



Deposited via The University of Leeds.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/id/eprint/108745/>

Version: Accepted Version

Article:

Sun, YD, Liu, XT, Yan, JX et al. (2017) Permian (Artinskian to Wuchapingian) conodont biostratigraphy in the Tieqiao section, Laibin area, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 465 (A). pp. 42-63. ISSN: 0031-0182

<https://doi.org/10.1016/j.palaeo.2016.10.013>

© 2016, Elsevier. Licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International <http://creativecommons.org/licenses/by-nc-nd/4.0/>

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

1 Early-Middle Permian conodont biostratigraphy in the Tieqiao
2 section, Laibin area, South China

3 Y.D. Sun^{1, 2*}, X.T. Liu³, J.X. Yan¹, B. Li⁴, B. Chen⁵, D.P.G. Bond⁶, M.M. Joachimski², P.B.

4 Wignall⁷, X.L. Lai^{1*}

5 *1. Key Laboratory of Geobiology and Environmental Geology, China University of*
6 *Geosciences, Wuhan 430074, P. R. China*

7 *2. GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Schlossgarten 5, 91054*
8 *Erlangen, Germany*

9 *3. Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese*
10 *Academy of Sciences, Qingdao 266071, China*

11 *4. Key Laboratory of Marine Mineral Resources, Guangzhou Marine Geological Survey,*
12 *Ministry of Land and Resources, Guangzhou 510075, China*

13 *5. State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology*
14 *and Palaeontology, 39 East Beijing Road, Nanjing 210008, R.P. China*

15 *6. Department of Geography, Environment and Earth Sciences, University of Hull, Hull HU6*
16 *7RX, UK*

17 *7. School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK*

18 *** Corresponding author:** E-mail: yadong.sun@cug.edu.cn (Y.D. Sun); xllai@cug.edu.cn (X.L.
19 Lai)

21 Abstract

22 Permian strata from the Tieqiao section (Jiangnan Basin, South China)
23 contain several distinctive conodont assemblages. Early Permian (Cisuralian)
24 assemblages are dominated by the genera *Sweetognathus*, *Pseudosweetognathus*
25 and *Hindeodus* with rare *Neostreptognathodus* and *Gullodus*. Gondolellids are
26 absent until the end of the Kungurian stage—in contrast to many parts of the
27 world where gondolellids and *Neostreptognathodus* are the dominant Kungurian
28 conodonts. A conodont changeover is seen at Tieqiao and coincided with a rise of
29 sea level in the latest Kungurian: the previously dominant sweetognathids were
30 replaced by mesogondolellids. The Middle and Late Permian (Guadalupian and
31 Lopingian Series) witnessed a dominance of gondolellids (*Jinogondolella* and
32 *Clarkina*), the common presence of *Hindeodus* and decimation of *Sweetognathus*.

33 Twenty one main and six subordinate conodont zones are recognized at
34 Tieqiao, spanning the lower Artinskian to lowermost Wuchiapingian Stage. The
35 main (first occurrence) zones are, in ascending order by stage: the
36 *Sweetognathus* (*Sw.*) *whitei*, *Neostreptognathodus* (*N.*) *pequopensis*-*Sw. toriyamai*,
37 and *Sw. asymmetrica* n. sp. Zones for the Artinskian; the *N. prayi*, *Sw. guizhouensis*,
38 *Sw. iranicus*, *Sw. adjunctus*, *Sw. subsymmetricus*, *Sw. hanzhongensis*, *Mesogondolella*
39 (*M.*) *idahoensis* and *M. lamberti* Zones for the Kungurian; the *Jinogondolella* (*J.*)
40 *nankingensis* Zone for the Roadian; the *J. aserrata* Zone for the Wordian; the *J.*
41 *postserrata*, *J. shannoni*, *J. altudaensis*, *J. prexuanhanensis*, *J. xuanhanensis*, *J. granti*
42 and *Clarkina* (*C.*) *hongshuiensis* Zones for the Capitanian and the *C. postbitteri*

43 Zone for the base of the Wuchiapingian. The subordinate (interval) zones are the
44 *Pseudosweetognathus costatus*, *Pseudosweetognathus monocornus*, *Hindeodus (H.)*
45 *gulloides*, *Pseudohindeodus ramovsi*, *Gullodus sicilianus*, *Gullodus duani* and *H.*
46 *excavates* Zones.

47 In addition, three new species, *Gullodus tieqiaoensis* n. sp., *Pseudohindeodus*
48 *ellipticae* n. sp. and *Sweetognathus asymmetrica* n. sp. are described. Age
49 assignments for less common species e.g., *Pseudosweetognathus monocornus* are
50 reassessed based on a rich conodont collection.

51 Key words: conodont, Permian, biostratigraphy, Cisuralian, Guadalupian,
52 Kungurian, South China

53

54 **1. Introduction**

55 Conodonts are important index fossils in the Palaeozoic and Triassic, due to
56 their high speciation rates, geographically widespread distribution and in part
57 high abundance in marine sediments. Conodont biostratigraphy provides the
58 best method for high-resolution, supra-regional correlations of Permian strata,
59 because other key taxa such as ammonoids are often scarce in many locations,
60 whilst foraminifers and brachiopods are generally long ranging and facies
61 controlled and thus less useful for age diagnosis. As a consequence, Permian
62 conodont taxonomy and biostratigraphy have been the topics of extensive study
63 since the 1950s (e.g., Youngquist et al., 1951; Clark and Behnken, 1971; Ritter,
64 1986; Wardlaw and Grant, 1990; Mei et al., 1994a; Wardlaw, 2000; Nestell et al.,
65 2006; Lambert et al., 2010; Shen et al., 2012). The importance of conodonts in
66 stratigraphy is exemplified by their use at Global Boundary Stratotype Section
67 and Points: as of 2016, conodonts define the bases of all but one of the 29
68 stages between the Pragian (Lower Devonian) and Rhaetian (Upper Triassic), 17
69 of which have been ratified by the International Commission on Stratigraphy.

70 The diversity of Permian conodonts is generally low in comparison to that
71 observed for other time periods, with typically less than five genera and two
72 dozens of species occurring in any given Permian stage. Conodont zones are also
73 relatively long for some intervals. For instance, though substantial investigations
74 have been carried out in West Texas (e.g., Wardlaw, 2000; Nestell et al., 2006;
75 Nestell and Wardlaw, 2010a; Wardlaw and Nestell, 2010), only one standard

76 conodont zone has been established for the Roadian and Wordian stages
77 (Henderson et al., 2012). This reflects a true low point in the diversity of
78 conodonts during their long evolutionary history. A further complication is that
79 minor changes in Permian conodont morphology require a careful taxonomic
80 examination of different species. New species are rarely reported from regions
81 other than West Texas and South China, perhaps owing to a decrease in research
82 effort and a substantial loss of expertise in recent years.

83 Establishing a robust biostratigraphic scheme in different areas is essential
84 for supra-regional correlation. Permian conodonts have been best studied in the
85 Urals of Russia (Early Permian), West Texas (Middle Permian) and South China
86 (Late Permian and the Permo-Triassic boundary) (e.g., Chuvashov et al., 1990;
87 Mei et al., 1994b; Zhang et al., 1995; Wardlaw, 2000; Lambert et al., 2002; Jiang et
88 al., 2007; Nestell and Wardlaw, 2010b). The Early to Middle Permian of South
89 China has attracted comparatively little research attention and is less
90 systematically studied.

91 This study presents a high-resolution conodont record for the Tieqiao
92 section, Guangxi, South China. New data, spanning the Artinskian (Early Permian)
93 to the early Wuchiapingian (Late Permian), substantially improve existing
94 records of the section, first described two decades ago in the context of the
95 Capitanian-Wuchiapingian (Guadalupian-Lopingian) transition (Mei et al., 1994c;
96 Wang, 2002).

97 **2. Geological Setting**

98 The Yangtze region was a large isolated platform situated within the Permian
99 equatorial Tethys (Fig. 1) with extensive carbonate deposition and diverse
100 sedimentary facies. It is an ideal location for conodont studies. The Laibin area is
101 located in the Jiangnan Basin towards the southwestern margin of the Yangtze
102 Platform (Wang and Jin, 2000). A series of superb sections are exposed along the
103 banks of Hongshui River (Shen et al., 2007) and these have been
104 comprehensively studied for the Capitanian-Wuchiapingian transition (e.g., Mei
105 et al., 1994c; Wang et al., 2004; Jin et al., 2006; Wignall et al., 2009b; Chen et al.,
106 2011).

107 The Permian strata of the region consist of thick Early Permian platform
108 carbonates, subordinate Middle Permian slope as well as basinal carbonates and
109 cherts. Late Permian rocks are geographically more variable, including coal
110 seams, reef build-ups and radiolarian cherts (Sha et al., 1990; Shen et al., 2007;
111 Qiu et al., 2013).

112 The studied section at Tieqiao (23° 42.733' N, 109° 13.533' E) is exposed on
113 the northern bank of the Hongshui River, southeast of the town of Laibin (Figs. 1,
114 2). The Permian strata measure 1307 m thick and comprise the Mapping, Chihsia,
115 Maokou, Heshan, Wuchiaping and Talung Formations, spanning the earliest
116 Permian (Asselian) to the Permian-Triassic boundary (Sha et al., 1990). The
117 section is very fossiliferous with foraminifers, calcareous algae, crinoids, sponges

118 and corals being prolifically abundant (e.g., Wang and Sugiyama, 2000; Bucur et
119 al., 2009; Zhang et al., 2015), whilst bivalves and ammonoids occur less
120 frequently. Well-preserved *Zoophycos* trace fossils are also abundant (Gong et al.,
121 2010).

122 Sha and colleagues (1990) pioneered the study of the Tieqiao section and
123 subdivided the section into 15 Members and 139 Beds. Our study follows these
124 subdivisions (Figs. 3-5) for consistency and focuses on the stratigraphy and
125 conodont zonation of the Chihsia and Maokou formations (Bed 1 to Bed 109).
126 The Chihsa Fm. generally records deposition in a carbonate ramp setting, whilst
127 the Maokou Fm. comprises slope to basin transition facies. The two formations
128 are overall 710 m thick and range from the Sakmarian (?) to the
129 Capitanian-Wuchiapingian boundary (Figs. 3-5).

130 **3. Materials and Methods**

131 The section was sampled over four field campaigns between 2005-2010.
132 During the spring of 2010, the water of the Hongshuihe River fell to its lowest
133 level of the past ten years due to a severe drought, which allowed us to describe
134 and sample several normally submerged parts of the section (e.g., Bed 17 and
135 Bed 112). A total of 374 rock samples were collected with a sampling resolution
136 of ~1-2 m for most parts of the section. Cherts and grainstones bearing abundant
137 corals and fusulinid foraminifers were avoided during sampling due to
138 complications in conodont extraction and low conodont yields. Each sample

139 weighed between 2.5 and 8 kg.

140 Three hundred and eleven samples were processed in the micropaleontology
141 laboratory at China University of Geosciences (Wuhan) and 63 samples were
142 processed at the GeoZentrum Nordbayern, Universität Erlangen-Nürnberg. All
143 samples were dissolved using 7-10% diluted acetic acid, wet sieved and air-dried.
144 The insoluble residues were separated by using heavy liquid fractionation (Jiang
145 et al., 2007). Conodont specimens were hand picked using a binocular. Conodonts
146 from Tieqiao are generally well preserved with colour alternation index ranging
147 from 1.5 to 2.5. A total of 8 733 specimens were obtained from sample process at
148 Wuhan lab and about ~3 000 specimens was recovered at Erlangen. Results from
149 both laboratories were cross checked.

150 **4. Stratigraphy and Conodont Zonation**

151 4.1 Sakmarian (?)

152 The lowermost part of the studied section (Beds 1 to 16, Chihhsia Fm.)
153 consists mainly of thin-to-medium bedded dark-grey bioclastic micrites, marls
154 and black shales (Fig. 2). Brachiopods, gastropods, crinoids, bryozoans and
155 sponges are the most abundant fossils. Age assignment for this part of the section
156 is controversial. Sha et al. (1990) suggested an Asselian age for the underlying
157 Maping Fm. and reported the occurrence of the fusulinacean *Eoparafusulina* sp.,
158 *Nankinella* sp., *Pamirina* sp., *Staffella* sp. and *Pseudofusulina* sp. from Bed 1 to Bed
159 16, implying a possible Sakmarian age for the unit. Mei et al. (1998) inferred this

160 unit to be of “Longlinian” age—a Chinese equivalent of the Artinskian by original
161 definition (Sheng and Jin, 1994; Jin et al., 1997), now re-defined as Sakmarian
162 (Fig. 24.1 in Henderson et al., 2012). Based on consideration of all published
163 fossil materials, Shen et al. (2007) tentatively assign this part of the section to the
164 Artinskian.

165 Few conodonts were recovered from this part of the section, despite great
166 efforts. Many ramiform elements were recovered from Bed 8, but none is
167 age-diagnostic. The precise age of this unit therefore remains unresolved.

168 4.2 Artinskian

169 Beds 17 to 26 consist mainly of dark-grey to grey bioclastic pack- and
170 grainstones. The conodont assemblage is dominated by *Sweetognathus whitei*
171 and affinitive species and thus indicates an Artinskian age. *Neostreptognathodus*
172 and *Hindeodus* are rare whilst gondolellids are absent. The base of the Artinskian
173 stage cannot be precisely defined because the first appearance datum (FAD) of
174 *Sweetognathus whitei* cannot be ascertained due to the inaccessibility of the
175 submerged lower part of Bed 17 and the absence of diagnostic conodonts from
176 beds below this level. In ascending order, three conodont zones were established
177 for the Artinskian.

178 1). *Sweetognathus whitei* Zone

179 The lower limit of this zone is not defined. The upper limit is defined by the
180 FAD of *Sweetognathus* (Sw.) *toriyamai* and *Neostreptognathodus ex gr.*

181 *pequopensis*.

182 *Sw. whitei* was one of the most cosmopolitan conodonts during the Early
183 Permian (Mei et al., 2002). It is known e.g. from North and South China, Japan,
184 U.S.A., Canada and Colombia. (Rhodes, 1963; Igo, 1981; Orchard, 1984; Ritter,
185 1986; Ding and Wan, 1990; Ji et al., 2004) and is considered a good marker for
186 the base of Artinskian.

187 2). *Neostreptognathodus ex gr. pequopensis* - *Sweetognathus toriyamai* Zone

188 Lower limit: FAD of *Sw. toriyamai* and *Neostreptognathodus (N.) ex gr.*
189 *pequopensis* with both taxa first occurring at the same level. Upper limit: FAD of
190 *Sw. asymmetrica* n. sp. The FAD of *Sw. bogoslovskajae* occurs in this zone. *Sw.*
191 *bogoslovskajae* is known to co-exist with *N. pequopensis* in Nevada and has a
192 range restricted to the upper “Baigendzhinian” (equivalent to uppermost
193 Artinskian to lower Kungurian) (Ritter, 1986). Wang (2002) reported the
194 occurrence of *Sw. variabilis* in this zone (in Bed 18 of Tieqiao). We have found
195 morphotypes which are similar to *Sw. variabilis* but the specimens are not
196 sufficiently well-preserved to make an identification.

197 3). *Sw. asymmetrica* n. sp. Zone

198 Lower limit: FAD of *Sw. asymmetrica* n. sp. Upper limit: FAD of
199 *Neostreptognathodus prayi*. *Hindeodus catalanoi* and *Sw.cf. windi* co-occur in this
200 zone. This zone probably straddles the Artinskian-Kungurian boundary due to
201 the absence of the *N. pnevi* zone at Tieqiao.

202 4.3 Kungurian

203 Kungurian rocks, spanning from Bed 27 to the lower part of Bed 109, consist
204 mainly of medium-to-thick bedded fossiliferous pack- and grainstones with
205 common chert nodules in the lower part. Medium to thin bedded lime mudstones
206 and wackestones were gradually developed higher in the Kungurian strata, with a
207 notable shift in fossil assemblages from a bryozoan- and calcareous
208 algae-dominated shallow water facies (Beds 89-99) to a sponge spicule and
209 radiolarian rich deeper water facies (Beds 100-111).

210 The conodont biostratigraphy of the basal Kungurian stage has been a matter
211 of debate (Wang et al., 2011). Kozur et al. (1995) suggested the cline
212 *Neostreptognathodus pequopensis-N. pnevi* to be suitable for a definition for the
213 Artinskian-Kungurian boundary. Mei et al. (2002) proposed the FAD of *N.*
214 *pequopensis* or *Sw. guizhouensis* to define the base of the Kungurian whereas
215 Chuvashov et al. (2002) formally proposed the FAD of *N. pnevi* as diagnostic of
216 the base of the Kungurian, a definition that has been generally accepted
217 (Henderson et al., 2012). However, due to the absence of *N. pnevi* at Tieqiao, we
218 alternatively suggest the base of the Kungurian be defined by the FAD of *N. prayi*.
219 Eight conodont zones were established for the Kungurian, described in ascending
220 order below:

221 4). *Neostreptognathodus prayi* Zone

222 Lower limit: FAD of *Neostreptognathodus prayi*. Upper limit: FAD of *Sw.*

223 *guizhouensis*. The *N. prayi* Zone is the second oldest zone of the Kungurian in the
224 standard Permian conodont zonation (Henderson et al., 2012) and so the *N. prayi*
225 zone at Tieqiao does not indicate the “true” earliest Kungurian (Fig. 6). *Sw. clarki*,
226 a species most commonly seen in the late Artinskian (Beauchamp and Henderson,
227 1994), also occurs in this zone. The first occurrence (FO) of *Sw. clarki* at Tieqiao
228 is only slightly lower than that of *Sw. guizhouensis*.

229 5) *Sw. guizhouensis* Zone

230 Lower limit: FAD of *Sw. guizhouensis*. Upper limit: FAD of *Sw. iranicus*. Except
231 for in the lower part of this ~180 m thick conodont zone, conodonts are
232 relatively rare. The long-ranging species *Pseudosw. costatus* is the only species
233 that was sparsely recovered in the upper part of this zone.

234 6) *Sw. iranicus* Zone

235 Lower limit: FAD of *Sw. iranicus*. Upper limit: FAD of *Sw. subsymmetricus*. As
236 with the *Sw. guizhouensis* Zone, both conodont diversity and abundance are very
237 low. A major stratigraphic complication at this level of the section is that Beds
238 76-88 are a tectonic repetition of older beds (also see Sha et al., 1990).

239 7) *Sw. adjunctus* Zone

240 Lower limit: FAD of *Sw. adjunctus*. Upper limit: FAD of *Sw. subsymmetricus*. *Sw.*
241 *cf. paraguizhouensis* appears in this zone. Sha et al. (1990) reported the
242 occurrence of “*Neogondolella*” *bisselli* in this zone (Bed 91). However, “*N.*” *bisselli*
243 is an older species which often co-occurred with the Artinskian *Sw. whitei* group

244 (e.g., Behnken, 1975; Clark et al., 1979; Orchard, 1984; Wang, 1994; Mei et al.,
245 2002). The occurrence of *bisselli* obviously contradicts a Kungurian age of the
246 host strata and also is not confirmed by our dataset.

247 *Sw. adjunctus* is also known from the uppermost Victorio Peak Formation
248 from Texas and the upper Pequop Formation from Nevada, USA (Behnken, 1975)
249 as well as from south-central British Columbia, Canada (Orchard and Forster,
250 1988): All of these occurrences are dated to be of late Leonardian age in the
251 Permian regional stratigraphy (=middle to late Kungurian). Because of the wide
252 distribution of *Sw. adjunctus*, this zone therefore has high potential for
253 super-regional correlation.

254 8) *Sw. subsymmetricus* Zone

255 Lower limit: FAD of *Sw. subsymmetricus*. Upper limit: FAD of *Sw.*
256 *hanzhongensis*. This zone correlates to the Kungurian “*M. siciliensis*-*Sw.*
257 *subsymmetricus*” zone in southern Guizhou (Mei et al., 2002).

258 *Sw. subsymmetricus* is well known from the Kungurian of Guizhou and
259 Guangxi in South China, as well as from Thailand and Oman (Mei et al., 2002 and
260 this study; Henderson and Mei, 2003; Metcalfe and Sone, 2008; Burrett et al.,
261 2015). The assertion that *Sw. subsymmetricus* is restricted to the Roadian (Kozur,
262 1993) is incorrect.

263 9) *Sw. hanzhongensis* Zone

264 Lower limit: FAD of *Sw. hanzhongensis*. Upper limit: FAD of *M. idahoensis*. The

265 FAD of *Pseudohindeodus augustus* and *Pseudohindeodus ramovsi* occurs in the
266 middle part of this zone. A turnover in the dominant conodont fauna initiated
267 during this zone. *Hindeodus* becomes abundant whilst the abundance and the
268 diversity of *Sweetognathus* decreases. *Hindeodus permicus*, *H. gulloides* and *H. aff.*
269 *wordensis* all occur in this zone.

270 10) *Mesogondolella idahoensis* Zone

271 Lower limit: FAD of *M. idahoensis*. Upper limit: FAD of *M. lamberti*. Conodont
272 faunas change from *Hindeodus-Pseudohindeodus-Sweetognathus*- dominated and
273 gondolellid-free assemblages to gondolellid-dominated assemblages in this zone
274 (Bed 109). This shift in conodont assemblage coincides with a lithological change
275 from thick- and medium- bedded wackestones to more cherty, medium- to thin-
276 bedded wacke- and carbonate mudstones.

277 11) *M. lamberti* Zone

278 Lower limit: FAD of *M. lamberti*. Upper limit: FAD of *J. nankingensis*.
279 Carbonate of the *M. lamberti* Zone (Beds 110-111) are more thinly bedded with
280 an increasing abundance of sponge spicules and radiolarian tests, indicating
281 deepening and a relative sea level rise in the latest Kungurian.

282 4.4 Roadian

283 The Roadian strata consist of less than 5 m thick finely laminated and thinly
284 bedded carbonate mudstones starting at the top of Bed 111 (Fig. 2B). A major
285 sea-level rise is known from the Early-Middle Permian transition and is manifest

286 at Tieqiao by a transition to thinly bedded radiolarian cherts by Bed 112
287 (Wordian age). By this time, deep, basinal sedimentation was established in the
288 region. The minor thickness of the Roadian strata may be attributed either to
289 condensation during this sea level rise or to hiatus resulting in a loss of strata
290 (due to sudden loss of carbonate production below the carbonate compensation
291 depth). Only one conodont zone is recognized.

292 12) *Jinogondolella nankingensis* Zone

293 Lower limit: FAD of *J. nankingensis*. Upper limit: FAD of *J. aserrata*.
294 *Pseudohindeodus ramovsi* are abundant. Fine lamination in the upper (Roadian)
295 part of Bed 111 indicates minor bioturbation.

296 4.5 Wordian

297 Wordian strata are presented by Bed 112 to lowermost part of Bed 116. The
298 sediments consist of thinly bedded radiolarian cherts in the lower part (Beds
299 112-113), thickly bedded bioclastic wacke- and packstones in the middle (Bed
300 114, also known as “the Great White Bed”) and alternation of cherts and lime
301 mudstones in the upper part (Bed 115-116). One conodont zone is recognized.

302 13) *J. aserrata* Zone

303 Lower limit: FAD of *J. aserrata*. Upper limit: FAD of *J. postserrata*. The FAD of *J.*
304 *palmata* occurs at the same level as the FAD of *J. aserrata*. This is generally
305 consistent with the record in west Texas where the FAD of *J. palmata* was
306 reported very close to the FAD of *J. aserrata* (Nestell and Wardlaw, 2010a).

307 Several species, such as *J. errata*, *Gulloodus duani* and the long ranging species *Sw.*
308 *hanzhongensis* and *Pseudohin. ramovsi* appear in the middle-upper part of this
309 zone.

310 4.6 Capitanian

311 The Capitanian (Beds 116-119) is the most intensively studied interval in the
312 Laibin area (Mei et al., 1994c; Jin et al., 2006; Chen et al., 2009; Wignall et al.,
313 2009b). Strata of this age consist of medium bedded alternating cherts and lime
314 mudstones in the lower part (Beds 116-118) overlain by pack- to grainstones
315 (Laibin Limestone Member, Bed 119). Here we only give a brief description of the
316 conodont zones of this stage since they have been well studied.

317 14) *J. postserrata* Zone

318 Lower limit: FAD of *J. postserrata*. Upper limit: FAD of *J. shannoni*.

319 15) *J. shannoni* Zone

320 Lower limit: FAD of *J. shannoni*. Upper limit: FAD of *J. altudaensis*.

321 16) *J. altudaensis* Zone

322 Lower limit: FAD of *J. altudaensis*. Upper limit: FAD of *J. prexuanhanensis*. This
323 interval is characterized by higher extinction rates as well as the onset of
324 Emeishan volcanism (Wignall et al., 2009a; Sun et al., 2010). Losses include many
325 foraminifers, calcareous algae in the equatorial realm and many brachiopods in
326 the boreal realm (Bond et al., 2010; Bond et al., 2015). Though there are no

327 obvious lithological changes in the *J. altudaensis* Zone at Tieqiao, the last
328 appearances of several long-ranging conodonts, such as *Gulloodus duani*, *Sw.*
329 *hanzhongensis* and *Pseudohind. ramovsi*, are all recorded in this zone.

330 17) *J. prexuanhanensis* Zone

331 Lower limit: FAD of *J. prexuanhanensis*. Upper limit: the FAD of *J.*
332 *xuanhanensis*. This zone has not been recognized in western Texas (Lambert et al.,
333 2002). However, it is also distinguishable in the Tieqiao (Guangxi, this study) and
334 at Dukou (Sichuan, Mei et al., 1994a) sections. In condensed sections in Guizhou,
335 the *J. prexuanhanensis* zone is often combined with the younger *J. xuanhanensis*
336 zone as the *J. prexuanhanensis*-*J. xuanhanensis* assemblage zone (Sun et al., 2010).

337 *Sw. fengshanensis* occurs in this zone. *Sw. fengshanensis* was established in
338 the late Capitanian strata at Fengshan, northwestern Guangxi (Mei et al., 1998).
339 At the Penglaitan section, *Sw. fengshanensis* spans from the upper *J. postserrata*
340 zone to the lower *J. xuanhanensis* zone, representing the last in the evolutionary
341 lineage of sweetognathids in South China (Mei et al., 2002).

342 18) *J. xuanhanensis* Zone

343 Lower limit: FAD of *J. xuanhanensis*. Upper limit: FAD of *J. granti*. Many
344 mature morphotypes of *J. shannoni* occur in the lowermost part of this zone and
345 are very similar to their counterparts from West Texas (Lambert et al., 2002;
346 Wardlaw and Nestell, 2010). Volcaniclastic material starts to be deposited during
347 this zone and becomes more common in the overlying *J. granti* Zone, presumably

348 corresponding to the large scale of explosive eruptions of the Emeishan Traps
349 (e.g., Sun et al., 2010).

350 19) *J. granti* Zone

351 Lower limit: FAD of *J. granti*. Upper limit: FAD of *Clarkina hongshuiensis*.

352 Conodonts are prolifically abundant in this zone with a typical yield rate of ~100
353 specimens per kg rock.

354 20) *Clarkina hongshuiensis* Zone

355 Lower limit: FAD of *C. hongshuiensis*. Upper limit: FAD of *C. postbitteri*.

356 4.7 Wuchiapingian

357 The early Wuchiapingian (Bed 120) is characterized by deposition of
358 extensive bedded cherts with intercalated pinkish limestone lenses. Evidence for
359 a relative sea level fall towards the end of Wuchiapingian is indicated by a
360 reduction of chert thickness up-section with carbonate sedimentation increasing.
361 Eventually, this basinal setting evolved into a sponge reef facies (Beds 124-132)
362 in the middle-late Wuchiapingian lacking conodonts. *Clarkina transcaucasica* was
363 found in Bed 134. One conodont zone is established for the earliest
364 Wuchiapingian at Tieqiao:

365 21) *Clarkina postbitteri* Zone

366 Lower limit: FAD of *C. postbitteri*. Upper limit: not determined.

367 **5. Subordinate zones and reassessment for age assignments of rare species**

368 Seven subordinate zones are established at Tieqiao, representing interval
369 zones based on occurrences of long ranging species. The subordinate zones are
370 less effective for stratigraphic correlation but can provide a valuable reference
371 for cases when a single conodont assemblage is obtained from an age-ambiguous
372 lithologic unit (e.g., Burrett et al., 2015). In the following section, we first
373 describe the ranges of these subordinate zones in the Tieqiao section, followed
374 by comments on the range of the zonal species. A correlation with the main
375 conodont zones is shown in figure. 6. Note that the range of the species can be
376 much longer than the respective zone.

377 1) *Pseudosweetognathus* (*Pseudosw.*) *costatus* Interval Zone

378 Lower limit: FAD of *Pseudosw. costatus*. Upper limit: FAD of *Pseudosw.*
379 *monocornus*. The *Pseudosw. costatus* Zone spans the early Artinskian to middle
380 Kungurian (Bed 19 to Bed 94). Elements of long-ranging species *H. minutus* are
381 abundant in the lower part of this zone and there is a single occurrence of *H. aff.*
382 *catalanoi* in the lowermost.

383 *Pseudosweetognathus costatus* was established in Artinskian strata of South
384 China (Wang et al., 1987) and also reported from Thailand, co-existing with a
385 typical Kungurian taxon *Sw. subsymmetricus* (Metcalf and Sone, 2008). Our data
386 confirm former observations and indicate that the range of *Pseudosw. costatus*
387 extends from the Artinskian *Sw. asymmetrica* n. sp. Zone to the Kungurian *Sw.*
388 *adjunctus* Zone. In the middle Kungurian, *Pseudosw. costatus* was replaced by

389 *Pseudosw. monocornus*.

390 2) *Pseudosweetognathus monocornus* Interval Zone

391 Lower limit: FAD of *Pseudosw. monocornus*. Upper limit: FAD of *H. gulloides*.

392 This zone comprises Bed 94 to Bed 102 at Tieqiao, and is of late Kungurian age.

393 Li et al. (1989) established the species *Pseudosweetognathus monocornus*
394 (under the genus “*Sichuanognathodus*”) from the upper part of Maokou Fm. at
395 Shangsi. A later and detailed study of the same section reported a *Jinogondolella*
396 and *Hindeodus* dominated fauna which indicates an early Capitanian age for the
397 upper Maokou Fm. (Sun et al., 2008).

398 *Pseudosweetognathus monocornus* is found in the upper part of Chihsia Fm.
399 and lower part of Maokou Fm. at Tieqiao and here is reassigned a
400 middle-Kungurian to early-Roadian age. This species only occurred with shallow
401 water, high energy assemblage composed of calcareous algae, corals and
402 foraminifers found in thickly bedded bioclastic pack- and grainstones. We thus
403 speculate that the occurrence of *Pseudosw. monocornus* might be facies-related,
404 and its presence in Wordian to lower Capitanian strata elsewhere (Li et al., 1989)
405 cannot be excluded.

406 3) *Hindeodus gulloides* Interval Zone

407 Lower limit: FAD of *H. gulloides*. Upper limit: FAD of *Pseudohindeodus ramovsi*.

408 This zone occupies Bed 102 and correlates to the middle part of *Sw.*
409 *hanzhongensis* zone, representing a Late Kungurian age.

410 The species *H. gulloides* Kozur and Mostler, 1995, ranges from upper
411 Kungurian to Roadian. In northeast Thailand, *H. gulloides* occurs at an
412 age-equivalent level as in South China and co-existed with a typical late
413 Kungurian assemblage which consists of species *Mesogondolella siciliensis*,
414 *Pseudohindeodus oertlii* (= *angustus*) and *Sw. subsymmetricus* (Burrett et al.,
415 2015). In west Texas, the species was recovered from the upper part of Road
416 Canyon Fm., representing a late Roadian age (Kozur and Mostler, 1995).

417 4) *Pseudohindeodus ramovsi* Interval Zone

418 Lower limit: the FAD of *Pseudohindeodus ramovsi*. Upper limit: the
419 occurrence of *Gullodus sicilianus*. This zone spans from Bed 103 to Bed 115,
420 representing a latest Kungurian to Wordian age.

421 The species *Pseudohindeodus ramovsi* Gullo and Kozur, 1992 has a much
422 longer range than the Interval Zone. Wardlaw (2000) reported sporadic
423 occurrences of this species from the Kungurian to Capitanian. Our data are
424 consistent with Wardlaw (2000), suggesting that *Pseudohindeodus ramovsi*
425 spanned from the late Kungurian *Sw. hanzhongensis* to the middle Capitanian *J.*
426 *altudaensis* Zone.

427 Another associate species in this zone is *Pseudosw. augustus* (Igo, 1981). This
428 species has been reported from coeval Kungurian strata in Japan (Igo, 1981; Shen
429 et al., 2012), but can also occur in much older strata such as in the Artinskian
430 (Orchard and Forster, 1988).

431 5) *Gullodus sicilianus* Interval Zone

432 Lower limit: FO of *G. sicilianus*. Upper limit: FAD of *Gullodus duani*. This zone
433 covers the middle part of Bed 115, representing a middle-late Wordian age.

434 *Gullodus sicilianus* (Bender and Stoppel, 1965) ranges from the Roadian to
435 Wordian (Kozur, 1993). It is a rare taxon that is known mostly from the Tethys
436 realm during the Wordian (Kozur, 1995).

437 6) *Gullodus duani* Interval Zone

438 Lower limit: FAD of *Gullodus duani*. Upper limit: prolific occurrence of *H.*
439 *excavatus*. This zone comprises Bed 115 to Bed 118, covering much of the
440 Capitanian. An associated taxon *Hindeodus catalanoi* ranges through the upper
441 part of this zone. Though Gullo and Kozur (1992) assigned a Wordian age for *H.*
442 *catalanoi*, this form is found in the Capitanian at Tieqiao, suggesting a longer
443 range of the species than its original definition.

444 *Gullodus duani* Mei et al. 2002 is a rather rare species in the Guadalupian.
445 This species was originally recovered from the Maokou Fm. from Guangxi and is
446 only known from South China. At Tieqiao, this species is known from uppermost
447 Wordian to middle Capitanian strata.

448 7) *H. excavatus* Interval Zone

449 Lower limit: the prolific occurrence of *H. excavatus*. Upper limit: FAD of *C.*
450 *postbitteri* (the Capitanian-Wuchiapingian boundary). At Tieqiao, this zone is

451 represented by the Laibin Limestone Member (Bed 119) of a late Capitanian age.

452 *Hindeodus excavatus* is another long-ranging species in the Permian, but its
453 use as a zonal fossil derives from its prolific abundance in the late Capitanian.

454 **6. Systematic palaeontology**

455 **Genus *Gullodus* Kozur, 1993**

456 *Emended diagnosis:* Spathognathodiform elements with a medium to long
457 anterior blade and a posteriorly positioned, strongly expanded basal cavity.
458 Denticles occur on the blade and above the basal cavity and are in most cases
459 without ornamentations. Denticles are generally 10-15 in number and those
460 above the basal cavity can be expanded and form a carina-like structure or
461 narrow transverse ridges. Small coalesced denticles are sometimes developed on
462 the anterior edge forming an “anterior blade”. Length/height ratio is between 1.5
463 and 3. Basal cavities are greatly expanded, non-ornamented and occupy 1/3 to
464 2/3 of the full body.

465 *Remarks:* the diagnosis of this genus (Kozur, 1993) should be emended because it
466 is often hard to differentiate between *Gullodus* and *Hindeodus*. The emended
467 diagnosis also includes wider variability of *Gullodus* species. Key differences
468 between *Gullodus* and *Hindeodus* are the shape and position of the basal cavity
469 and the length/height ratio: *Hindeodus* has a more centrally positioned basal
470 cavity and lower length/height ratio. A key difference between *Gullodus* and
471 *Sweetognathus* is that denticles of *Gullodus* are not ornamented while those of

472 *Sweetognathus* develop nodes. *Gullodus* can be differentiated from
473 *Pseudohindeodus* because the basal cavity of the latter is more (horizontally)
474 expanded and ornamented with a surface apron and occupies $\geq 2/3$ of the full
475 element length.

476 Based on the revised diagnosis, *Gnathodus sicilianus* Bender and Stoppel,
477 1965 should remain as *Gullodus sicilianus* as suggested by Kozur (1993).
478 However, *Pseudohindeodus catalanoi* Gullo and Kozur (1992) and *Gullodus*
479 *hemicircularis* Kozur, 1993 should belong to *Hindeodus*, rather than
480 *Pseudohindeodus* or *Gullodus*.

481 *Occurrence:* Kungurian to Capitanian

482

483 ***Gullodus tieqiaoensis* n. sp. Sun and Lai**

484 Plate 4, figs. 6, 7.

485 No reported specimens are similar to this species.

486 *Etymology:* From the name of the section from where the species is described.

487 *Holotype:* Specimen S1_060 (Pl. 4, fig.6) from sample 41-1 of Bed 41, Chihsia Fm.,
488 Tieqiao Section, South China.

489 *Paratype:* Specimen S1_062 (Pl. 4, fig.7) from sample 41-2 of Bed 41, Chihsia Fm.,
490 Tieqiao Section, South China.

491 *Diagnosis:* A *Gullodus* species with a high length/height ratio and a robust cusp.

492 *Description:* Body slim and elongated. Length/height ratio is ~2. The cusp is tall,
493 wide and robust, normally twice as high as the denticles and three times wider
494 than the denticles. 13-17 densely arrayed denticles decrease in height posteriorly.
495 Posterior denticles on the basal cavity are more expanded and thus wider than
496 the rest. They can be lower and more fused. The basal cavity is expanded, leaf or
497 irregular shaped and occupies the posterior 2/3 of the element. The widest point
498 is in the posterior 1/4 to 1/3.

499 *Remarks:* This species has a very high length/height ratio and a posteriorly
500 positioned, expanded but non-ornamented basal cavity that extends to the
501 posterior end. It thus belongs to *Gulloodus* rather than *Hindeodus* or
502 *Pseudohindeodus*.

503 *Occurrence:* lower Chihsia Fm. (early Kungurian), Tieqiao, South China

504

505 **Genus *Hindeodus* Rexroad & Furnish, 1964**

506 ***Hindeodus catalanoi* Gullo and Kozur, 1992**

507 Plate 7, Figs. 6-8.

508 *Pseudohindeodus catalanoi* Gullo and Kozur, 1992 p. 225, pl. 5, fig. A.

509 *Hindeodus gulloides* Burrett et al. 2015, p. 111-113, Fig. 6, figs. J-I.

510 *Diagnosis:* A *Hindeodus* species that is triangular shaped with 2 to 3 anterior
511 coalesced denticles and 12-15 densely arrayed denticles.

512 *Remarks:* The species resembles its Artinskian-Kungurian and “Roadian”
513 predecessors *H. hemicircularis* Kozur 1993 and *H. gulloides* Kozur and Mostler,
514 1995. They all have two to three anterior denticles. However, *H. hemicircularis* is
515 sub-semicircular shaped and has fewer but wider denticles while *H. gulloides* is
516 more elongated and has a much broader cusp than the current species.

517 *Occurrence:* upper Maokou Fm. (middle-late Capitanian), Tieqiao, South China;
518 Wordian of Sicily.

519 ***Hindeodus* sp. A Sun and Lai**

520 Plate 4, Figs. 23, 26.

521 *Diagnosis:* A *Hindeodus* species whose outline is close to that of an isosceles
522 triangle.

523 *Description:* Body triangular shaped with a long anterior edge. Anterior angle is
524 around 45°-60°. Two or three small coalesced denticles may develop on the
525 anterior edge. Medium sized cusp followed by three low denticles. Posterior
526 denticles are taller and wider and decrease in height towards the posterior end.
527 The basal cavity is medially expanded and central positioned.

528 *Remarks:* The species resembles *H. permicus* but differs by its outline and shapes
529 of denticles.

530 *Occurrence:* upper Kungurian, basal Maokou Fm. of South China

531 **Genus *Pseudohindeodus* Gullo and Kozur, 1992**

532 ***Pseudohindeodus ellipticae* n. sp. Sun and Lai**

533 Plate 4, fig. 13; Plate 7. fig. 14.

534 *Pseudohindeodus* sp. Wang, 1995, pl. 1, figs. 1a, 1b.

535 *Etymology*: From the oval shape of the basal cavity of the species.

536 *Holotype*: Specimen S7_001 (Pl. 7, fig. 14) from sample 104-2 of Bed 104, Maokou
537 Fm., Tieqiao Section, South China.

538 *Paratype*: Specimen S2_075 (Pl. 4, fig. 13) from sample 104-2 of Bed 104, Maokou
539 Fm., Tieqiao Section, South China.

540 *Diagnosis*: A *Gullodus* species with an asymmetrical basal cavity that is near oval
541 in shape.

542 *Description*: Element is small and rounded. Cusp is large, robust and higher and
543 broader than any following denticles. The 5-8 denticles immediately behind the
544 cusp are thin and more fused with each other and thus can appear as a ridge. The
545 last 4-6 denticles are the largest amongst all denticles. They are lower, more
546 rounded in shape and relatively evenly spaced with each other with a small gap
547 in between. The basal cavity is decorated with an apron, horizontally expanded,
548 asymmetrical and very rounded. The outline of the basal cavity is close to an oval.

549 *Remarks*: the species resembles *Pseudohindeodus ramovsi*. However, *ramovsi* has
550 a near triangular basal cavity whilst *Pseudohindeodus ellipticae* n. sp. has a more
551 rounded basal cavity.

552 *Occurrence:* upper Kungurian to lowermost Roadian, basal Kufeng Fm. and lower
553 Maokou Fm. of South China.

554
555

Genus *Sweetognathus* Clark, 1972

556 ***Sweetognathus asymmetrica* n. sp. Sun and Lai**

557 Plate 1, Figs. 1, 7, 14, 17.

558 *Etymology:* The species name refers to its asymmetric anterior transverse ridges.

559 *Holotype:* Specimen S1_018 (Pl. 1, Fig.1) from sample 18-1 of Bed 18, Chihsia Fm.,
560 Tieqiao Section, South China.

561 *Paratypes:* Specimen S1_037 (Pl. 1, Fig.7) from sample 22-2 of Bed 22, Chihsia
562 Fm., Tieqiao Section, South China.

563 *Diagnosis:* A Type III sweetognathid (definition follows Ritter, 1986) with short
564 blade and asymmetric anterior transverse ridges.

565 *Description:* Short blade, often bearing 4-6 denticles; the cusp is moderately big,
566 the first denticle is the biggest and very often fused with the cusp and forms a
567 high robust cusp; the other denticles are much smaller, lower and more fused
568 toward to the carina. The first two denticles are occasionally both very high,
569 robust and triangular in shape. Transverse ridges are clearly incised. There are
570 commonly 6 to 8 transverse ridges. The first one or two ridges are always
571 asymmetrically developed—in most cases the left nodes are missing. The widest
572 part of the carina is in the middle. The basal cavity is leaf- to heart-shaped and

573 moderately expanded, occupying the posterior half of the full element length.

574 *Remarks:* This species is similar to *Sw. subsymmetricus*. Both species developed
575 asymmetric anterior transverse ridges. However, the current species differs from
576 *Sw. subsymmetricus* by: 1) the length ratio of free blade/carina < 1 (most
577 commonly $1/3$), whereas that of *Sw. subsymmetricus* is generally ≥ 1 ; 2) the cusp is
578 large tall and robust, whereas that of *Sw. subsymmetricus* is moderately large,
579 compared with other denticles on the blade; 3) an apparent gap between blade
580 and carina; *Sw. subsymmetricus* has low small denticles connecting blade and
581 carina; 4) *Sw. subsymmetricus* has a less expanded basal cavity and a narrower
582 carina, therefore appears more “slim”; 5) gaps between transverse ridges that
583 become larger toward the posterior end.

584 Though *Sw. subsymmetricus* and *Sweetognathus asymmetrica* n. sp. may have
585 close affinities, *Sw. asymmetrica* n. sp. is restricted to the Artinskian to earliest
586 Kungurian whereas *Sw. subsymmetricus* is found in younger rocks of late
587 Kungurian to Roadian age (Kozur, 1995). Many reported occurrences of *Sw.*
588 *subsymmetricus* in pre-middle-Kungurian strata (that have not been illustrated)
589 should be reassessed.

590 The paratype shares a few common features with *Sw. variabilis*. They both
591 have two big triangular-shaped denticles. The key difference is the position of the
592 basal cavity. *Sw. variabilis* has a basal cavity near the posterior end. In addition,
593 *Sw. variabilis* has a long blade (blade/carina ratio ≥ 1) and five transverse ridges

594 with the widest being near the posterior end. *Sw. asymmetrica* n. sp. has a
595 blade/carina ratio always <1, and usually seven or more transverse ridges while
596 the widest occurs near the middle of the body. In addition, neither of *Sw.*
597 *subsymmetricus* and *Sw. variabilis* should be considered as synonyms of *Sw.*
598 *paraguizhouensis* and *Sw. guizhouensis* (Shen et al., 2012).

599 Occurrence: Artinskian-basal Kungurian, basal Chihhsia Fm. of South China

600 *Note:* The specimen shown in fig. 3 in Pl. 4 seemly has a gap between blade and
601 carina. This is only because in the lateral view the SEM took the part with missing
602 nodes in the asymmetric anterior transverse ridges.

603 ***Sweetognathus sp. A***

604 Pl. 1 fig. 9

605 *Diagnosis:* A Type III sweetognathid with tall and slim denticles and narrow
606 ridges.

607 *Description:* Body elongated with a height/length ratio $\approx 1/2$. Cusp tall and slim,
608 at least twice as high as any following denticles. The cusp is immediately
609 followed by five to six very slim denticles. The first and third denticles are the
610 lowest. A gap is developed between the fourth and fifth denticles. Nodes are
611 short, forming 5-7 low and generally evenly spaced ridges.

612 ***Sweetognathus toriyamai* (Igo, 1981)**

613 Pl.1, fig. 12, 15.

614 *Neostreptognathodus toriyamai* Igo, 1981, p. 42-43, pl. 6, figs. 1-16

615 *Sweetognathus whitei* Igo, 1981, Pl. 7, fig.7?

616 *Remarks:* The denticles of this species point forwards. The carina is
617 lens-shaped—thus the widest is near the middle. There is a short and narrow
618 ridge connecting the blade and carina. The ridge is relatively high anteriorly and
619 decreases in height towards the carina, thus giving a triangular shape if laterally
620 viewed.

621 *Comparisons:* The short narrow ridge between the free blade and carina is one of
622 the most distinguishable features of this species. This species has a broad,
623 lens-like carina, which is similar to *Sw. behnkeni*. However, the latter species has
624 “ledge-like” decorations on the carina, whereas *Sw. toriyamai* is decorated by
625 lower transverse ridges.

626 *Occurrence:* Artinskian, basal Chihhsia Fm. of South China and Kuchibora Fm. of
627 Japan.

628

629 7. Conclusions:

630 A detailed conodont biostratigraphic and taxonomic study of the Early and
631 Middle Permian strata at Tieqiao, South China has enabled recognition of 21
632 main and 7 subordinate conodont zones. Three new species are established. The
633 following conclusions can be drawn:

634 1) The Tieqiao strata record a change in conodont faunas from Early Permian
635 *Sweetognathus* dominated assemblages to Middle Permian gondolellids
636 dominated assemblages from the latest Kungurian onwards. This shift coincided
637 with a relative sea-level rise and change to deeper water facies.

638 2) The Early Permian *Sweetognathus* fauna represents an important evolution
639 lineage and a shallower (surface?) water group, which evolved in parallel to the
640 contemporary but possibly deeper-dwelling *Mesogondolella* fauna.

641 3) The Chihhsia Fm., which had been in many cases erroneously regarded as a
642 Middle Permian unit, is of Early Permian age. It spans the Artinskian to the late
643 Kungurian whilst the overlying Maokou Fm. straddles the Early and Middle
644 Permian from the late Kungurian to latest Capitanian. The Chihhsia/Maokou
645 lithological boundary is thus locally not suitable for defining the Early-Middle
646 Permian boundary (Kungurian-Roadian stage boundary).

647 4) Species such as *J. palmata* and *J. errata* occur at time-equivalent stratigraphic
648 levels at Tieqiao as in west Texas, suggesting that they can be used for
649 intercontinental correlations.

650

651 Acknowledgements

652 Many colleagues helped with field and lab work, including H.S. Jiang (Wuhan),
653 F. Li (now Guilin), Q. Li (now Qingdao), D. Lutz (Erlangen), F. Nanning (now
654 Münster), W. Pan (now Guangzhou), L.N. Wang (Wuhan), Y.J. Yan (now

655 Lianyungang) and W.Q. Xue (Wuhan). H. Igo and B. R. Wardlaw are thanked for
656 providing conodont literature. Y.D. Sun acknowledges the Alexander von
657 Humboldt Foundation for a fellowship. This study is supported by the Chinese
658 Fundamental Research Funds for the Central Universities (CUG130615), 973
659 Program (2011CB808800), the Natural Science Foundation of China (41272044;
660 41472087; 41572002) and the 111 Project (B08030). DB acknowledges funding
661 from the UK Natural Environment Research Council (grant NE/J01799X/1).

662

663 References

- 664 Beauchamp, B., Henderson, C.M., 1994. The Lower Permian Raanes, Great Bear
665 Cape and Trappers Cove Formations, Sverdrup Basin, Canadian Arctic -
666 Stratigraphy and Conodont Zonations. *Bulletin of Canadian Petroleum
667 Geology*, 42(4): 562-597.
- 668 Behnken, F.H., 1975. Leonardian and Guadalupian (Permian) Conodont
669 Biostratigraphy in Western and Southwestern United States. *Journal of
670 Paleontology*, 49(2): 284-315.
- 671 Bender, H., Stoppel, D., 1965. Perm-Conodonten. *Geologisches Jahrbuch*, 82:
672 331-364.
- 673 Bond, D.P.G., Hilton, J., Wignall, P.B., Ali, J.R., Stevens, L.G., Sun, Y., Lai, X., 2010. The
674 Middle Permian (Capitanian) mass extinction on land and in the oceans.
675 *Earth-Science Reviews*, 102(1-2): 100-116.
- 676 Bond, D.P.G., Wignall, P.B., Joachimski, M.M., Sun, Y., Savov, I., Grasby, S.E.,
677 Beauchamp, B., Blomeier, D.P.G., 2015. An abrupt extinction in the Middle
678 Permian (Capitanian) of the Boreal Realm (Spitsbergen) and its link to
679 anoxia and acidification. *Geological Society of America Bulletin*, 127(9-10):
680 1411-1421.

- 681 Bucur, I.I., Munnecke, A., Granier, B., Yan, J., 2009. Remarks on the Permian
682 dasycladalean alga *Sinoporella leei* Yabe, 1949. *Geobios*, 42(2): 221-231.
- 683 Burrett, C., Udchachon, M., Thassanapak, H., Chitnarin, A., 2015. Conodonts,
684 radiolarians and ostracodes in the Permian E-Lert Formation, Loei Fold
685 Belt, Indochina Terrane, Thailand. *Geological Magazine*, 152(01): 106-142.
- 686 Chen, B., Joachimski, M.M., Sun, Y.D., Shen, S.Z., Lai, X.L., 2011. Carbon and
687 conodont apatite oxygen isotope records of Guadalupian-Lopingian
688 boundary sections: Climatic or sea-level signal? *Palaeogeography
689 Palaeoclimatology Palaeoecology*, 311(3-4): 145-153.
- 690 Chen, Z.Q., George, A., Yang, W.R., 2009. Effects of Middle-Late Permian sea-level
691 changes and mass extinction on the formation of the Tieqiao skeletal
692 mound in the Laibin area, South China. *Australian Journal of Earth
693 Sciences*, 56(6): 745-763.
- 694 Chuvashov, B.I., Dyupina, G.V., Mizens, G.A., Chernykh, V.V., 1990. Basic Sections of
695 Carboniferous and Lower Permian of Western Slope of Urals. Ural Branch
696 Academic Science of Russia, Sverdlovsk, 369 pp.
- 697 Clark, D.L., Behnken, F.H., 1971. Conodonts and Biostratigraphy of the Permian.
698 *Geological Society of America Memoir*, 127: 415-439.
- 699 Clark, D.L., Carr, T.R., Behnken, F.H., Wardlaw, B.R., Collinson, J.W., 1979. Permian
700 Conodont Biostratigraphy in the Great Basin. In: Sandberg, C.A., Clark, D.L.
701 (Eds.), *Conodont biostratigraphy of the Great Basin and Rocky Mountains*.
702 Brigham Young University, Geology Studies, pp. 143-150.
- 703 Ding, H., Wan, S., 1990. The Carboniferous-Permian conodont event-stratigraphy
704 in the South of the North China Platform. *Courier Forschungsinstitut
705 Senckenberg*, 118: 131-155.
- 706 Gong, Y.-M., Shi, G.R., Zhang, L.-J., Weldon, E.A., 2010. *Zoophycos* composite
707 ichnofabrics and tiers from the Permian neritic facies in South China and
708 south-eastern Australia. *Lethaia*, 43(2): 182-196.
- 709 Gullo, M., Kozur, H., 1992. Conodonts from the pelagic deep-water Permian of
710 central Western-Sicily (Italy). *Neues Jahrbuch für Geologie und*

711 Paläontologie Abhandlungen, 184(2): 203-234.

712 Henderson, C.M., Mei, S., 2003. Stratigraphic versus environmental significance of
713 Permian serrated conodonts around the Cisuralian-Guadalupian boundary:
714 new evidence from Oman. *Palaeogeography, Palaeoclimatology,*
715 *Palaeoecology*, 191(3-4): 301-328.

716 Henderson, C.M., Davydov, D.I., Wardlaw, B.R., 2012. The Permian Period. In:
717 Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), *The Geologic Time*
718 *Scale 2012*. Elsevier, pp. 653-679.

719 Igo, H., 1981. Permian conodont biostratigraphy of Japan. *Palaeontological*
720 *Society of Japan special papers*, 24. Palaeontological Society of Japan,
721 Tokyo, 51 pp.

722 Ji, Z.S., Yao, J.X., Jin, X.C., Yang, X.N., Wang, Y.Z., Yang, H.L., Wu, G.C., 2004. Early
723 Permian Conodonts from the Baoshan Block, Western Yunnan, China. *Acta*
724 *Geologica Sinica*, 78(6): 1179-1184.

725 Jiang, H.S., Lai, X.L., Luo, G.M., Aldridge, R., Zhang, K.X., Wignall, P.B., 2007.
726 Restudy of conodont zonation and evolution across the P/T boundary at
727 Meishan section, Changxing, Zhejiang, China. *Global and Planetary Change*,
728 55: 39-55.

729 Jin, Y.G., Wardlaw, B.R., Glenister, B.F., Kotlyar, G.V., 1997. Permian
730 chronostratigraphic subdivisions. *Episodes*, 20(1): 10-15.

731 Jin, Y.G., Shen, S.Z., Henderson, C.M., Wang, X.D., Wang, W., Wang, Y., Cao, C.Q.,
732 Shang, Q.H., 2006. The Global Stratotype Section and Point (GSSP) for the
733 boundary between the Capitanian and Wuchiapingian Stage (Permian).
734 *Episodes*, 29(4): 253-262.

735 Kozur, H., 1993. *Gullodus* n. gen.-a new conodont genus and remarks to the
736 pelagic Permian and Triassic of Western Sicily. *Jb. Geol. B. -A.*, 136(1):
737 77-87.

738 Kozur, H., 1995. Permian Conodont Zonation and its Importance for the Permian
739 Stratigraphic Standard Scale. *Geol. Palaont. Mitt. Innsbruck*, 20(165-205).

740 Kozur, H., Mostler, H., 1995. Guadalupian (Middle Permian) conodonts of

741 sponge-bearing limestones from the margins of the Delaware Basin, West
742 Texas. *Geologia Croatica*, 48(2): 107-128.

743 Lambert, L.L., Wardlaw, B.R., Nestell, M.K., Nestell, G.P., 2002. Latest Guadalupian
744 (Middle Permian) conodonts and foraminifers from West Texas.
745 *Micropaleontology*, 48(4): 343-364.

746 Lambert, L.L., Gorden L. Bell, J., Fronimos, J.A., Wardlaw, B.R., O.Yisa, M., 2010.
747 Conodont biostratigraphy of a more complete Reef Trail Member section
748 near the type section, latest Guadalupian Series type region.
749 *Micropaleontology*, 56(1-2): 233-253.

750 Li, Z.S., Zhan, L.P., Dai, J.Y., Jin, R.G., Zhu, X.F., Zhang, J.H., Huang, H.Q., Xu, D.Y., Yan,
751 Z., Li, H.M., 1989. Study on the Permian-Triassic biostratigraphy and event
752 stratigraphy of northern Sichuan and southern Shaanxi. *Geological*
753 *Memoirs*, 9. Geological Publishing House, Beijing, 435 pp.

754 Mei, S.L., Jin, Y.G., Wardlaw, B.R., 1994a. Succession of conodont zones from the
755 Permian 'Kuhfeng' Formation, Xuanhan, Sichuan and its implication in
756 global correlation. *Acta Palaeontologica Sinica*, 33(1): 1-23.

757 Mei, S.L., Jin, Y.G., Wardlaw, B.R., 1994b. Succession of Wuchiapingian conodonts
758 from northeast Sichuan Province and its worldwide correlation. *Acta*
759 *Micropalaeontologica Sinica*, 11: 121-139.

760 Mei, S.L., Jin, Y.G., Wardlaw, B.R., 1994c. Zonation of conodonts from the
761 Maokouan-Wuchiapingian boundary strata, South China. *Palaeoworld*, 4:
762 225-233.

763 Mei, S.L., Jin, Y.G., Wardlaw, B.R., 1998. Conodont Succession of the
764 Guadalupian-Lopingian Boundary Strata in Laibin of Guangxi, China and
765 West Texas, USA. *Palaeoworld*, 9: 53-76.

766 Mei, S.L., Henderson, C.M., Wardlaw, B.R., 2002. Evolution and distribution of the
767 conodonts *Sweetognathus* and *Iranognathus* and related genera during the
768 Permian, and their implications for climate change. *Palaeogeography,*
769 *Palaeoclimatology, Palaeoecology*, 180(1-3): 57-91.

770 Metcalfe, I., Sone, M., 2008. Biostratigraphy and palaeobiogeography of Lower

771 Permian (lower Kungurian) conodonts from the Tak Fa Formation
772 (Saraburi Limestone), Thailand. *Palaeogeography, Palaeoclimatology,*
773 *Palaeoecology*, 257(1-2): 139-151.

774 Nestell, M.K., Nestell, G.P., Wardlaw, B.R., Sweatt, M.J., 2006. Integrated
775 biostratigraphy of foraminifers, radiolarians and conodonts in shallow
776 and deep water Middle Permian (Capitanian) deposits of the "Rader slide",
777 Guadalupe Mountain, West Texas. *Stratigraphy*, 3(3): 161-194.

778 Nestell, M.K., Wardlaw, B.R., 2010a. *Jinogondolella palmata*, a new Gondolellid
779 conodont species from the Bell Canyon Formation, Middle Permian, West
780 Texas. *Micropaleontology*, 56(1-2): 185-194.

781 Nestell, M.K., Wardlaw, B.R., 2010b. Radiolarians and conodonts of the
782 Guadalupian (Middle Permian) of West Texas: advances in taxonomy and
783 biostratigraphy. *Micropaleontology*, 56(1-2): 1-6.

784 Orchard, M.J., 1984. Early Permian conodonts from the Harper Ranch beds,
785 Kamloops area, southern British Columbia. Paper - Geological Survey of
786 Canada, 84-1B: 207-215.

787 Orchard, M.J., Forster, P.J.L., 1988. Permian conodont biostratigraphy of the
788 Harper Ranch Beds, near Kamloops, south-central British Columbia.
789 Energy, Mines and Resources Canada, pp. 1-27.

790 Qiu, Z., Wang, Q., Zou, C., Yan, D., Wei, H., 2013. Transgressive-regressive
791 sequences on the slope of an isolated carbonate platform (Middle-Late
792 Permian, Laibin, South China). *Facies*, 10.1007/s10347-012-0359-4: 1-19.

793 Rhodes, F.H., 1963. Conodont from the topmost Tensleep Sandstone of the
794 eastern Big Horn Mountains, Wyoming. *Journal of Paleontology*, 37:
795 401-408.

796 Ritter, S.M., 1986. Taxonomic revision and phylogeny of post-Early Permian crisis
797 *bisselli-whitei* Zone conodonts with comments on late Paleozoic diversity.
798 *Geologica et Palaeontologica*, 20: 139- 165.

799 Sha, Q.A., Wu, S.W., Fu, J.M., 1990. An integrated investigation on the Permian
800 System of Qin-Gui areas, with discussion on hydrocarbon potential.

801 Science Press, Beijing.

802 Shen, S.Z., Wang, Y., Henderson, C.M., Cao, C.Q., Wang, W., 2007. Biostratigraphy
803 and lithofacies of the Permian System in the Laibin-Heshan area of
804 Guangxi, South China. *Palaeoworld*, 16(1-3): 120-139.

805 Shen, S.Z., Yuan, D.X., Henderson, C.M., Tazawa, J., Zhang, Y.C., 2012. Implications
806 of Kungurian (Early Permian) conodonts from Hatahoko, Japan, for
807 correlation between the Tethyan and international timescales.
808 *Micropaleontology*, 58(6): 505-522.

809 Sheng, J.Z., Jin, Y.G., 1994. Correlation of Permian deposits of China. *Palaeoworld*,
810 4: 14-113.

811 Sun, Y.D., Lai, X.L., Jiang, H.S., Luo, G.M., Sun, S., Yan, C.B., Wignall, P.B., 2008.
812 Guadalupian (Middle Permian) Conodont Faunas at Shangsi Section,
813 Northeast Sichuan Province. *Journal of China University of Geosciences*,
814 19(5): 451-460.

815 Sun, Y.D., Lai, X.L., Wignall, P.B., Widdowson, M., Ali, J.R., Jiang, H.S., Wang, W., Yan,
816 C.B., Bond, D.P.G., Védryne, S., 2010. Dating the onset and nature of the
817 Middle Permian Emeishan large igneous province eruptions in SW China
818 using conodont biostratigraphy and its bearing on mantle plume uplift
819 models. *Lithos*, 119(1-2): 20-33.

820 Wang, C.Y., Ritter, S.M., Clark, D.L., 1987. The *Sweetognathus* complex in the
821 Permian of China: implications for evolution and homeomorphy. *Journal*
822 *of Paleontology*, 61: 1047-1057.

823 Wang, C.Y., 2002. Permian conodonts from Laibin and Heshan, Guangxi. *Bulletin*
824 *of Nanjing Institute of Geology and Palaeontology, Academia Sinica*, 15:
825 180-190.

826 Wang, W., Cao, C.Q., Wang, Y., 2004. The carbon isotope excursion on GSSP
827 candidate section of Lopingian-Guadalupian boundary. *Earth and*
828 *Planetary Science Letters*, 220(1-2): 57-67.

829 Wang, X.-D., Sugiyama, T., 2000. Diversity and extinction patterns of Permian
830 coral faunas of China. *Lethaia*, 33(4): 285-294.

- 831 Wang, Y., Jin, Y.G., 2000. Permian palaeogeographic evolution of the Jiangnan
832 Basin, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*,
833 160(1-2): 35-44.
- 834 Wang, Y., Wang, J., Chen, J., Wang, W.J., Shen, S.Z., Henderson, C.M., 2011. Progress,
835 Problems and Prospects on the Stratigraphy and Correlation of the
836 Kungurian Stage, Early Permian (Cisuralian) Series. *Acta Geologica Sinica*,
837 85(2): 387-398.
- 838 Wang, Z.H., 1994. Early Permian Conodonts from the Nashui Section, Luodian of
839 Guizhou. *Palaeoworld*, 4: 203-224.
- 840 Wardlaw, B.R., Grant, R.E., 1990. Conodont biostratigraphy of the Permian Road
841 Canyon Formation, Glass Mountains, Texas. *U.S. Geological Survey Bulletin*,
842 1895: 63-66.
- 843 Wardlaw, B.R., 2000. Guadalupian conodont biostratigraphy of the Glass and Del
844 Norte Mountains. In: Wardlaw, B.R., Grant, R.E., Rohr, D.M. (Eds.), *The*
845 *Guadalupian symposium-Smithsonian Contributions to the Earth Sciences*,
846 pp. 37-87.
- 847 Wardlaw, B.R., Nestell, M.K., 2010. Latest Middle Permian conodonts from the
848 Apache Mountains, West Texas. *Micropaleontology*, 56(1-2): 149-183.
- 849 Wignall, P.B., Sun, Y., Bond, D.P.G., Izon, G., Newton, R.J., Védérine, S., Widdowson,
850 M., Ali, J.R., Lai, X., Jiang, H., Cope, H., Bottrell, S.H., 2009a. Volcanism, Mass
851 Extinction, and Carbon Isotope Fluctuations in the Middle Permian of
852 China. *Science*, 324: 1179-1182.
- 853 Wignall, P.B., Védérine, S., Bond, D.P.G., Wang, W., Lai, X.-L., Ali, J.R., Jiang, H.-S.,
854 2009b. Facies analysis and sea-level change at the Guadalupian–Lopingian
855 Global Stratotype (Laibin, South China), and its bearing on the
856 end-Guadalupian mass extinction. *Journal of the Geological Society*,
857 166(4): 655-666.
- 858 Youngquist, W.L., Hawley, R.W., Miller, A.K., 1951. Phosphoria conodonts from
859 southeastern Idaho. *Journal of Paleontology*, 25(3): 356-364.
- 860 Zhang, K.X., Lai, X.L., Ding, M.H., Liu, J., 1995. Conodont Sequence and its Global

861 Correlation of Permian-Triassic Boundary in Meishan Section, Changxing,
862 Zhejiang Province. Earth Science-Journal of China University of
863 Geosciences, 20(6): 669-676.

864 Zhang, Z., Wang, Y., Zheng, Q.F., 2015. Middle Permian smaller foraminifers from
865 the Maokou Formation at the Tieqiao section, Guangxi, South China.
866 Palaeoworld, 24(3): 263-276.

867

868 Figure captions

869 Fig. 1 Middle Permian palaeogeographic reconstructions of South China and
870 Laibin area (after Wang and Jin, 2000; Wignall et al., 2009b).

871

872 Fig. 2 Field photographs of the studied section. A, an overview of the Chihhsia Fm.
873 in the lower part of the section. A digger in the far side (blue square) as scale. B, a
874 close review of fine laminated Bed 111-112 transition (Roadian-Wordian). The
875 pen (~15 cm long) as scale.

876

877 Fig. 3 Log of the lower part of Tieqiao section (Asselian to Kungurian) with
878 conodont ranges and zonation.

879

880 Fig. 4 Log of the middle part of Tieqiao section (Kungurian to Wordian) with
881 conodont ranges and zonation. Keys are the same as in Fig. 3. Note that the
882 reported occurrence of *Mesogondolella bisselli* in Bed 91 (Sha et al., 1990) cannot

883 be confirmed by our dataset (for details see discussion of the *Sw. adjunctus* zone).

884 Keys is the same as in figure 3.

885

886 Fig. 5 Log of the upper part of Tieqiao section (Wordian to Wuchiapingian) with

887 conodont ranges and zonation. Keys is the same as in figure 3.

888

889 Fig. 6 Correlation chart of the Early-Middle Permian with standard conodont

890 zonation (Henderson et al. 2012) and Tieqiao (this study) and Nashui (Mei et al.,

891 2002) sections. 1., *Pseudosw. monocornus*; 2., *H. gulloides*; 3., *G. sicilianus*; 4., *H.*

892 *excavates*.

893

894 Plate 1. SEM images of Tieqiao conodonts-genus *Sweetognathus*. Bar scale for 100

895 μm , 'a' for oral view, 'b' for lateral view. Default is oral view. 1, 7, 14, 17.

896 *Sweetognathus asymmetrica* n. sp., 1, holotype, S1_018 (18-1); 7, paratype,

897 S1_037 (22-2); 14, S_001 (18-1); 17, S_006 (24A); 2, 16. *Sweetognathus whitei*

898 (Rhodes, 1963), 2, S1_019 (18-1); 16, S_005 (23A); 3, 8. *Pseudosweetognathus*

899 *costatus* Wang, Ritter and Clark, 1987, 3, S1_021 (19-2), 8, S1_025 (21-2). 4.

900 *Sweetognathus* sp. 4, S1_023 (19-2); 5. Transitional form from *Sw. inornatus* to *Sw.*

901 *asymmetrica* n. sp., S1_038 (22-2); 6. *Sweetognathus* sp., S1_031 (22-1). 9.

902 *Sweetognathus* sp. A., S1_026 (21-2); 10. *Sweetognathus inornatus* Ritter, 1986,

903 S1_030 (22-1); 11. *Sweetognathus* cf. *bogoslovskajae* Kozur in Kozur and Mostler,

904 1976, S1_020 (18-1); 12, 15. *Sweetognathus toriyamai* (Igo, 1981), 12, S_002
905 (17c), 15, juvenile form, S_003 (17c); 13. *Neostreptognathodus ex gr. pequopensis*,
906 S_004 (17c).

907

908 Plate 2. SEM images of Tieqiao conodonts—genera *Sweetognathus*,
909 *Pseudosweetognathus*, *Neostreptognathodus* and *Hindeodus*. Scale bar is 100 μ m,
910 'a' for oral view, 'b' for lateral view. Default is oral view. 1, 2, 4, 9. *Sweetognathus*
911 *bogoslovskajae* Kozur in Kozur and Mostler, 1976, 1, S1_039 (22-2), 2, S1_043
912 (24-3), 4, juvenile, S1_057 (39-1), 9, S1_051 (27-1); 3, 12. *Sweetognathus*
913 *guizhouensis* Bando et al., 1980, 3. S1_048 (26-3), 12. S1_055 (39-1); 5-7.
914 *Pseudosweetognathus costatus* Wang, Ritter and Clark, 1987, 5, S1_047 (26-2), 6.
915 S1_049 (26-4), 7. S1_045 (25-2); 8. *Neostreptognathodus prayi* Behnken, 1975,
916 gerontic form, S1_046 (25-2); 10. *Sweetognathus clarki* Morphotype I, (Kozur,
917 1976), S1_050 (27-1); 11. *Sweetognathus inornatus* Ritter, 1986, S1_053 (29-1);
918 13. *Hindeodus* aff. *catalanoi*, S1_022 (19-2); 14, 16, 17. *Hindeodus minutus*
919 (Ellison, 1941), 14, S1_044 (25-1), 16, S1_056 (39-1), 17, S1_052 (28-1); 15.
920 *Hindeodus* sp. S1_042 (23-3).

921

922 Plate 3. SEM images of Tieqiao conodonts—genera *Sweetognathus* and
923 *Pseudosweetognathus*. Scale bar is 100 μ m, 'a' for oral view, 'b' for lateral view.
924 Default is oral view. 1-3. *Pseudosweetognathus costatus* Wang, Ritter and Clark,

925 1987, 1. S1_065 (52-2); 2. S1_066 (58-1), 3. S1_068 (65-2); 4, 5. *Sweetognathus*
926 *iranicus* Kozur, 1975, 4, S1_069 (66-3), 5, S1_071 (71-1); 6. *Pseudosweetognathus*
927 *monocornus* (Dai and Zhang, 1989), S2_001 (94-2); 7, 9, 19. *Sweetognathus* sp. 7.
928 S1_072 (90-7), 9. S2_002 (97-2), 19. S2_020 (100-1); 8, 10, 11. *Sweetognathus*
929 *adjunctus* (Behnken, 1975), 8. S2_004 (97-2), 10. S2_005 (97-2), 11. S1_076
930 (91-1); 12, *Sweetognathus* cf. *paraguizhouensis* S1_078 (91-3); 13. Transitional
931 form between *Sweetognathus iranicus* and *Sweetognathus hanzhongensis*, S2_007
932 (99-4); 14. *Sweetognathus subsymmetrics* Wang, Ritter and Clark, 1987, S2_039
933 (100-3); 15-18. *Sweetognathus hanzhongensis* (Wang, 1978), 15, S2_038 (100-5),
934 16, S2_018 (100-1), 17, S2_010 (100-1), 18, S2_028 (100-3).

935

936 Plate 4. SEM images of Tieqiao conodonts—genera *Sweetognathus*, *Gullodus*,
937 *Hindeodus* and *Pseudohindeodus*. Scale bar is 100 μ m, 'a' for oral view, 'b' for
938 lateral view. Default is oral view. 1. *Sweetognathus* sp. S2_049 (102-2); 2-4.
939 *Sweetognathus subsymmetrics* Wang, Ritter and Clark, 1987, 2. S2_051 (102-3); 3.
940 S2_056 (102-4); 4. S2_058 (102-4); 5, 15. *Sweetognathus iranicus* Kozur, 1975, 5,
941 S2_082 (105-3), 15, S2_072 (103-2); 6-7. *Gullodus tieqiaoensis* n sp., 6. holotype,
942 S1_060 (41-1), 7. paratype, S1_062 (41-2); 8. *Gullodus sicilianus* (Bender and
943 Stoppel, 1956), S3_020 (115-4); 9, 10, 16, 18. Transitional forms between
944 *Hindeodus* and *Pseudohindeodus*. Note that these elements developed weak apron
945 structures on basal cavities. 9. S1_074 (91-1), 10. S1_075 (91-1), 16. S2_057
946 (102-4), 18. S2_053 (102-3); 11, 12. *Gullodus duani* Mei et al., 2002, 11. S1_013

947 (TQ-28), 12. S3_022 (115-7); 13. *Pseudohindeodus ellipticae* n. sp. Sun and Lai,
948 paratype, S2_075 (104-2); 14. *Pseudohindeodus ramovsi* Gullo and Kozur, 1992,
949 S2_073 (103-4); 17. *Hindeodus* cf. *wordensis* Wardlaw, 2000; 17, S2_060 (102-5);
950 19, 20. *Hindeodus* cf. *julfensis* 19, S2_014 (100-1), 20. S2_011 (100-1); 21.
951 *Hindeodus* cf. *permicus*, S2_050 (102-2); 22, 36. *Hindeodus* sp. 22, S2_061 (102-5),
952 36, S2_022 (100-3); 23, 26. *Hindeodus* sp. A. 23, S2_068 (103-2); 26, S2_084
953 (106-1). 24, 25, 27, 30-32, 34, 35. *Hindeodus permicus* (Igo, 1981) 24. S2_081
954 (105-3), 25. S2_034 (100-4), 27. S2_026 (100-3), 30. S2_083 (105-3), 31. S2_016
955 (100-1), 32. S2_062 (103-1), 34. S2_071 (103-2); 35, S2_067 (103-2). 28, 29.
956 *Hindeodus minutus* (Ellison, 1941), 28. S2_027 (100-3); 29. S2_021 (100-2); 33.
957 *Hindeodus golloides* Kozur and Mostler, 1995, S2_066 (103-2).

958

959 Plate 5. SEM images of Tieqiao conodonts—genera *Mesogondolella* and
960 *Jinogondolella*. Scale bar is 100 μ m, 'a' for oral view, 'b' for lateral view. Default is
961 oral view. 1, 7. transitional type between *M. lamberti* to *J. nankingensis*, 1, S3_001
962 (109-2), 7, S3_012 (113-2); 2. *Mesogondolella lamberti* Mei and Henderson, 2002,
963 S3_002 (109-2); 3, 8. *Mesogondolella* sp., 3, S3_004 (109-3), 8. S3_013 (113-7); 4.
964 *Mesogondolella idahoensis* (Youngquist, Hawley, Miller, 1951), S3_005 (110-2); 5,
965 6. *Mesogondolella siciliensis* (Kozur, 1975), 5. S3_007 (111-1); 6. S3_006 (111-1);
966 9. *Jinogondolella nankingensis* (Ching, 1960), S3_011 (111-5); 10-11. *Jinogondolella*
967 *errata* Wardlaw and Nestell, 2000, 10. S3_019 (115-3), 11. S3_017 (115-2); 12.
968 *Jinogondolella aserrata* (Clark and Behnken, 1979), S3_021 (115-4); 13, 16.

969 *Jinogondolella* sp., 13. SP_051 (115-3), 16, S3_037 (116-7); 14, 15. *Jinogondolella*
970 *postserrata* (Behnken, 1975), S3_028 (116-1); 15. S3_036 (116-7); 17, 18.
971 *Jinogondolella shannoni* (Wardlaw, 1994), 17. S3_040 (116-8); 18, S3_030 (116-2);
972 19. *Jinogondolella altudaensis* (Kozur, 1992), S3_033 (116-3).

973

974 Plate 6. SEM images of Tieqiao conodonts—genera *Jinogondolella* and *Clarkina*.
975 Scale bar is 100 μ m, 'a' for oral view, 'b' for lateral view and 'c' for back view.
976 Default is oral view. 1. *Jinogondolella prexuanhanensis* (Mei and Wardlaw, 1994),
977 S4_004 (TQ-11); 2. *Jinogondolella* cf. *prexuanhanensis* SP_010 (118-2); 3-5.
978 *Jinogondolella shannoni* (Wardlaw, 1994), 3. S3_062 (118-2); 4. S4_006 (TQ-17+);
979 5, SP_014 (118-2); 6, 17. *Jinogondolella* sp., 6, SP_013 (118-2), 17, S_035 (119A);
980 7. *Jinogondolella xuanhanensis* (Mei and Wardlaw, 1994), 06-70_023 (TQ-6f);
981 8-11. *Jinogondolella granti* (Mei and Wardlaw, 1994), 8. 06-70_024 (TQ-6f), 9.
982 06-70_022 (TQ-6f), 10. TQ6f_010 (TQ-6f), 11. 06-70_027b (TQ-6f); 12-13.
983 *Clarkina postbitteri* Mei and Wardlaw, 1994, 12. S6_054 (TQ-1), 13. C6_040a
984 (TQ-1). 14. *Clarkina* sp., S6_055 (TQ-1); 15. *Clarkina transcaucasica* Gullo and
985 Kozur, 1992, S4_003 (134-9); 16. *Clarkina hongshuiensis* Henderson, Mei and
986 Wardlaw, 2002, S_029 (TQ-1).

987

988 Plate 7. SEM images of Tieqiao conodonts—genera *Hindeodus*, *Jinogondolella*,
989 *Mesogondolella* and *Sweetognathus*. Scale bar is 100 μ m, 'a' for oral view, 'b' for

990 lateral view. Default is oral view. 1, transitional form between *Sweetognathus*
991 *bogoslovskajae* and *Sweetognathus inornatus*, S_007 (24A); 2. *Sweetognathus*
992 *inornatus* Ritter, 1986, S_008 (26C); 3. *Sweetognathus fengshanensis* Mei and
993 Wardlaw, 1998, S_016 (117-3); 4. *Mesogondolella idahoensis* (Youngquist, Hawley
994 and Miller, 1951), S_009 (109-2); 5. *Jinogondolella palmata* (Nestell and Wardlaw,
995 2010), S_025 (111-1-2); 6-8. *Hindeodus catalanoi* (Gullo and Kozur, 1992), 6,
996 S3_052 (117-2), 7, S3_052 (117-2), 8, S3_043 (116-12); 9-10. *Sweetognathus*
997 *hanzhongensis* (Wang, 1978), 9, S4_012 (TQ-25), 10, S_025 (115-8). 11-12.
998 *Pseudohindeodus augustus* (Igo, 1981), 11, S7_007 (102-4), 12, S7_005 (102-4).
999 13. *Pseudohindeodus* sp. S7_003 (104-2). 14. *Pseudohindeodus ellipticae* n. sp. Sun
1000 and Lai, holotype, S7_001 (104-2).