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Article:

Li, H, Dong, H, Jiang, H et al. (8 more authors) (2022) Integrated conodont biostratigraphy and $\delta^{13}\text{C}_{\text{carb}}$ records from end Permian to Early Triassic at Yiwagou Section, Gansu Province, northwestern China and their implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 601. 111079. ISSN 0031-0182

<https://doi.org/10.1016/j.palaeo.2022.111079>

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1 Integrated conodont biostratigraphy and $\delta^{13}\text{C}_{\text{carb}}$ records from end
2 Permian to Early Triassic at Yiwagou Section, Gansu Province,
3 northwestern China and their implications
4

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16
17 **Abstract**

18 The South Qinling Belt is a key area for understanding the collisional history of the
19 South China and North China blocks during the Lopingian (late Permian) and Triassic.

20 This paper establishes the first integrated timescale based on conodont biostratigraphy

21 and $\delta^{13}\text{C}_{\text{carb}}$ records from a continuous end Permian to the end-Early Triassic

22 succession at Yiwagou, South Qinling Platform (SQP). Ten Early Triassic conodont

23 zones are established. They are, in ascending order, *Hindeodus parvus*, *H.*
24 *postparvus*, *Neospathodus dieneri*, *Eurygnathodus costatus* and *E. hamadai*,
25 *Novispathodus waageni*-*Scythogondolella mosheri*,
26 *Pachycladina-Parachirognathus* assemblage, *Triassospathodus hungaricus*, *Ns.*
27 *robustispinus* and *T. clinatus* zones. Our record of $\delta^{13}\text{C}_{\text{carb}}$ fluctuations shows close
28 correspondence to known Early Triassic carbon isotope fluctuations and, in
29 combination with the conodont data, helps achieve a high-resolution age model for
30 the region. The use of *E. costatus* as a good auxiliary marker for the
31 Induan-Olenekian boundary (IOB), within palaeolatitudes of 40°N-40°S, is supported
32 but it can not replace the use of *Nv. waageni*, because the former is absent in
33 higher-latitude and cooler regions. The conodont faunas from the Palaeo-Tethyan
34 Yiwagou section closely resemble those from the Northern Yangtze Platform (NYP),
35 but they differ somewhat from the contemporaneous Nanpanjiang Basin at species
36 level. Thus, the Qinling Sea was likely well connected with the NYP in the Early
37 Triassic, but was more isolated from the Nanpanjiang Basin. The remarkable
38 reappearance of *Hindeodus* fauna around the IOB at Yiwagou implies that the
39 shallow-water Qinling Sea was a refuge area for this genus long after its
40 disappearance elsewhere.

41

42 **Key Words:** Conodonts, Qinling, Permo-Triassic, Carbon isotope, Tethys

43

44 **1. Introduction**

45 The end Permian witnessed the most severe mass extinction in the history of life
46 with the subsequent aftermath in the Early Triassic marked by unfavourable
47 environmental conditions, including high temperatures and marine anoxia, and major
48 perturbations of the carbon isotope record (e.g., Payne et al., 2004; Sun et al., 2012;
49 Wignall, 2015). Several smaller crises occurred in the Early Triassic, especially
50 around the Smithian-Spathian boundary (SSB) (e.g., Lyu et al., 2019; Song et al.,
51 2019; Zhang et al., 2019a; Chen et al., 2021). During this period, conodonts are the
52 most important index fossils for marine stratigraphic division and correlation, and
53 they can provide even higher resolution correlation when combined with carbon
54 isotope records. The GSSP of the Induan-Olenekian boundary (IOB) in the Early
55 Triassic is not yet defined, however *Novispathodus waageni* sensu lato is a
56 promising candidate index taxon in two candidate sections, the West Pingdingshan
57 section in Chaohu of South China (Tong et al., 2003; Zhao et al., 2007, 2008a, 2008b,
58 2013; Tong and Zhao, 2011; Lyu et al., 2018) and the Mud section in Spiti of India
59 (Krystyn et al., 2005, 2007; Orchard, 2007; Orchard and Krystyn, 2007). The
60 widespread *Eurygnathodus costatus* is another possible index fossil for the IOB
61 (Lyu et al., 2020). As for the SSB, the first appearance datum (FAD) of *Nv.*
62 *pingdingshanensis* has been proposed as a marker at the West Pingdingshan section
63 in Chaohu (Liang et al., 2011). However, this species may have originated a little
64 earlier than the SSB and sometimes co-occurs with late Smithian ammonoids or
65 conodonts (e.g., Orchard and Zonneveld, 2009; Goudemand et al., 2018; Chen et al.,
66 2021). Besides *Nv. pingdingshanensis*, other early Spathian conodonts, such as
67 *Triassospathodus hungaricus*, *T. ex. gr. homeri*, *Neogondolella jubata* and
68 *Icriospathodus collinsoni*, together with a sharp positive carbon isotope shift, can
69 also help constrain the SSB.

70 A large number of palaeontological and palaeoenvironmental studies from
71 Lopingian to Early Triassic strata have been undertaken in South China. These have
72 especially focused on the sections from the Northern Yangtze Platform (NYP) and
73 Nanpanjiang Basin (Fig. 1, e.g., Jiang et al., 2007; Chen et al., 2015; Yang et al., 2014,
74 2019). The NYP is mainly located in Hubei, Anhui, and Jiangsu provinces, and in
75 northeastern Sichuan Province and Chongqing City. The Nanpanjiang Basin is mostly
76 located in Guangxi, and parts of Hunan and Guizhou provinces. Studies have revealed
77 some differences between the conodont faunas from two areas, for example, the
78 discovery of *Scythogondolella* at West Pingdingshan in Anhui, and at Longtan and
79 Qinshan in Jiangsu (Liang et al., 2011; Liu et al., 2020), and *Parafurnishus*
80 *xuanhanensis* at Panlongdong in northeastern Sichuan (Yang et al., 2014), which are
81 not matched by any discoveries in the Nanpanjiang Basin.

82 Outcrops of Lower Triassic strata also occur in the South Qinling region and the
83 associated faunas have characteristics transitional between South China and North
84 China, although they become more comparable to South China in the Middle Triassic
85 (Lai et al., 1992, 1995). However, only a few studies have been undertaken on the
86 Lopingian to Lower Triassic in the region because of the high altitude and poor access
87 (e.g., Lai et al., 1992, 1994; Li et al., 2019). Here we establish a high-resolution
88 conodont biostratigraphy and the first carbon isotope record from the Yiwagou
89 section in the western South Qinling Belt (SQB), and compare these with sections in
90 South China and elsewhere (Fig. 1). The study interval encompasses the
91 Permo-Triassic mass extinction and the Smithian-Spathian crisis and therefore
92 provides insight into these times of environmental stress on the little-known,
93 north-western margin of the South China Block.

95 **2. Geological setting and stratigraphy**

96 The Qinling Orogenic Belt is located in the central part of China, and can be
97 subdivided into four tectonic units, the southern margin of the North China Block
98 (NCB), the North Qinling Belt (NQB), the South Qinling Belt (SQB), and the
99 northern margin of the Yangtze Block (Fig. 1, Bao et al., 2015). These terranes
100 amalgamated during the collision of SCB and NCB (e.g., Lai et al., 1995; Yang et al.,
101 2002) causing the closure of the Mianlue Ocean along the southern edge of the
102 Qinling belt. Ocean destruction occurred gradually from the Lopingian in the east to
103 the Late Triassic in the west according to fossil evidence (Li et al., 2021; Wu et al.,
104 2021) and detrital zircon ages (Zheng et al., 2021). The Yiwagou section is located in
105 Têwo County, Gansu Province, northwestern China, and lies in the western part of the
106 SQB (start point GPS 34°15'21"N, 103°12'14"E, Height 4060 m). From Lopingian to
107 Early Triassic times, it was situated in the South Qinling Carbonate Platform (Figs. 1,
108 2). The continuous section spans the Lopingian to Lower Triassic, and is composed of
109 the Yangu, Zhalishan and Maresongduo formations (Fig. 3). The Yangu Formation is
110 composed of grey, thick-bedded limestone, oolitic limestone and dolomite. The
111 Zhalishan Formation is mainly characterized by grey or red, thin- to medium-bedded
112 limestone, bioclastic limestone and lime mudstone. The Maresongduo Formation
113 consists of red or grey, thick-bedded crystalline dolomite, dolomitic limestone and
114 micritic limestone.

115

116 **3. Materials and methods**

117 A total of 162 conodont samples (each weighing 4–5 kg) were collected. Closest
118 spacing was around the Permian-Triassic interval (one sample every 0.5 m) with
119 wider spacing in the other intervals (one sample every 3 to 5 m). All samples were
120 crushed into small fragments, then completely dissolved in an 8% solution of acetic
121 acid, followed by heavy liquid separation. The residue was examined using a
122 stereoscopic binocular microscope to find conodonts. Finally, a scanning electron
123 microscope (SEM) was used for photography.

124 A total of 297 geochemical samples were collected every 2-3 m from
125 Changhsingian to early Spathian level. About 2–3 g powder was generated from each
126 sample using an electric drill whilst avoiding weathered surfaces, calcified veins,
127 fossils and recrystallized parts. The powders were reacted with 100% phosphoric acid
128 at 72 °C to produce CO₂ gas, which was analyzed using a MAT-253 mass
129 spectrometer with standard methodology (see Song et al., 2013) in the State Key
130 Laboratory of Biogeology and Environmental Geology, China University of
131 Geosciences (Wuhan). Isotopic values are showed as per mil relative to the Vienna
132 Pee Dee belemnite (V-PDB) standard and the analytical precision was better than ±
133 0.1‰ for δ¹³C and ± 0.2‰ for δ¹⁸O for repeated samples.

134

135 **4. Results**

136 In total, about 6500 conodont specimens belonging to 30 species and 12 genera
137 have been obtained (Figs. 3-6, Supplementary material 1), enabling us to construct 10
138 conodont zones in ascending order. A carbon isotope curve is plotted from the top of
139 Yangu Formation to the bottom of Maresongduo Formation based on 297 $\delta^{13}\text{C}_{\text{carb}}$
140 values (Fig. 3).

141

142 **4.1 Conodont zonation**

143 In the Yangu Formation, *Clarkina orientalis* and *C. sp.* were recovered from the
144 grey, thick-bedded limestone of Bed -2 (Fig. 3). *C. orientalis* has a small cusp
145 separated from the carina, it can be distinguished from *C. abadehensis* by its
146 extremely wide posterior brim and a gap between the cusp and the posterior-most
147 denticle (Fig. 4.1). In addition, a previous study of the Yiwagou section has reported
148 *C. changxingensis* and *C. subcarinata* from Bed -5 and -6, and the fusulinid
149 *Reichelina tenuissima*, *R. sp.* from Bed -4 to Bed -6 (Lai et al., 1994). These
150 combined records indicate a Changhsingian (late Permian) age for the top of Yangu
151 Formation. In the overlying Zhalishan and Maresongduo formations ten conodont
152 zones have been recognized.

153

154 4.1.1 *Hindeodus parvus* Zone

155 Lower limit: first occurrence of *H. parvus*.

156 Upper limit: first occurrence of *H. postparvus*.

157 *Hindeodus parvus* first occurs in the grey micritic limestone of the upper part of
158 Bed 1 (at 0.7 m height), and ranges into the grey or red micritic limestone of the lower
159 part of Bed 3. Surprisingly, it reappears again around the Induan-Olenekian boundary
160 in grey or red limestone within the *Ns. dieneri* and *E. costatus* zones (Figs. 3, 4,
161 13-14). Yin et al. (1988) proposed the FAD of *H. parvus* to be the marker for the
162 base of the Triassic at the Meishan section. This level is widely accepted and has been
163 reported from numerous Tethyan and Panthalassan regions (Table 1, e.g., Jiang et al.,
164 2007; Chen et al., 2015; Yuan et al., 2014).

165

166 4.1.2 *Hindeodus postparvus* Zone

167 Lower limit: first occurrence of *H. postparvus*.

168 Upper limit: undefined.

169 *Hindeodus parvus* and *H. praeparvus* co-occur in this zone. *H. postparvus* is
170 found in three samples of grey and red limestones in lower part of Bed 3, and like *H.*
171 *parvus*, it reappears around the Induan-Olenekian boundary (Fig. 3). *H. postparvus*
172 was named by Kozur (1989) based on a specimen originally assigned to *Hindeodus*
173 *parvus* (Fig. 1c in Kozur and Pjatakova, 1976) in the Achura section of Azerbaijan.
174 In contrast to *H. parvus*, it has strongly diverging denticles that develop a curved line
175 of tips. The species sometimes has a reduced anterior bar with one or two small
176 denticles. *H. postparvus* is widespread during the Griesbachian in Tethyan and
177 Panthalassan regions, including South China, India, Oman, Tibet, Japan, Southern
178 Armenia and Slovenia (e.g., Orchard and Krystyn, 1998; Kolar-Jurkovšek and
179 Jurkovšek, 2015; Zhang et al., 2019b, Table 1).

180

181 4.1.3 *Neospathodus dieneri* Zone

182 Lower limit: undefined.

183 Upper limit: first occurrence of *E. costatus*.

184 *Hindeodus parvus*, *H. postparvus*, *H. aff. sosioensis*, *H. sp.*, *Neospathodus*
185 *aff. pakistanensis*, *Pachycladina* spp. and *Parafurnishus xuanhanensis* co-occur
186 in this zone. *Ns. dieneri* appears in the red limestone at the base of Bed 11, and it was
187 also found and illustrated in Lai (1992) from Bed 10 at Yiwagou. Three Morphotypes
188 of *Ns. dieneri* have been distinguished and corresponding subzones are established in
189 Chaohu (Table 1, Zhao et al., 2007). The specimen (Fig. 4. 24) has a broad cusp and a
190 short denticle posterior to the cusp, typical of *Neospathodus dieneri* Morphotype 3.

191 *Ns. dieneri* is widely distributed in eastern Palaeo-Tethys, the southern margin
192 of Neo-Tethys, Panthalassa and Boreal realms from the Dienerian to Smithian (Table
193 1), although it has not been found from western Palaeo-Tethys (Kolar-Jurkovšek and
194 Jurkovšek, 2015). We correlate this zone at Yiwagou is correlated with the same zone
195 from the west Pingdingshan (Zhao et al., 2007) and Guandao sections of the
196 Nanpanjiang Basin (Lehrmann et al., 2015) in South China, and also from the Spiti
197 area, India (Krystyn et al., 2004, 2007; Sun et al., 2021), British Columbia, Canada
198 (Orchard and Tozer, 1997; Orchard, 2008) and Kamura, Japan (Zhang et al., 2019b).

199

200 4.1.4 *Eurygnathodus costatus* Zone

201 Lower limit: first occurrence of *E. costatus*

202 Upper limit: first occurrence of *E. hamadai*

203 *Parafurnishus xuanhanensis*, *H. parvus*, *H. postparvus* and *H. aff.*
204 *sosioensis* co-occur in this zone. *E. costatus* was recovered from grey limestone of
205 Bed 12 and the base of Bed 13. It mainly occurs from the latest Dienerian to the early

206 Smithian within 40°N-40°S (Fig. 2, see discussion below), but it has also been found
207 in middle or late Smithian strata in the Three Gorges area in Hubei, South China
208 (Zhao et al., 2013). This widespread zone can also be found in Slovenia (Chen et al.,
209 2016), the Lichuan area of Hubei, South China (Wang and Cao, 1981), the
210 Palaeo-Tethyan Spiti area, India, the southern margin of Neo-Tethys (Sun et al., 2021)
211 and a Panthalassa terrane in southwest Japan (Koike, 1988).

212

213 4.1.5 *Eurygnathodus hamadai* Zone

214 Lower limit: first occurrence of *E. hamadai*,

215 Upper limit: first occurrence of *Nv. waageni* and *Sc. mosheri*.

216 *Parafurnishus xuanhanensis* co-occurs in this zone. *E. hamadai* occurs with
217 *E. costatus* in grey limestone at the base of Bed 13. It is a Smithian species that
218 usually appears a little after *E. costatus* and may have evolved from the latter (Chen
219 et al., 2016; Lyu et al., 2020). This zone is known from Tethyan regions and
220 Panthalassa, and correlates with the *E. hamadai* zone in Slovenia (Chen et al., 2016),
221 Spiti, India (Krystyn et al., 2007) and southwest Japan (Koike, 1988).

222

223 4.1.6 *Novispathodus waageni*–*Scythogondolella mosheri* Assemblage Zone

224 Lower limit: first occurrence of *Nv. waageni* and *Sc. mosheri*.

225 Upper limit: first occurrence of *Pc. obliqua*.

226 *Scythogondolella phryna* and *Sc. cf. milleri* co-occur in this zone. They occur
227 in grey, thin-bedded limestone at the lower part of Bed 14. *Nv. waageni* is a
228 widespread species reported from many locations (e.g., Zhao et al., 2008a, 2008b;
229 Orchard and Krystyn, 2007; Orchard, 2008, fig. 2), although it has never been found
230 in central southern Europe (Chen et al., 2016). The genus *Scythogondolella* is the

231 only widespread gondolellid in the Smithian, and *Sc. mosheri* was found in
232 Panthalassa, Boreal realms and higher-latitude Tethyan regions, but not in
233 low-latitude Tethyan regions (Fig. 2, Li et al., 2019).

234

235 4.1.7 *Pachycladina–Parachirognathus* Assemblage Zone

236 Lower limit: first occurrence of *Pc. obliqua*.

237 Upper limit: last occurrence of *Pc. qinlingensis*.

238 Large number of *Pachycladina obliqua*, *Pc. qinlingensis*, *Parachirognathus*
239 *delicatulus*, *Pg. semicircnelus* and *Hadrodontina anceps* co-occur in this zone.

240 They were recovered from red and grey limestone, grey micritic limestone and red
241 oolitic limestone from the upper part of Bed 14 to the middle part of Bed 18.

242 *Pachycladina* and *Parachirognathus* are widely distributed in low-latitude
243 Palaeo-Tethys, Panthalassa and western USA in the Smithian and are typically
244 encountered in shallow, high energy facies (Duan et al., 1989; Sun et al., 2012; Wu et
245 al., 2021). The constituent taxa of this Smithian zone disappeared before Spathian
246 (Zhang et al., 2019a).

247

248 4.1.8 *Triassospathodus hungaricus* Zone

249 Lower limit: first occurrence of *T. hungaricus*.

250 Upper limit: first occurrence of *Ns. robustispinus*.

251 *Triassospathodus qinlingensis* sp. nov. co-occurs in this zone. *T. hungaricus*
252 was recovered from thick-bedded, crystalline dolomite of Bed 20. It was originally
253 reported from Hungary (Kozur and Mostler, 1970), later from Sichuan, China (Tian et
254 al., 1983), and more recently from Slovenia (Chen et al., 2016; Kolar-Jurkovšek et al.,
255 2017) and Bosnia Herzegovina (Kolar-Jurkovšek et al., 2014; Kolar-Jurkovšek et al.

256 2021). “*Neospathodus*” cf. *hungaricus* has also been reported from Nevada (Lucas
257 and Orchard, 2007), but the specimen is not well-preserved and is unlikely to be
258 related to *T. hungaricus*, because it is about four times larger than the average size of
259 *T. hungaricus* in Palaeo-Tethyan regions. In addition, the Nevadan specimen has no
260 obvious senile characteristics (e.g. more denticles (4-5) or strongly folded basal cavity)
261 suggesting that it is not a gerontic specimen. The *T. hungaricus* Zone is also known
262 from Slovenia (Chen et al., 2016, Table 1) and is of Spathian age.

263

264 4.1.9 *Neospathodus robustispinus* Zone

265 Lower limit: first occurrence of *Ns. robustispinus*.

266 Upper limit: first occurrence of *T. clinatus*.

267 *Triassospathodus qinlingensis* sp. nov., *T.* sp. indet and *Icriospathodus zaksi*
268 co-occur in this zone. *Ns. robustispinus* was recovered from light grey, thick-bedded
269 dolomicrite of Bed 21. It was first reported from the lower Spathian of the West
270 Pingdingshan section, Chaohu, South China (Zhao et al., 2008b). In Slovenia, a *T.*
271 *homeri* - *Ns. robustispinus* Assemblage Zone or *Ns. robustispinus* Zone was
272 established, from above the *T. hungaricus* and *T. symmetricus* zones
273 (Kolar-Jurkovšek and Jurkovšek, 2015; Chen et al., 2016). The associated species *I.*
274 *zaksi* is an inappropriate zonal species because it has also been reported from latest
275 Smithian strata (where it co-occurs with *Sc. milleri* or *Nv. pingdingshanensis*) in
276 Oman (Chen et al., 2019), southwest Japan (Maekawa et al., 2021) and Russia (Buryi,
277 1979). This zone is of Spathian age.

278

279 4.1.10 *Triassospathodus clinatus* Zone

280 Lower limit: first occurrence of *T. clinatus*.

281 Upper limit: undefined.

282 *Triassospathodus clinatus* was recovered from red, thick-bedded, dolomitic
283 limestone in Bed 24 from the Maresongduo Formation. Orchard (1995) distinguished
284 *T. clinatus* from *T. triangularis* by the former's more uniformly reclined denticles
285 and less conspicuously folded basal cavity. *T. clinatus* was first founded in the early
286 Anisian *Chiosella timorensis* Zone in Pakistan (type sample in Sweet, 1970;
287 illustrated in Orchard, 1995, pl.3, figs. 5-7), and then in the Spathian-age, Marble
288 Canyon Formation in Nevada (Orchard and Bucher, 1992, pl.1, fig. 16). Later, in the
289 Nanpanjiang Basin, it was reported from the Anisian-age, Wantou section (Yan et al.,
290 2015, fig. 3. 25) and the Spathian-age Mingtang section (Liang et al., 2016, pl.4, figs.
291 6-7, 12, 17). *Ns. triangularis* reported from Spathian strata in Jiangsu, China (Duan,
292 1987, only pl.3, fig. 5) possibly belongs to this species. Because some typical
293 Spathian *T. hungaricus* were reported from Bed 27 at Yiwagou (Lai, 1992), this zone
294 probably begins in the Spathian.

295

296 **4. 2 Carbon isotope stratigraphy**

297 The average values of $\delta^{13}\text{C}_{\text{carb}}$ are +2.6‰ (ranging from -1.4‰ to +7.3‰), and
298 $\delta^{18}\text{O}_{\text{carb}}$ are -6.6‰ (ranging from -14.5‰ to -1.4‰). The two sets of values show
299 almost no correlation ($R^2 = 0.0967$, supplementary material 2) suggesting that there
300 has been little diagenetic change. The colour alteration index (CAI) of the conodont
301 specimens is lower than 5 at the section, except for one sample (M-24) from
302 thick-bedded crystalline dolomite in the lowermost Maresomgduo Formation (Bed
303 20). Some of the isotopic values in the Yangu Formation and lowermost Maresongduo
304 Formation derive from dolomitic samples that have potentially had their primary

305 $\delta^{13}\text{C}_{\text{carb}}$ records altered. However, the carbon isotope composition of the dolomitic
306 samples follows the same trends as the associated carbonate samples suggesting they
307 are primary values. This conclusion is also supported by the close correspondence of
308 carbon isotope profile from Yiwagou to other Permian-Triassic isotope records (e.g.,
309 Payne et al., 2004; Tong et al., 2007; Song et al., 2013; Sun et al., 2021). These show
310 a series of high-amplitude, negative and positive excursions that have been labelled
311 N1–N4 and P1–P4 (Song et al., 2013).

312

313 **5. Discussions**

314 5.1 Intercalibrated conodont– $\delta^{13}\text{C}_{\text{carb}}$ correlation framework

315 The Yiwagou results enable us to establish an integrated conodont biostratigraphy
316 and $\delta^{13}\text{C}_{\text{carb}}$ records from latest Permian to the Early Triassic. Carbon isotope values
317 show a small negative shift from late Changhsingian to around the base of the *H.*
318 *parvus* Zone. A negative shift beginning slightly prior to the PTB has been noted in
319 many regions and coincides with the end Permian mass extinction (Fig. 7; e.g., Cao et
320 al., 2009; Korte and Kozur, 2010; Song et al., 2013), although the magnitude of the
321 excursion is relatively small ($\sim -1.8\text{‰}$) at Yiwagou. The more negative values seen
322 elsewhere may be absent at Yiwagou because of the presence of a hiatus around the
323 level of an oolitic limestone (Bed -1) although no obvious weathering surface was
324 observed at this level in the field.

325 Above the Permian-Triassic boundary $\delta^{13}\text{C}_{\text{carb}}$ values increase upwards ($\sim +7.0\text{‰}$)
326 for ~ 200 m and define a major positive (P2) excursion which is composed of double

327 peaks around the IOB, with the second peak having higher values (Fig. 3). In
328 Palaeo-Tethyan regions, this P2 excursion is also known from the West Pingdingshan
329 (Tong et al., 2007) and Guandao sections (Lehrmann et al., 2015) in South China, and
330 the Žiri area of Slovenia (Chen et al., 2016). It is also known in Neo-Tethyan regions,
331 such as Musandam (Clarkson et al., 2013), Oman (Richoz, 2006), Spiti (Sun et al.,
332 2021) and Iran (southern margin, Horacek et al., 2007). In most sections in the world,
333 the IOB is defined by the first occurrence of *Nv. waageni* sensu lato around P2.
334 However, at Yiwagou, *Nv. waageni* sensu lato only occurs in one sample of Bed 14,
335 which is much a higher level than the level of P2. But *E. costatus* first occurs in the
336 lower part of Bed 12, just between the double peaks of P2, which can be well
337 correlated with the first occurrence of this species at two IOB candidate sections, the
338 West Pingdingshan and the Mud sections (Fig. 7). Hence the IOB can be placed in the
339 lower part of Bed 12.

340 Above the P2 excursion, there is an ~8.5‰ negative shift in the $\delta^{13}\text{C}_{\text{carb}}$ curve
341 from the IOB into the middle-late Smithian, followed by a quick rebound across the
342 SSB to P3 (~+6.5‰) in the earliest Spathian. The peak values of both P2 (~+7.3‰)
343 and P3 (~+6.5‰) are considerably heavier than the values seen in South China at this
344 time (Fig. 7, e.g., Payne et al., 2004; Tong and Zhao, 2011; Song et al., 2013, 2019;
345 Lyu et al., 2019). The typical Spathian species - *T. hungaricus* first occurs at the base
346 of Maresongduo Formation, leaving a 60-m thick interval that is barren of conodonts
347 below this level. The *T. hungaricus* Zone, which can be equivalent to the ammonoid
348 *Tirolites cassianus* Zone (Kozur, 2003; Kolar-Jurkovšek et al. 2021), is not the first
349 conodont zone in Spathian. In the Idrija–Žiri area, Slovenia, the early Spathian *Ns.*

350 *robustus*, *Platyvillosus corniger* and *Pl. regularis* zones were found lower than *T.*
351 *hungaricus* Zone (Chen et al., 2016, table 1). Hence the SSB should be somewhere
352 within the 60-m barren interval. Zhang et al. (2019a) suggested SSB to be around the
353 midpoint between N3 and P3 of $\delta^{13}\text{C}$ curve; using this criterion, the SSB would lie in
354 the upper part of Bed 18.

355

356 5.2 The conodont marker for the IOB: *Nv. waageni* or *E. costatus*?

357 *Novispathodus waageni* sensu lato and *Eurynathodus costatus* are both
358 potential index fossils to define the base of Olenekian (e.g., Tong et al., 2003; Lyu et
359 al., 2018, 2020). Here we compare their attributes. Firstly, *Nv. waageni* has a wider
360 distribution than *E. costatus* which is restricted to palaeolatitudes within 40°N –
361 40°S (Fig. 2). In comparison, *Nv. waageni* is globally distributed (although not
362 known from western Palaeo-Tethyan regions), and is also common in northern
363 high-latitude regions, Middle Sikhote Alin (Klets, 1995), Canadian Arctic (Orchard,
364 2008), Svalbard (Nakrem et al., 2008) and Siberia (Eastern Laptev Sea coast and
365 Kotelny Island (Dagys, 1984; Klets and Yadrenkin, 2001; Klets and Kopylova, 2006;
366 Konstantinov et al., 2013), Lena River lower reaches of the Western Verkhoyansk
367 region (Klets and Kopylova, 2006), Shevlya River basin (Kuz'min and Klets, 1990),
368 and Churki Ridge (Klets, 2008)). It also occurs in southern high-latitude regions,
369 Nepal (Hatileberg and Clark, 1984), South Tibet (Wang, 1995) and Western Australia
370 (Metcalf et al., 2013). Secondly, *Eurygnathodus* has lighter $\delta^{18}\text{O}_{\text{apatite}}$ values than
371 coeval neospathodids (*Neospathodus* and *Novispathodus*), which suggests it
372 prefers shallower and warmer waters than the neospathodids (Sun et al., 2012; Chen

373 et al., 2021). This likely explains the abundance of *Eurygnathodus* in shallow,
374 epeiric ramp settings in Europe where *Nv. waageni* is absent (e.g., Chen et al., 2016,
375 2021). Thirdly, *E. costatus* has shorter stratigraphic range around the IOB, whilst the
376 *Nv. waageni* group can range up into Spathian (Zhao et al., 2008a; Liang et al., 2011),
377 so that the occurrence of *E. costatus* often corresponds to a P2 positive $\delta^{13}\text{C}_{\text{carb}}$
378 excursion, but *Nv. waageni* does not (Fig. 7). In summary, *E. costatus* provides an
379 auxiliary marker for the IOB within 40°N-40°S, but cannot replace the more
380 widespread *Nv. waageni*.

381

382 5.3 The surprisingly long-range of *Hindeodus* in South Qinling

383 An abundant *Hindeodus* fauna, including *H. parvus*, *H. postparvus*, *H. aff.*
384 *sosioensis* and *H. sp.*, appears around the IOB at Yiwagou, and co-occurs with
385 *Parafurnishus xuanhanensis* and *E. costatus*. Because this *Hindeodus* fauna
386 appears about 200 m above the earliest Griesbachian *Hindeodus* occurrences but not
387 in the intervening strata it is unlikely that this reappearance is due to reworking.
388 Furthermore, the *Hindeodus* specimens do not show evidence of abrasion suggesting
389 they have not been transported any distance which again suggests they are unlikely to
390 have been reworked from old strata (Figs. 4. 13-14). The genus *Hindeodus* occurred
391 globally in the Griesbachian, and was considered to either become extinct in late
392 Griesbachian (Kozur, 1998) or to have perhaps extended into the earliest Dienerian
393 (Orchard, 2007). Based on oxygen isotope analysis, *Clarkina* and *Hindeodus*
394 inhabited similar water depths in the Lopingian, but separated into different water
395 depth in the earliest Triassic when *Hindeodus* lived in shallower waters than

396 *Clarkina* (Joachimski et al., 2012). *Hindeodus*' widespread distribution in the
397 Griesbachian at a time of widespread anoxic bottom waters also suggests a
398 surface-dwelling life site (Lai et al., 2001). Compared with its global Griesbachian
399 distribution, the restriction of *Hindeodus* to Yiwagou in the IOB interval marks a
400 major contraction in its range. Presumably the shallow water environments of this
401 western-most South China location provided a final refuge area for this long-lived
402 genus.

403

404 5.4 Comparison of conodont faunas in Palaeo-Tethys

405 The conodont faunas from the SQP reported here have their greatest similarity
406 with conodonts from the NYP both in terms of genera and species, but have less
407 similarity with those from the Nanpanjiang Basin at species level (Table 2). In the
408 Induan, *Parafurnishus xuanhanensis* is known from Panlongdong, Sichuan, and
409 from Yiwagou, but it has not been found in the Nanpanjiang Basin or Europe.
410 *Scythogondolella*, a cosmopolitan Smithian genus, is represented at Yiwagou by *Sc.*
411 *mosheri*, *Sc. phryna* and *Sc. cf. milleri*, whilst in the NYP, *Sc. milleri*, *Sc. milleri*
412 *parva*, *Sc. aff. mosheri*, *Sc. ellesmerensis* and *Sc. aff. lachymiformis* occur in the
413 Longtan and Qingshan sections, Jiangsu (Liu et al., 2020; Sun et al., 2020) and *Sc.*
414 *milleri* (*Neogondolella* sp., fig. 3, 10 in Liang et al., 2011) occurs at West
415 Pingdingshan, Anhui. However, *Scythogondolella* is not known from either the
416 Nanpanjiang Basin nor in Europe. During the Spathian, *T. hungaricus* occurs at
417 Yiwagou and NYP sections: Wangcang, Sichuan (Tian et al., 1983) and Xiejiacao,
418 Chongqing (our unpublished materials), and in Europe (e.g., Hungary (Kozur and
419 Mostler, 1970), Slovenia (Chen et al., 2016; Kolar-Jurkovšek et al., 2017) and Bosnia

420 Herzegovina (Kolar-Jurkovšek et al., 2014; Kolar-Jurkovšek et al. 2021)). *Ns.*
421 *robustispinus* is found at Yiwagou and West Pingdingshan (Zhao et al., 2008b), and
422 also in Slovenia (Kolar-Jurkovšek and Jurkovšek, 2015; Chen et al., 2016). All these
423 species mentioned above have not been found in the Nanpanjiang Basin so far. It can
424 be inferred that the NYP was well connected with the SQP in the Early Triassic, based
425 on the near-identical conodont biota, whilst the Nanpanjiang Basin was partly isolated
426 from this region perhaps because of a series of intervening barriers (e.g., small
427 islands). The differences of conodont faunas between eastern and western
428 Palaeo-Tethys was likely due to the long distance separation and different
429 environments.

430

431 **6. Systematic palaeontology**

432

433 Class: Conodonta Eichenberg, 1930

434 Order Ozarkodinida Dzik, 1976

435 Family Gondolellidae Lindström, 1970

436 Subfamily Novispathodinae Orchard, 2005

437 Genus *Triassospathodus* Kozur, 1998

438 Type species: *Triassospathodus homeri* (Bender, 1970)

439

440 Remarks: according to the multielement conodont apparatus, *Triassospathodus* and
441 *Neospathodus* belong to different subfamilies with different S₀, S₂-S₄ elements
442 (Orchard, 2005). In terms of morphology, the lower side of basal cavity is upward
443 curved in the P₁ element of *Neospathodus*, but straight or downward curved in
444 *Triassospathodus* (Kozur et al., 1998). A folded basal cavity (triangular or
445 heart-shaped) is more common in *Triassospathodus* than *Neospathodus* or
446 *Novispathodus*.

447

448 *Triassospathodus qinlingensis* sp. nov. Li and Lai

449 Figures 6. 8-14

450

451 Holotype: Fig. 6. 14 from sample M-21 (Bed 20), in the *T. hungaricus* Zone, about
452 582 m above the P-T boundary at the Yiwagou section, Têwo, Gansu Province,
453 China.

454

455 Paratypes: Fig. 6. 9 from sample M-20 (Bed 20), 6. 13 from sample M-21 (Bed 20) in
456 the *T. hungaricus* Zone.

457

458 Derivation of name: from the South Qinling belt, the type locality.

459

460 Diagnosis: P₁ element generally bears 5-7 largely fused denticles with increasing
461 inclination toward the posterior end. The terminal cusp is prominent and most
462 strongly reclined. The expanded subtriangular or heart-shaped basal cavity occupies
463 1/2 to 2/3 of the lower side.

464

465 Description: This species has a ratio of length: height about 1.3: 1. It bears 5-7 largely
466 fused, posteriorly inclined denticles, with increasing inclination toward the posterior
467 end. The denticle on the posterior end (cusp) is inclined most strongly and always
468 projects beyond the posterior margin of basal cavity. The length of denticles increases
469 from anterior end to posterior end. The expanded basal cavity occupies 1/2 to 2/3 of
470 the element's length, is subtriangular or heart-shaped, and usually widest at the
471 posterior end. The lower margin of the basal cavity is slightly downward curved.

472

473 Remarks: This species is similar to *Ns. robustispinus* and *T. brevissimus*, but can
474 be distinguished from them by its more posteriorly inclined denticles (especially the
475 cusp) and the slightly folded basal cavity. Compared with *T. hungaricus*, it has
476 different dimensions with more denticles. In comparison with *Ns. planus*, this
477 species has a less inflated basal cavity, and its highest denticle is the second or third
478 one from posterior end, whereas it is the first one (cusp) in *Ns. planus* (Chen et al.,
479 2016).

480

481 Materials: 39 specimens from sample M-21, M-20, M-19 in Bed 20, M-9, M-5 in Bed
482 21, Maresongduo Formation.

483

484 Age: Spathian

485

486 **Conclusions**

487 A detailed conodont biostratigraphic and chemostratigraphic study was carried
488 out at the Yiwagou section from the western part of the South Qinling Belt,
489 northwestern China. A total of ~6500 specimens were obtained and these have been
490 assigned to 30 species of 12 genera in strata spanning the end Permian to Early
491 Triassic interval. One new species *Triassospathodus qinlingensis* sp. nov. is
492 introduced. Ten conodont zones have been recognized in the Early Triassic at
493 Yiwagou. They are, in ascending order, *H. parvus* Zone, *H. postparvus* Zone, *Ns.*
494 *dieneri* Zone, *E. costatus* Zone, *E. hamadai* Zone, *Nv. waageni-Sc. mosheri*
495 *Assemblage* Zone, *Pachycladina-Parachirognathus* *Assemblage* Zone, *T.*
496 *hungaricus* Zone, *Ns. robustispinus* Zone and *T. clinatus* Zone. Based on a
497 combination of conodont zonation and carbon isotope records, the PTB, IOB and SSB
498 are all clearly defined at Yiwagou.

499 The $\delta^{13}\text{C}_{\text{carb}}$ curve is comparable to that seen elsewhere. It shows a negative shift
500 from the late Changhsingian to the PTB followed by a positive trend that culminates
501 in the double peak positive excursion around the IOB, the P2 excursion of Song et al.
502 (2013). A negative into the late Smithian, is followed by a quick rebound to the P3

503 positive peak in the earliest Spathian. The peak values of both P2 (~+7.3‰) and P3
504 (~+6.5‰) are considerably heavier than the values seen in South China.

505 The conodont faunas of South Qinling Sea are closely similar to those of the
506 North Yangtze Platform. In contrast, the conodonts from the Nanpanjiang Basin in
507 Early Triassic are somewhat different at species level pointing to the isolation of this
508 basin. The difference between Yiwagou assemblages and those of more distant
509 Western Tethyan realms are likely due to the long distance and different environments
510 in the regions. *Hindeodus*, which was thought to have gone extinct in the late
511 Griesbachian, has an unexpected final reappearance around the IOB at Yiwagou
512 suggesting the South Qinling region provided the final refuge for this long-lived
513 genus.

514 Our study also provides new data for supporting the contention that *E. costatus*
515 can be used as an auxiliary marker for the IOB within palaeolatitudes of 40°N-40°S,
516 although *Nv. waageni* is widespread at all latitudes at this time and is therefore a
517 more useful marker for this level.

518

519 **Declaration of competing interest**

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

523

524 **Acknowledgments**

525 This work was supported by the National Natural Science Foundation of China [grant
526 numbers 41830320, 45172002, 41661134047] and China Scholarship Council. We
527 thank Kang Li, Ye Qian, Niu Xiaohong, Song Hong, He Pengfei, Li Linfeng, Ma
528 Haiyuan, Ma Zujun, Li Yongchao, Wang Miaoyan, Yi Zhaoyang and Chen Yan for
529 their great help during fieldwork or the experiments. We also thank two anonymous
530 reviewers for their helpful comments and valuable suggestions.

531

532 **Figure and Table Captions**

533 Figure 1. Early Triassic palaeogeography of Qinling and South China (modified after
534 Lai and Yin, 1992; Feng et al., 1997), and simplified tectonic map of the Qinling
535 orogen (modified after Bao et al., 2015). MLSZ = Mianlue suture zone.

536

537 Figure 2. Global palaeogeographic map (modified after
538 <http://www.scotese.com/newpage5.htm>) and selected conodont distributions. *E.*
539 *costatus* is seen to be restricted to within 40°N – 40°S whilst *Nv. waageni* is
540 globally distributed (except for western Palaeo-Tethyan regions). *Scythogondolella*
541 is the only widespread gondolellid in the Smithian. Locations: 1. Yiwagou, South
542 Qinling; 2. Chaohu, South China; 3. Nanpanjiang Basin, South China; 4. Northeastern
543 Vietnam; 5. Japan; 6. Timor; 7. Malay Peninsula; 8. West Malaysia; 9. South
544 Primorye, Russia; 10. Middle Sikhote Alin (Klets, 1995); 11. Qinghai, China; 12.
545 Lhasa Terrane, Tibet, China; 13. Afghanistan; 14. United Arab Emirates; 15. Oman;
546 16. Salt Range, Pakistan; 17. India; 18. Nepal ; 19. Himalaya Terrane, Tibet; 20.

547 Western Australia; 21. South Tyrol, Italy; 22. Slovenia and Croatia; 23. Bosnia and
548 Herzegovina (Kolar-Jurkovšek et al. 2021); 24. Serbia; 25. Western USA; 26. British
549 Columbia, Canada; 27. Alberta, Canada; 28. Canadian Arctic; 29. Svalbard, Norway.
550 1-9, 12-22, 24-29 *Nv. waageni* and *E. costatus* (after Lyu et al., 2020 and its
551 references), *Scythogondolella* and other gondolellids (after Li et al., 2019 and its
552 references). Siberia: 30. Eastern Laptev Sea coast and Kotelnny Island (Dagys, 1984;
553 Klets and Yadrenkin, 2001; Klets and Kopylova, 2006; Konstantinov et al., 2013); 31.
554 Lena River lower reaches, Western Verkhoyansk region (Klets and Kopylova, 2006);
555 32. Shevlyya River basin (Kuz'min and Klets, 1990); 33. Churki Ridge (Klets, 2008).

556

557 Figure 3. Conodont distributions and carbon isotopes from Lopingian to Lower
558 Triassic strata at Yiwagou, Têwo, northwestern China.

559

560 Figure 4. SEM photos of conodonts from Yiwagou: 1. *Clarkina orientalis*, sample
561 2YG-1; 2-8. *Hindeodus praeparvus*, 2-4, sample ZLSO-21, 5-8, sample ZLSO-22;
562 9-14. *H. parvus*, 9-10, sample ZLSO-22, 11, sample ZLSO-23, 12, sample ZLSO-22,
563 13, sample ZLS-2, 14, sample ZLS-5; 15-23. *H. postparvus*, 15-16, sample
564 ZLSO-21, 17-18, 22-23, sample ZLS-5, 19-21, sample ZLS-2; 24. *Neospathodus*
565 *dieneri* M3, sample ZLS-C2-8; 25. *Neospathodus* aff. *pakistanensis*, sample
566 ZLS-C2-8; 26-27. *Pachycladina* spp., sample ZLS-C2-8. Scale bar = 100 µm.

567 Numbers in red denote *Hindeodus* around the IOB.

568

569 Figure 5. SEM photos of conodonts from Yiwagou: 1. *Eurygnathodus costatus*,

570 sample ZLS-9 (after figs. 4. 34-36 in Li et al., 2019); 2. *Eurygnathodus hamadai*,
571 sample ZLS-9 (after figs. 4. 40-42 in Li et al., 2019); 3. *Parafurnishius*
572 *xuanhanensis*, sample ZLS-13 (after figs. 4. 13-15 in Li et al., 2019); 4-5.
573 *Scythogondolella mosheri*, sample ZLS-30 (after figs. 5. 4-6, 16-18 in Li et al.,
574 2019); 6. *Scythogondolella* cf. *milleri*, sample ZLS-30 (after figs. 5. 22-23 in Li et
575 al., 2019); 7. *Scythogondolella phryna*, sample ZLS-30 (after figs. 5. 24-26 in Li et
576 al., 2019); 8-9. *Novispathodus waageni waageni*, sample ZLS-30 (after figs. 6. 1-2,
577 5-6 in Li et al., 2019); 10. *Novispathodus waageni eowaageni*, sample ZLS-30
578 (after figs. 6. 7-8 in Li et al., 2019); 11–13. *Pachycladina qinlingensis*, 11. P₂
579 element, sample ZLS-88 (after fig. 6. 14 in Li et al., 2019), 12. P₂ element, sample
580 ZLS-74 (after fig. 6. 16 in Li et al., 2019), 13. S₂ element, sample ZLS-67 (after fig. 6.
581 19 in Li et al., 2019); 14. *Pachycladina obliqua*, S₂ element, sample ZLS-42 (after
582 fig. 6. 13 in Li et al., 2019); 15-16. *Parachirognathus semicircnelus*, 15. S₁
583 elements, sample ZLS-88 (after fig. 6. 22 in Li et al., 2019), 16. S₂ element, sample
584 ZLS-88 (after fig. 6. 20 in Li et al., 2019). Scale bar = 100 µm.

585

586 Figure 6. SEM photos of conodonts from Yiwagou: 1-2. *Hindeodus* aff. *sosioensis*,
587 1, sample ZLS-2, 2, sample ZLS-5. 3-7. *Triassospathodus hungaricus*, 3, 7, sample
588 M-20, 4-6, sample M-21; 8-14. *Triassospathodus qinlingensis* sp. nov., holotype
589 (14), paratypes (9 and 13), 8, sample M-19, 9, sample M-20, 10, sample M-5, 11, 13,
590 sample M-21, 12, sample M-9, 14, sample M-21; 15. *Novispathodus robustispinus*,
591 sample M-5; 16. *Icriospathodus zaksi*, sample M-2; 17-19. *Triassospathodus*
592 *clinatus*, 18, sample MRSD-1, 17, 19, sample MRSD-2. Scale bar = 100 µm.

593

594 Figure 7. Comparison of latest Permian – Early Triassic carbon isotope records from
595 South China and Mud, Spiti with the Yiwagou section. Meishan Section, Changxing
596 (Cao et al., 2009); Guandao Section, Nanpanjiang Basin (Payne et al., 2004); West
597 Pingdingshan Section, Chaohu (black from Tong and Zhao, 2011; blue from Lyu et al.,
598 2019), Mud Spiti (black from Sun et al., 2021; blue from Krystyn et al., 2007). Red
599 lines denote the first occurrence of *E. costatus*, purple lines denote the first occurrence
600 of *E. hamadai*.

601

602 Table 1. Correlation of the Lower Triassic conodont zones around the world.
603 Abbreviations: *B.* = *Borinalla*, *C.* = *Clarkina*, *D.* = *Discretalla*, *E.* = *Eurynathodus*,
604 *H.* = *Hindeodus*, *Ha.* = *Hadrodontina*, *I.* = *Isarcicella*, *Ic.* = *Icriospathodus*, *Nc.* =
605 *Neoclarkina*, *Ng.* = *Neogondolella*, *Ns.* = *Neospathodus*, *Nv.* = *Novispathodus*,
606 *Pu.* = *Paullella*, *Pl.* = *Platyvillosus*, *Sc.* = *Scythogondolella*, *Sw.* =
607 *Sweetospathodus*, *T.* = *Triassospathodus*.

608

609 Table 2. Comparison of conodont faunas in Palaeo-Tethys. The faunas from the SQP
610 strongly resemble those in the NYP, but shows less similarity with those from the
611 Nanpanjiang Basin at species level or Europe at both genus and species level.

612

613 Supplementary materials

614 1. Statistics and distribution of conodont species at the Yiwagou section.

615 2. Data of carbonate carbon isotope and oxygen values from the Yiwagou section.

616

617 **References**

- 618 Bao, Z.W., Wang, C.Y., Zeng, L.J., Sun, W.D., Yao, J.M., 2015, Slab break-off
619 model for the Triassic syn-collisional granites in the Qinling orogenic belt,
620 Central China: Zircon U-Pb age and Hf isotope constraints, *International*
621 *Geology Review*, <http://dx.doi.org/10.1080/00206814.2015.1017777>
- 622 Bender, H., 1970. Zur Gliederung der Mediterranen Trias II. Die
623 Conodontenchronologie der mediterranen Trias. *Annales Géologiques des*
624 *Pays Helléniques*. 19, 465–540.
- 625 Buryi, G.I., 1979, Lower Triassic Conodonts of Southern Primor' e: Moscow, Instituta
626 *Geologii i Geofiziki, Sibirskoe Otdelenie, Akadamie Nauk SSSR*, 142 p. [in
627 Russian]
- 628 Cao, C.Q., Love, G.D., Hays, L.E., Wang, W., Shen, S.Z., Summons, R.E., 2009.
629 Biogeochemical evidence for euxinic oceans and ecological disturbance
630 presaging the end-Permian mass extinction event. *Earth and Planetary Science*
631 *Letters*. 281, 188-201.
- 632 Chen, Y.L., Jiang, H.S., Lai, X.L., Yan, C.B., Richoz, S., Liu, X.D., Wang, L., 2015.
633 Early Triassic conodonts of Jiarong, Nanpanjiang Basin, southern Guizhou
634 Province, South China. *Journal of Asian Earth Sciences*. 105, 104-121.
- 635 Chen, Y.L., Kolar-Jurkovšek, T., Jurkovšek, B., Aljinović, D., Richoz, S., 2016. Early
636 Triassic conodonts and carbonate carbon isotope record of the Idrija–Žiri area,
637 Slovenia. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 444, 84-100.

638 Chen, Y.L., Richos, S., Krystyn, L., Zhang, Z.F., 2019. Quantitative stratigraphic
639 correlation of Tethyan conodonts across the Smithian-Spathian (Early Triassic)
640 extinction event. *Earth-Science Reviews*. 195, 37-51.

641 Chen, Y.L., Joachimski, M.M., Richoz, S., Krystyn, L., Aljinović, D., Smirčić, D.,
642 Kolar-Jurkovšek, T., Lai, X.L., Zhang Z.F., 2021. Smithian and Spathian (Early
643 Triassic) conodonts from Oman and Croatia and their depth habitat revealed.
644 *Global and Planetary Change*. 196, 103362.

645 Clarkson, M.O., Richoz, S., Wood, R.A., Maurer, F., Krystyn, L., McGurty, D.J.,
646 Astratti, D., 2013. A new high-resolution $\delta^{13}\text{C}$ record for the Early Triassic:
647 insights from the Arabian Platform. *Gondwana Res.* 24, 233–242.

648 Dagens, A.A., 1984. Early Triassic Conodonts from Northern Middle Siberia: *Trudy*
649 *Akademiia SSSR, Sibirskoe otdelenie Instituta Geologii I Geofiziki*. 554, 3–69.
650 [in Russian]

651 Duan, J.Y., 1987. Permian-Triassic conodonts from southern Jiangsu and adjacent
652 areas, with indexes of the color alteration. *Acta Micropalaeontologica Sinica*. 4,
653 351-368.

654 Duan, J.Y., 1989, Palaeoecological Environment And Palaeogeographical
655 Significance of *Pachycladina* (Conodonta), *Acta Micropalaeontologica Sinica*, 6,
656 91-95. [in Chinese]

657 Dzik, J., 1976, Remarks on the evolution of Ordovician conodonts: *Acta*
658 *Palaeontologica Polonica*, v. 21, p. 395–455.

659 Eichenberg, W., 1930, Conodonten aus dem Culm des Harzes: *Palaontologische*
660 *Zeitschrift*, v. 12, p. 177–182.

661 Feng, Z.Z., Bao Z.D., Li S.W., 1997, Potential of Oil and GAS of the Middle and
662 Lower Triassic of South China from the Viewpoint of Lithofacies
663 Paleogeography, Journal of the University of Petroleum, China, 21. [in Chinese]

664 Goudemand, N., Romano, C., Leu, M., Bucher, H., Trotter, J., Williams, I., 2018.
665 Dynamic interplay between climate and marine biodiversity upheavals during the
666 Early Triassic Smithian-Spathian biotic crisis. Earth Sci. Rev.
667 <https://doi.org/10.1016/j.earscirev.2019.01.013>.

668 Hatleberg, E.W., Clark, D.L., 1984. Lower Triassic conodonts and biofacies
669 interpretations: Nepal and Svalbard. *Geologica et Palaeontologica*, 18, 101-125.

670 Horacek, M., Richoz, S., Brandner, R., Krystyn, L., Spotl, C., 2007. Evidence for
671 recurrent changes in Lower Triassic oceanic circulation of the Tethys: the $\delta^{13}\text{C}$
672 record from marine sections in Iran. *Palaeogeography, Palaeoclimatology,*
673 *Palaeoecology*. 252, 355–369.

674 Jiang, H.S., Lai, X.L., Luo, G.M., Aldridge, R., Zhang, K.X., Wignall, P.B., 2007.
675 Restudy of conodont zonation and evolution across the P/T boundary at Meishan
676 Section, Changxing, Zhejiang, China. *Global and Planetary Change*. 55, 39–55.

677 Joachimski, M.M., Lai, X.L., Shen, S.Z., Jiang, H.S., Luo, G.M., Chen, B., Chen, J.,
678 Sun, Y.D., 2012, Climate warming in the latest Permian and the Permian–
679 Triassic mass extinction, *Geology*. 40, 195-198.

680 Klets, T.V., 1995, Triassic Biostratigraphy and Conodonts of the Middle Sikhote Alin
681 (NGU, Novosibirsk) [in Russian].

682 Klets, T.V., 2008, Paleogeographic regionalization of Triassic seas based on
683 conodontophorids, *Stratigraphy and Geological*, 16, 467-489.

684 Klets T.V., and Kopylova, A.V., 2006, New Triassic conodontophorids from
685 Northeastern Asia, in *News in Paleontology and Stratigraphy*, Issue 8 (GEO,
686 Novosibirsk). 95–105 [in Russian].

687 Klets, T.V., and Yadrenkin, A.V., 2001, Conodonts from the Lower Triassic of the
688 Kotel'nyi Island (Taxonomic Composition, Correlation): *News in Paleontology*
689 and *Stratigraphy*. 4, 14 - 21. [in Russian]

690 Kolar-Jurkovšek, T., Jurkovšek, B., Vuks, V.J., Hrvatović, H., Aljinović, D., Šarić, Č.,
691 Skopljak, F., 2014. The Lower Triassic platy limestone in the Jajce area (Bosnia
692 and Herzegovina). *Geologija*. 57, 105-118.

693 Kolar-Jurkovšek, T., Jurkovšek, B., 2015. Conodont zonation of Lower Triassic strata
694 in Slovenia. *Geologija*. 58, 155–174.

695 Kolar-Jurkovšek, T., Chen, Y.L., Jurkovšek, B., Poljak, M., Aljinović, D., Richoz, S.,
696 2017. Conodont biostratigraphy of the Early Triassic in eastern Slovenia.
697 *Paleontological Journal*. 51, 687-703.

698 Kolar-Jurkovšek, T., Hrvatović, H., Aljinović, D., Nestell, G.P., Jurkovšek, B.,
699 Skopljak, F., 2021 Permian-Triassic biofacies of the Teočak section, Bosnia and
700 Herzegovina. *Global and Planetary Change*. 200, 103458.
701 [10.1016/j.gloplacha.2021.103458](https://doi.org/10.1016/j.gloplacha.2021.103458).

702 Koike, T., 1988. Lower Triassic conodonts *Platyvillosus* from the Tahoe Limestone in
703 Japan, Sci. Repts. Yokohama Natl. Univ. Sec. II, 61-79.

704 Konstantinov, A.G., Sobolev, E.S., and Yadrenkin, A.V., 2013. Triassic stratigraphy
705 of the Eastern Laptev Sea coast and New Siberian Islands: Russian Geology and
706 Geophysics. 54, 792–807.

707 Korte, C., Kozur, H.W., 2010. Carbon-isotope stratigraphy across the Permian–
708 Triassic boundary: a review. Journal of Asian Earth Sciences. 39, 215–235.

709 Kozur, H., 1989. Significance of events in conodont evolution for the Permian and
710 Triassic stratigraphy. Courier Forsch. -Inst. Senckenberg. 117, 385-408.

711 Kozur, H.W., 1998. Problems for evaluation of the scenario of the Permian–Triassic
712 boundary biotic crisis and of its causes. Geologia Croatica. 51, 135–162.

713 Kozur, H.W., 2003. Integrated ammonoid, conodont and radiolarian zonation of the
714 Triassic and some remarks to Stage/Substage subdivision and the numeric age of
715 the Triassic stages. Albertiana. 28, 57-74.

716 Kozur, H., Mostler, H., 1970. Neue Conodonten Aus Der Trias, Ber. Nat.-Med. Ver.
717 Innsbruck. 58, 429-464.

718 Kozur, H., Pjatakova, M., 1976. Die Conodontenart *Anchignathodus parvus* n. sp.,
719 eine Wichtige Leitform der Basalen Trias. Koninklijke Nederlandse Akademie
720 van Wetenschappen Proceeding (Series B). 79, 123-128.

721 Kozur H.W., Mostler H., Krainer K., 1998. *Sweetospathodus* n. gen. and
722 *Triassospathodus* n. gen. two important Lower Triassic conodont genera.
723 Geologia Croatica. 51, 1-5.

- 724 Krystyn, L., Balini, M., Nicora, A., 2004. Lower and Middle Triassic stage and
725 substage boundaries in Spiti. *Albertiana*. 30 Suppl., 39-52.
- 726 Krystyn, L., Bhargava, O.N., Bhatt, D.K., 2005. Muth (Spiti, Indian Himalaya) – A
727 Candidate Global Stratigraphic Section and Point (GSSP) for the base of the
728 Olenekian Stage. *Albertiana*. 33, 51-53.
- 729 Krystyn, L., Richoz, S., Bhargava, O.N., 2007. The Induan-Olenekian Boundary (IOB)
730 in Mud - an update of the candidate GSSP section M04. *Albertiana*. 36, 33-42.
- 731 Kuz'min S.P., and Klets, T.V., 1990, The Biostratigraphy of Lower Triassic Deposits
732 in the Shevlya River Basin, in Proceedings of the IV Far East RMSS (GKP PGO
733 "Dal'geologiya", Khabarovsk). 146–147 [in Russian].
- 734 Lai, X.L., 1992. Conodont, in Yin, H.F., Yang, F.Q., Huang, Q.S., Yang, H.S., and
735 Lai, X.L., eds., *Triassic in Qinling and Adjacent Areas*: China University of
736 Geosciences Press, Wuhan. 66–68. [in Chinese]
- 737 Lai, X.L., Yin, H.F., 1992. Early Triassic paleogeography, in Yin, H.F., Yang, F.Q.,
738 Huang, Q.S., Yang, H.S., and Lai, X.L., eds., *Triassic in Qinling and Adjacent*
739 *Areas*: China University of Geosciences Press, Wuhan. 66–68. [in Chinese]
- 740 Lai, X.L., Yin, H.F., Yang, F.Q., 1992. The character and evolution of ecostratigraphy
741 and paleobiogeography of Triassic Qinling Basin. *Earth Science*. 17, 345–352.
742 [in Chinese with English abstract]
- 743 Lai, X.L., Yang, F.Q., Yin, H.F., 1994. Research of Permian-Triassic boundary strata,
744 in west Qinling Area. *Geoscience*. 8, 20–26. [in Chinese with English abstract]

745 Lai, X.L., Yin, H.F., Yang, F.Q., 1995. Reconstruction of the Qinling Triassic
746 Paleo-ocean. *Earth Science*. 20, 648–656. [in Chinese with English abstract]

747 Lai, X.L., Wignall, P.B., Zhang, K.X., 2001. Palaeoecology of the conodonts
748 *Hindeodus* and *Clarkina* during the Permian–Triassic transitional period.
749 *Palaeogeography, Palaeoclimatology, Palaeoecology*. 171, 63–72.

750 Lehrmann, D.J., Stepchinski, L., Altiner, D., Orchard, M.J., Montgomery, P., Enos, P.,
751 Ellwood, B.B., Bowring, S.A., Ramezani, J., Wang, H.M., Wei, J.Y., Yu, M.Y.,
752 Griffiths, J.D., Minzoni M., Schaal, E.K., Li, X.W., Meyer, K.M., Payne, J.L.,
753 2015. An integrated biostratigraphy (conodonts and foraminifers) and
754 chronostratigraphy (paleomagnetic reversals, magnetic susceptibility, elemental
755 chemistry, carbon isotopes and geochronology) for the Permian–Upper Triassic
756 strata of Guandao section, Nanpanjiang Basin, south China. *Journal of Asian
757 Earth Sciences*. 108, 117-135.

758 Li, H.X., Jiang, H.S., Chen, Y.L., Wignall, P.B., Wu, B.J., Zhang, Z.T., Zhang, M.H.,
759 Ouyang, Z.M., Lai, X.L., 2019. Smithian platform-bearing gondolellid
760 conodonts from Yiwagou Section, northwestern China and implications for their
761 geographic distribution in the Early Triassic. *Journal of Paleontology*. 93,
762 496-511.

763 Li, H.X., Wang, M.Y., Zhang, M.H., Wignall, P.B., Rigo, M., Chen, Y.L., Wu, X.L.,
764 Ouyang, Z.M., Wu, B.J., Yi, Z.Y., Zhang, Z.T., Lai, X.L., 2021. First records of
765 Late Triassic conodont fauna and $\delta^{13}\text{C}_{\text{carb}}$ from the Dengdengqiao Section,

766 Dangchang County, Gansu Province, northwestern China. *Journal of Earth*
767 *Science*. 32, 646-656.

768 Liang, D., Tong, J.N., Zhao, L.S., 2011. Lower Triassic Smithian-Spathian boundary
769 at West Pingdingshan Section in Chaohu, Anhui Province. *Sci China Earth Sci.*
770 41, 149-157.

771 Liang, L., Tong, J.N., Song, H.J., Song, T., Tian, L., Song, H.Y., Qiu, H.O., 2016.
772 Lower-Middle Triassic conodont biostratigraphy of the Mingtang section,
773 Nanpanjiang Basin, South China, *Palaeogeography, Palaeoclimatology,*
774 *Palaeoecology*. 459, 381-393.

775 Lindström, M., 1970, A suprageneric taxonomy of the conodonts: *Lethaia*, v. 3, p.
776 427–445.

777 Liu, S., Sun, Z.Y., Ji, C., Zhou, M., Jiang, D.Y., 2020. Conodont Biostratigraphy and
778 Age of the Early Triassic Fish-Bearing-Nodule Levels from Nanjing and Jurong,
779 Jiangsu Province, South China. *Journal of Earth Science*. 31, 9-22.

780 Lucas, S.G., Orchard, M.J. 2007. Triassic lithostratigraphy and biostratigraphy north
781 of Currie, Elko County, Nevada. In: Lucas, S.G. & Spielmann, J.A. (eds.): *The*
782 *Global Triassic*. New Mexico Museum of Natural History and Science Bulletin.
783 40, 119–126.

784 Lyu, Z.Y., Orchard, M.J., Chen, Z.Q., Zhao, L.S., Zhang, L., Zhang, X.M., 2018. A
785 Taxonomic re-Assessment of the *Novispathodus waageni* Group and its role in
786 defining the base of the Olenekian (Lower Triassic). *Journal of Earth Science*. 29,
787 824–836.

788 Lyu, Z.Y., Zhang, L., Algeo, T.J., Zhao, L.S., Chen, Z.Q., Li, C., Ma, B., Ye, F.H.,
789 2019. Global-ocean circulation changes during the Smithian–Spathian transition
790 inferred from carbon-sulfur cycle records, *Earth-Science Reviews*, 195, 114-132.

791 Lyu, Z.Y., Orchard, M.J., Chen, Z.Q., Henderson, C.M., Zhao, L.S., 2020. A
792 proposed ontogenesis and evolutionary lineage of conodont *Eurygnathodus*
793 *costatus* and its role in defining the base of the Olenekian (Lower Triassic).
794 *Palaeogeography, Palaeoclimatology, Palaeoecology*. 559.

795 Maekawa, T., Komatsu, T., Shigeta, Y., Takashima, R., Yamaguchi, T., 2021. Carbon
796 isotope chemostratigraphy and conodont biostratigraphy around the Smithian–
797 Spathian boundary in the Panthalassan carbonate succession (SW Japan). *Journal*
798 *of Asian Earth Sciences*. 205, 104570.

799 Metcalfe, I., Nicoll, R.S., Willink, R., Ladjavadi, M., Grice, K., 2013. Early Triassic
800 (Induan – Olenekian) conodont biostratigraphy, global anoxia, carbon isotope
801 excursions and environmental perturbations: new data from Western Australian
802 Gondwana. *Gondwana Res.* 23, 1136 – 1150.

803 Nakrem, H.A., Orchard M.J., Weitschat W., Hounslow M.W., Beatty T.W., Mørk A.,
804 2008. Triassic conodonts from Svalbard and their Boreal correlations. *Polar*
805 *Research*. 27, 523-539.

806 Orchard, M.J., 1995. Taxonomy and Correlation of Lower Triassic (Spathian)
807 segminate conodonts from Oman and revision of some species of
808 *Neospathodus*. *Journal of Paleontology*, 69, 110-122.

809 Orchard, M.J., 2005. Multielement conodont apparatuses of Triassic Gondolelloidea.
810 *Papers in Palaeontology*. 73, 73-101.

811 Orchard, M.J., 2007. Conodont diversity and evolution through the latest Permian and
812 Early Triassic upheavals. *Palaeogeography, Palaeoclimatology, Palaeoecology*.
813 252, 93–117.

814 Orchard, M.J., 2008. Lower Triassic conodonts from the Canadian Arctic, their
815 intercalibration with ammonoid-based stages and a comparison with other North
816 American Olenekian faunas. *Polar Research*. 27, 393-412.

817 Orchard, M.J., Bucher, H., 1992. Conodont-ammonoid intercalibration around the
818 Lower-Middle Triassic boundary: Nevadan clocks help tell British Columbian
819 time; in *Current Research, Part E*. Geological Survey of Canada. Paper 92-1E,
820 133-140.

821 Orchard, M.J., Krystyn, L., 1998. Conodonts of the Lowermost Triassic of Spiti, and
822 new zonation based on *Neogondolella* successions. *Rivista Italiana di*
823 *Paleontologia e Stratigrafia*. 104, 341-368.

824 Orchard, M.J., Krystyn, L., 2007. Conodonts from the Induan-Olenekian boundary
825 interval at Mud, Spiti. *Albertiana*. 35, 30-34.

826 Orchard, M.J., Tozer, E.T., 1997. Triassic conodont biochronology, its calibration with
827 the ammonoid standard, and a biostratigraphic summary for the western Canada
828 Sedimentary Basin. *Bulletin of Canadian Petroleum Geology*. 45, 675-692.

829 Orchard, M.J., Zonneveld, J.P., 2009. The Lower Triassic Sulphur Mountain
830 Formation in the Wapiti Lake area: lithostratigraphy, conodont biostratigraphy,
831 and a new biozonation for the lower Olenekian (Smithian). *Can. J. Earth Sci.* 46,
832 757-790.

833 Payne, J.L., Lehrmann, D.J., Wei, J.Y., Orchard, M.J., Schrag, D.P., Knoll, A.H.,
834 2004. Large Perturbations of the Carbon Cycle During Recovery from the
835 End-Permian Extinction, *Science*. 305, DOI: 10.1126/science.1097023

836 Richoz, S., 2006. Stratigraphic et variations isotopiques du carbone dans le Permien
837 supérieur et le Trias inférieur de quelques localités de la Néo-Téthys (Turquie,
838 Oman et Iran). *Mémoires de Géologie (Lausanne)*, 46, 275.

839 Song, H.Y., Tong, J.N., Algeo, T.J, Horacek, M., Qiu, H.O., Song, H.J., Tian, L.,
840 Chen, Z.Q., 2013. Large vertical $\delta^{13}\text{C}_{\text{DIC}}$ gradients in Early Triassic seas of the
841 South China craton: implications for oceanographic changes related to Siberian
842 Traps volcanism. *Global and Planetary Change*, 105, 7-20.

843 Song, H.Y., Du, Y., Algeo, T.J., Tong, J.N., Owens, J.D., Song, H.J., Tian, L., Qiu,
844 H.O., Zhu, Y.Y., Lyons, T.W., 2019. Cooling-driven oceanic anoxia across the
845 Smithian/Spathian boundary (mid-early Triassic). *Earth-Science Reviews*, 195,
846 133-146.

847 Sun, Y.D., Joachimski, M.M., Wignall, P.B., Yan, C.B., Chen, Y. L., Jiang, H.S.,
848 Wang, L.N., Lai, X.L., 2012. Lethally hot temperatures during the Early Triassic
849 greenhouse. *Science*, 338, 366–370.

850 Sun, Y.D., Richoz, S., Krystyn, L., Grasby, S.E., Chen, Y.L., Banerjee, D.,
851 Joachimski, M.M., 2021. Integrated bio-chemostratigraphy of Lower and Middle
852 Triassic marine successions at Spiti in the Indian Himalaya: Implications for the
853 Early Triassic nutrient crisis. *Global and Planetary Change*, 196.

854 Sun, Z.Y., Liu, S., Ji, C., Jiang, D.Y., Zhou, M., 2020. Gondolelloid multielement
855 conodont apparatus (*Scythogondolella*) from the Lower Triassic of Jiangsu,
856 East China, revealed by high-resolution X-ray microtomography. *Palaeoworld*,
857 30, 286-295.

858 Sweet, W.C., 1970. Uppermost Permian and Lower Triassic Conodonts of the Salt
859 Range and Trans-Indus Ranges, West Pakistan, in *Stratigraphic Boundary*
860 *Problems: Permian and Triassic of West Pakistan*. Kummel, B. and Teichert, C.
861 eds. 207-275.

862 Tian, C.R., Dai, J., Tian, S.G., 1983. Chengdu Institute of Geology and Mineral
863 Resources, Triassic conodonts. *Paleontological atlas of Southwest China*, volume
864 of microfossils. Geological Publishing House, Beijing, pp. 345–398 (pl.79–100).

865 Tong, J.N., Zhao, L.S., 2011. Lower Triassic and Induan-Olenekian Boundary in
866 Chaohu, Anhui Province, South China. *Acta Geol. Sin.* 85, 399–407.

867 Tong, J.N., Zakharov, Y.D., Orchard, M.J., Yin, H.F., Hansen, H.J., 2003. A
868 candidate of the Induan–Olenekian Boundary stratotype in the Tethyan region.
869 *Sci. China D* 46, 1182–1200.

870 Tong, J.N., Zuo, J.X., Chen, Z.Q., 2007. Early Triassic carbon isotope excursions
871 from South China: Proxies for devastation and restoration of marine ecosystems
872 following the end-Permian mass extinction. *Geological Journal.* 42, 371-389.

873 Wang, Z.H., Cao, Y.Y., 1981. Early Triassic conodonts from Lichuan, Western Hubei.
874 *Acta Palaeontologica Sinica.* 20, 363-375, pls. 1-3. [In Chinese with English
875 abstract]

876 Wang, C.Y., 1995. Conodonts of Permian – Triassic boundary beds and stratigraphic
877 boundary. *Acta Palaeontol. Sin.* 34, 129 – 151 [in Chinese with English Abstract]

878 Wignall, P.B., 2015. *The Worst of Times: How Life on Earth Survived Eighty Million*
879 *Years of Extinctions*: Princeton, NJ, Princeton University Press. 199 p.

880 Wu, B.J., Li, H.X., Joachimski, M.M., Wignall, P.B., Jiang, H.S., Yan, J.X., Wang,
881 L.N., Wu, X.L., Lai, X.L., 2021. Roadian-Wordian (Middle Permian) Conodont
882 Biostratigraphy, Sedimentary Facies and Paleotemperature Evolution at the
883 Shuixiakou Section, Xikou Area, Southeastern Qinling Region, China, *Journal of*
884 *Earth Science*, 32, 534-553.

885 Wu, G.C, Ji Z.S, Kolar-Jurkovšek, T., Yao, J.X., Lash, G.G., 2021. Early Triassic
886 *Pachycladina* fauna newly found in the southern Lhasa Terrane of Tibet and its
887 palaeogeographic implications, 2021. *Palaeogeography Palaeoclimatology*
888 *Palaeoecology*, 562.

889 Yan, C.B., Jiang, H.S., Lai, X.L., Sun, Y.D., Yang, B., Wang, L.N., 2015. The
890 Relationship between the “Green-Bean Rock” Layers and Conodont *Chiosella*
891 *timorensis* and Implications on Defining the Early–Middle Triassic Boundary in
892 the Nanpanjiang Basin, South China. *Journal of Earth Science*. 26, 236-245.

893 Yang, B., Yuan, D.X., Henderson, C.M., Shen, S.Z., 2014. *Parafurnishius*, an
894 Induan (Lower Triassic) conodont new genus from northeastern Sichuan
895 Province, southwest China and its evolutionary implications. *Palaeoworld*. 23,
896 263-275.

897 Yang, B., Li, H.X., Wignall, P.B., Jiang, H.S., Niu, Z.J., Ye, Q., Wu, Q., Lai, X.L.,
898 2019. Latest Wuchiapingian to Earliest Triassic Conodont Zones and $\delta^{13}\text{C}_{\text{carb}}$
899 Isotope Excursions from Deep-Water Sections in Western Hubei Province, South
900 China. *Journal of Earth Science*, 30, 1059-1074.

901 Yang, Z.H., Guo, J.H., Su, S.R., Li, Y., Sun, C.Q., Zhang, C.L., Hei, A.Z., Liang, Y.,
902 2002. New advances in the geological study of the Qinling orogen. *Geology in*
903 *China*, 29, 246-256.

904 Yin, H.F., Yang, F.Q., Zhang, K.X., Yang, W.P., 1988. A proposal to the
905 biostratigraphy criterion of Permian/Triassic boundary. *Memorie della Societa*
906 *Geologica Italiana*. 34, 329–344.

907 Yuan, D.X., Shen, S.Z., Henderson, C.M., Chen, J., Zhang, H., Feng, H.Z., 2014.
908 Revised conodont-based integrated high-resolution timescale for the
909 Changhsingian Stage and end-Permian extinction interval at the Meishan
910 sections, South China. *Lithos*, 204, 220-245.

911 Zhang, K.X., Tong, J.N., Shi, G.R., Lai, X.L., Yu, J.X., He, W.H., Peng, Y.Q., Jin,
912 Y.L., 2007, Early Triassic conodont–palynological biostratigraphy of the
913 Meishan D Section in Changxing, Zhejiang Province, South China,
914 *Palaeogeography, Palaeoclimatology, Palaeoecology*. 2007, 4-23.

915 Zhang, L.Z., Orchard, M.J., Brayard, A., Algeo, T.J., Zhao, L.S., Chen, Z.Q., Lyu,
916 Z.Y., 2019a, The Smithian/Spathian boundary (late Early Triassic): A review of
917 T ammonoid, conodont, and carbon-isotopic criteria, *Earth-Science Reviews*.
918 195, 7-36.

919 Zhang, L., Orchard, M.J., Algeo, T.J., Chen, Z.Q., Lyu, Z.Y., Zhao, L.S., Kaiho, K.,
920 Ma, B.A., Liu, S.J., 2019b. An intercalibrated Triassic conodont succession and
921 carbonate carbon isotope profile, Kamura, Japan. *Palaeogeography,*
922 *Palaeoclimatology, Palaeoecology*, 519, 65-83.

923 Zhao, L., Orchard, M. J., Tong, J., Sun, Z., Zuo, J., Zhang, S., Yun, A., 2007. Lower
924 Triassic conodont sequence in Chaohu, Anhui Province, China and its global
925 correlation. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 252, 24-38.

926 Zhao, L.S., Tong, J.N., Sun, Z.M., Orchard, M.J., 2008a. A detailed Lower Triassic
927 conodont biostratigraphy and its implications for the GSSP candidate of the
928 Induan–Olenekian boundary in Chaohu, Anhui Province. *Progress in Natural*
929 *Science*. 18, 79-90.

930 Zhao, L.S., Tong, J.N., Zhang, S.X., Sun, Z.M., 2008b. An Update of Conodonts in
931 the Induan-Olenekian Boundary Strata at West Pingdingshan Section, Chaohu,
932 Anhui Province. *Journal of China University of Geosciences*. 19, 207-216.

933 Zhao, L.S., Chen, Y.L., Chen, Z.Q., Cao, L., 2013. Uppermost Permian to Lower
934 Triassic conodont zonation from Three Gorges Area, South China. *Palaios*. 28,
935 523-540.

936 Zheng, B.S., Mou, C.L., Wang, X.P., Chen, H.D., 2021, U-Pb ages, trace elements
937 and Hf isotopes of detrital zircons from the late Permian-early Triassic
938 sedimentary succession in the northern Yangtze Block, South China:
939 Implications for the reconstruction of the South China Block in Pangea, *Journal*
940 *of Asian Earth Sciences*, 206. 104609.

