample ZLS-67, registration nos.  
919 ZLS17067001. **(20–22)** *Parachirognathus semicircnelus* Tian and Dai in Tian et al., 1983: **(20)**  
920 S<sub>2</sub> element, from sample ZLS-88, registration nos. ZLS17088002; **(21, 22)** S<sub>1</sub> elements, from  
921 sample ZLS-88, registration nos. ZLS17088003–17088004. Scale bar = 100 μm.

922

923 **Figure 7.** SEM photos of conodonts obtained from the Yiwagou Section. **(1–7)** *Pachycladina*  
924 *qinlingensis*: **(1)** M element, from sample ZLS-83, registration nos. ZLS17083001; **(2)** M  
925 element, from sample ZLS-91, registration nos. ZLS17091001; **(3)** S<sub>3-4</sub> elements, from sample  
926 ZLS-98, registration nos. ZLS17098002; **(4)** S<sub>3</sub> element, from sample ZLS-50, registration nos.  
927 ZLS17050001; **(5)** S<sub>1</sub> element, from sample ZLS-50, registration nos. ZLS17050002; **(6)** S<sub>3</sub>  
928 element, from sample ZLS-67, registration nos. ZLS17067002; **(7)** S<sub>2</sub> element, from sample  
929 ZLS-82, registration nos. ZLS17082003. **(8–10)** *Pachycladina obliqua*: **(8)** M element, from  
930 sample ZLS-95, registration nos. ZLS17095001; **(9)** S<sub>3-4</sub> elements, from sample ZLS-96,  
931 registration nos. ZLS17096001; **(10)** S<sub>1</sub> element, from sample ZLS-98, registration nos.  
932 ZLS17098003. **(11)** *Parachirognathus delicatulus* Wang and Cao, 1981, S<sub>1</sub> element, from sample  
933 ZLS-83, registration nos. ZLS17083002. **(12, 13)** *Hadrodontina anceps* Staesche, 1964: **(12)** P<sub>1</sub>  
934 element, from sample ZLS-96, registration nos. ZLS17096002; **(13)** P<sub>1</sub> element, from sample  
935 ZLS-67, registration nos. ZLS17067003. Scale bar = 200 μm.

936

937 **Figure 8.** Global distribution of platform-bearing gondolellid conodonts in the Early Triassic

938 (palaeogeographic map is modified after Muttoni et al., 2009 and Sun et al., 2012; occurrences  
939 are given in the text).

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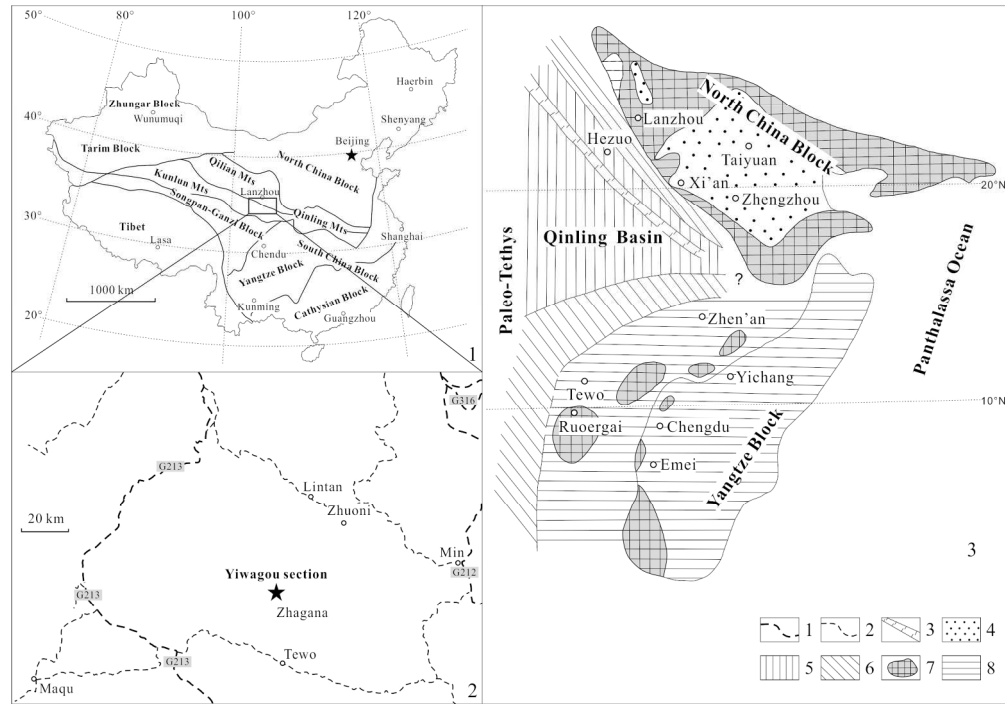


Figure 1. Geographic position of studied area. (1) Tectonic map of Qinling orogenic belt (modified after Dong et al., 2015). Scale bar = 1000 km; (2) Location of the Yiwagou Section, Tewo. Scale bar = 20 km; (3) Palaeogeography of Qinling Basin (modified after Lai et al., 1995). 1. National highway; 2. Main road; 3. Centre of an aulacogen; 4. Continental deposits; 5. Basinal deposits; 6. Slope deposits; 7. Old land; 8. Offshore deposits.

181x127mm (300 x 300 DPI)

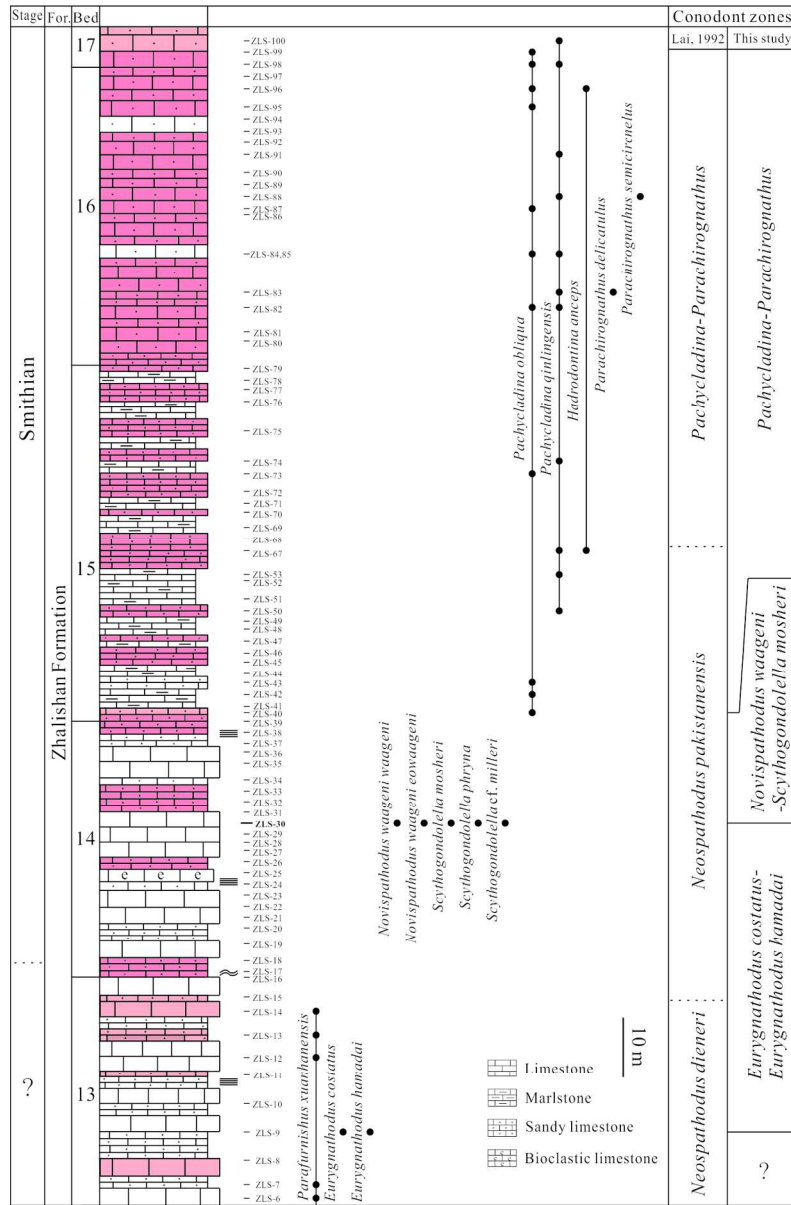


Figure 3. Conodont distribution in the Lower Triassic strata at the Yiwagou Section, Tewo, northwestern China. Scale bar = 10 m.

131x199mm (300 x 300 DPI)



Figure 2. Photographs of marine red beds in Zhailishan Formation from Dienerian to Smithian, Yiwagou Section. 13–17. Bed numbers. Scale bar = 10 m.

186x65mm (300 x 300 DPI)

Review Only

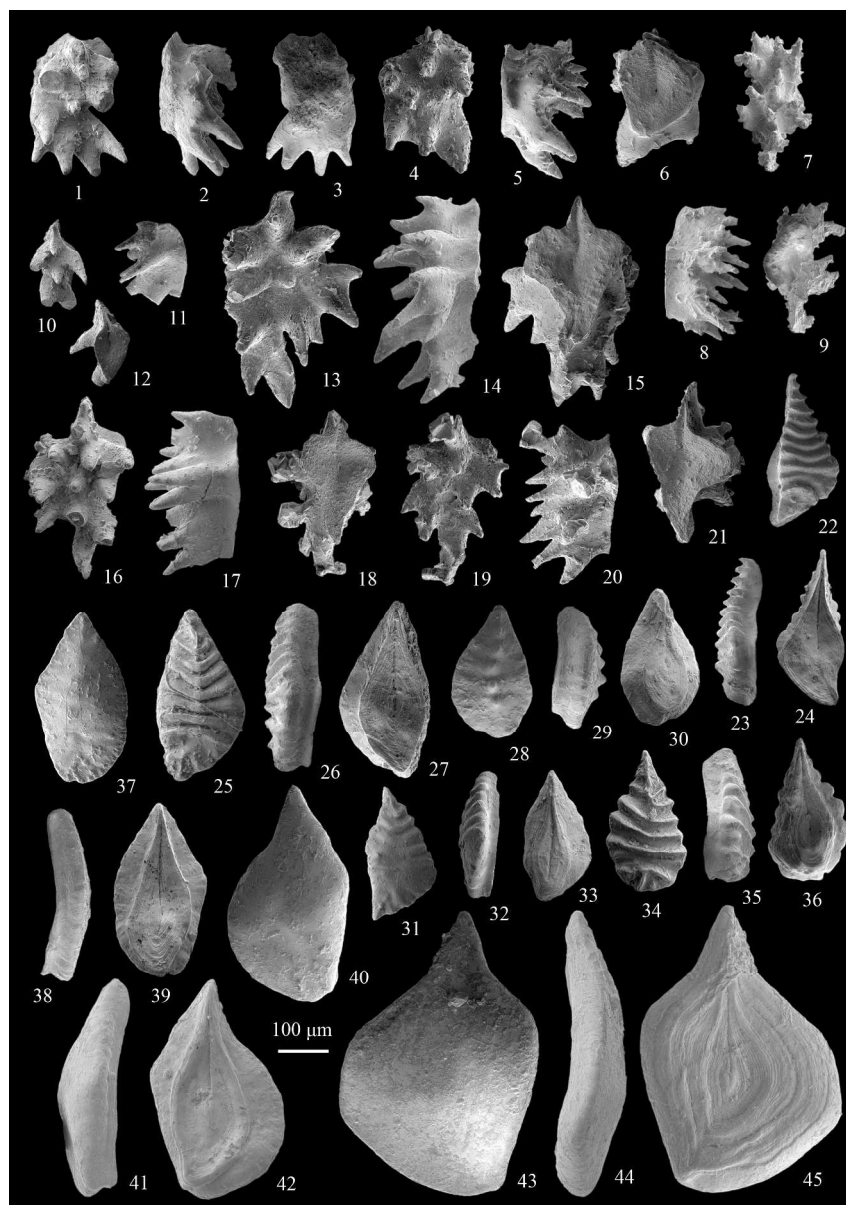


Figure 4. SEM photos of conodonts obtained from the Yiwagou Section. (1–21) *Parafurnishius xuanhanensis* Yang et al., 2014: (1–6) from sample ZLS-6, registration nos. ZLS17006001–17006002; (7–12) from sample ZLS-7, registration nos. ZLS17007001–17007002; (13–21) from sample ZLS-13, registration nos. ZLS17013001–17013003. (22–36) *Eurygnathodus costatus* Staesche, 1964, from sample ZLS-9, registration nos. ZLS17009001–17009005. (37–45) *Eurygnathodus hamadai* (Koike, 1982), from sample ZLS-9, registration nos. ZLS17009006–17009008. Scale bar = 100  $\mu\text{m}$ .

209x297mm (300 x 300 DPI)



Figure 5. SEM photos of conodonts obtained from the Yiwagou Section. (1–21) *Scythogondolella mosheri* (Kozur and Mostler, 1976), registration nos. ZLS17030001–17030007. (22–23) *Scythogondolella cf. milleri* (Müller, 1956), registration nos. ZLS17030008. (24–26) *Scythogondolella phryna* Orchard and Zonneveld, 2009, registration nos. ZLS17030009. All come from sample ZLS-30. Scale bar = 100  $\mu\text{m}$ .

209x297mm (300 x 300 DPI)

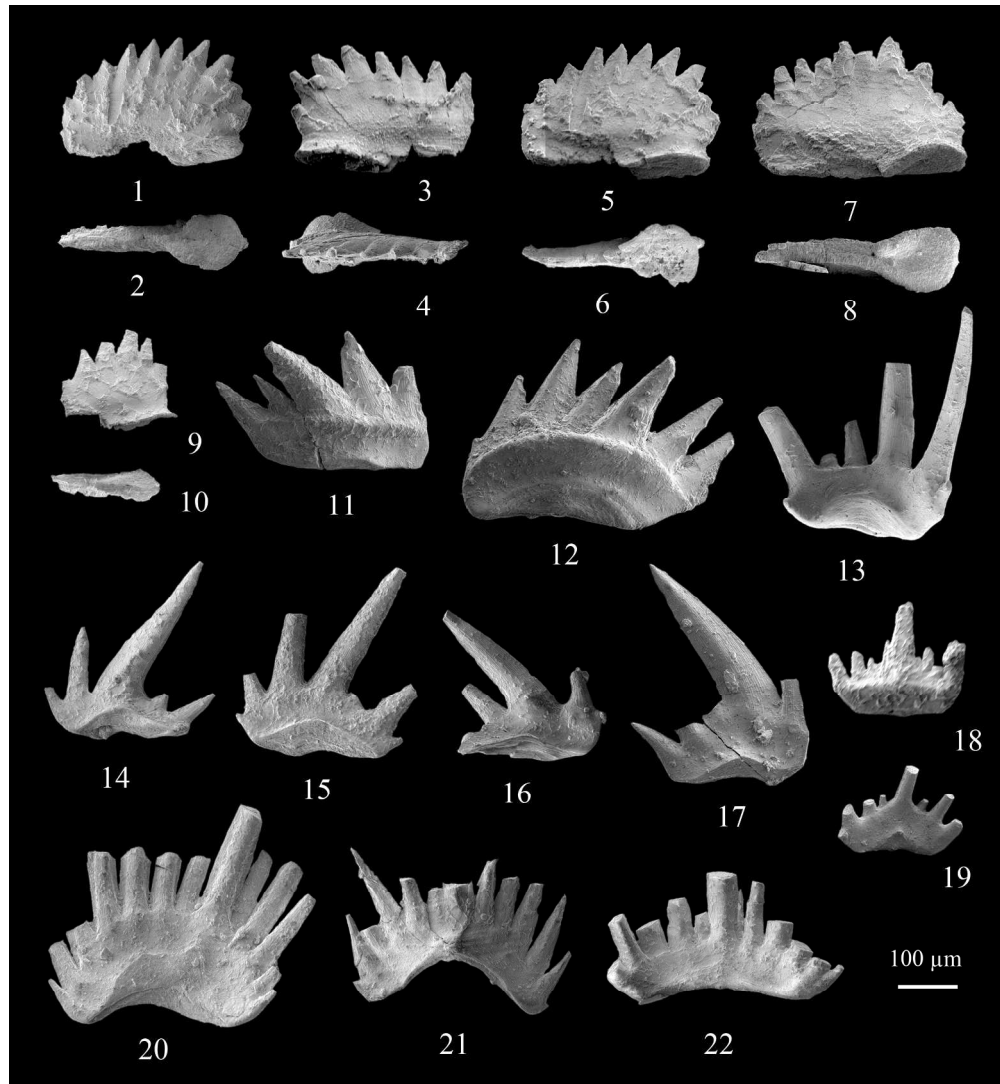


Figure 6. SEM photos of conodonts obtained from the Yiwagou Section. (1–6) *Novispathodus waageni* *waageni* (Sweet, 1970a), from sample ZLS-30, registration nos. ZLS17030039–17030041. (7–10) *Novispathodus waageni eowaageni* (Zhao and Orchard in Zhao et al., 2007), from sample ZLS-30, registration nos. ZLS17030042–17030043. (11–12) *Parachirognathus* n. sp. A, from sample ZLS-82, registration nos. ZLS17082001–17082002. (13) *Pachycladina obliqua* Staesche, 1964, S2 element, from sample ZLS-42, registration nos. ZLS17042001. (14–19) *Pachycladina qinlingensis* Lai, 1992: (14) P2 element, from sample ZLS-88, registration nos. ZLS17088001; (15) P2 element, from sample ZLS-85, registration nos. ZLS17085001; (16) P2 element, from sample ZLS-74, registration nos. ZLS17074001; (17) P2 element, from sample ZLS-53, registration nos. ZLS17053001; (18) S1 element, from sample ZLS-98, registration nos. ZLS17098001; (19) S2 element, from sample ZLS-67, registration nos. ZLS17067001. (20–22) *Parachirognathus semicircnelus* Tian and Dai in Tian et al., 1983: (20) S2 element, from sample ZLS-88, registration nos. ZLS17088002; (21, 22) S1 elements, from sample ZLS-88, registration nos. ZLS17088003–17088004. Scale bar = 100  $\mu$ m.

209x227mm (300 x 300 DPI)

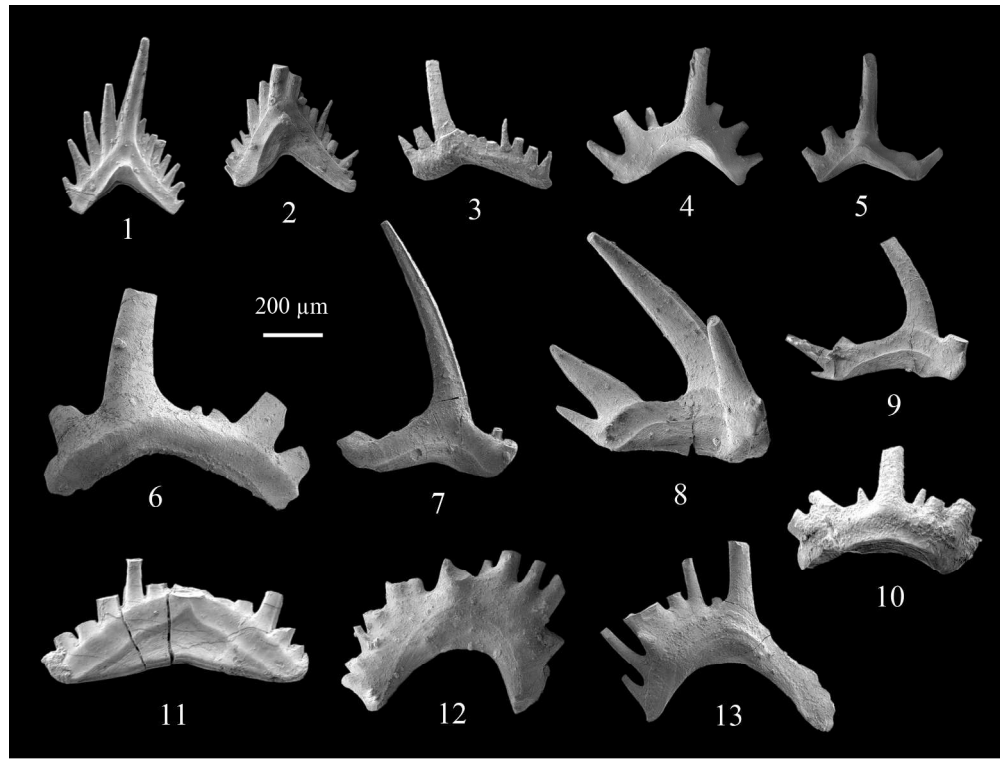


Figure 7. SEM photos of conodonts obtained from the Yiwagou Section. (1–7) *Pachycladina qinlingensis*: (1) M element, from sample ZLS-83, registration nos. ZLS17083001; (2) M element, from sample ZLS-91, registration nos. ZLS17091001; (3) S3-4 elements, from sample ZLS-98, registration nos. ZLS17098002; (4) S3 element, from sample ZLS-50, registration nos. ZLS17050001; (5) S1 element, from sample ZLS-50, registration nos. ZLS17050002; (6) S3 element, from sample ZLS-67, registration nos. ZLS17067002; (7) S2 element, from sample ZLS-82, registration nos. ZLS17082003. (8–10) *Pachycladina obliqua*: (8) M element, from sample ZLS-95, registration nos. ZLS17095001; (9) S3-4 elements, from sample ZLS-96, registration nos. ZLS17096001; (10) S1 element, from sample ZLS-98, registration nos. ZLS17098003. (11) *Parachirognathus delicatulus* Wang and Cao, 1981, S1 element, from sample ZLS-83, registration nos. ZLS17083002. (12, 13) *Hadrodontina anceps* Staesche, 1964: (12) P1 element, from sample ZLS-96, registration nos. ZLS17096002; (13) P1 element, from sample ZLS-67, registration nos. ZLS17067003. Scale bar = 200  $\mu$ m.

209x158mm (300 x 300 DPI)

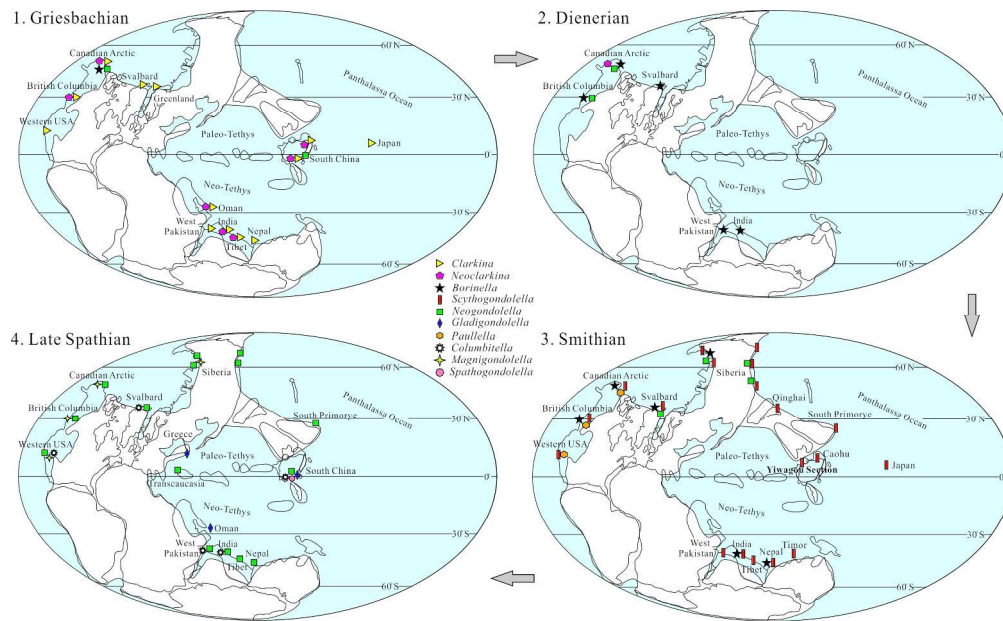


Figure 8. Global distribution of platform-bearing gondolellid conodonts in the Early Triassic (palaeogeographic map is modified after Muttoni et al., 2009 and Sun et al., 2012; occurrences are given in the text).

230x140mm (300 x 300 DPI)