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

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

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

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

Introduction

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

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

Geological setting and stratigraphy

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

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

Materials and methods

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

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

Results

A total of 2100 conodont specimens (221 P_1 elements) were obtained from the Yiwagou samples and this study focuses on those obtained from the upper Zhalishan Formation (Dienerian and Smithian, Figs. 4–7). Most samples were productive, including the sample no. ZLS-30 from the Zhalishan Formation which yielded abundant *Scythogondolella*, (38 P_1 elements in total). This conodont fauna has rarely been found in the Qinling Basin or in South China before. The sample no. ZLS-30 included 30 *Scythogondolella mosheri*, one *Sc. phryna* and one *Sc.* cf. *milleri*. The remaining specimens are difficult to be identified because of poor preservation. Only one segminiplanate conodont with a deformed platform, assigned to *Neogondolella* cf. *milleri* was found in Zhalishan Formation before this study (Lai, 1992). Other than *Scythogondolella*, 13 *Novispathodus* and some ramiform elements were also recovered from this sample, including six *Novispathodus waageni waageni* and three *Novispathodus waageni eowaageni*. All specimens in this sample have a Conodont Alteration Index (CAI) around five (i.e. a black in color).

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

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

Eurygnathodus costatus-Eurygnathodus hamadai Assemblage Zone.—

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

Upper limit: first occurrence of *Novispathodus waageni*

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

Novispathodus waageni-Scythogondolella mosheri Assemblage Zone.—

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

Upper limit: First occurrence of *Pc. obliqua*

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

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

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

Smithian strata worldwide. In conclusion, the *Novispathodus waageni-Scythogondolella mosheri* Assemblage Zone at Yiwagou is considered to be of Smithian age.

Pachycladina-Parachirognathus Assemblage Zone.—

Lower limit: First occurrence of *Pc. obliqua*

Upper limit: undefined

Hundreds of ramiform elements occur in this zone, and their sizes vary substantially from bed to bed (and will be subject to future study). This zone is characterized by the bloom of *Pachycladina* and *Parachirognathus*, including *Pachycladina obliqua*, *Pc. qinlingensis*, *Pc.* sp., *Parachirognathus delicatulus*, *Pa. semicircnelus* and *Pa*. sp.. The conodont *Hadrodontina anceps* also occurs. *Pachycladina* and *Parachirognathus* are widely distributed in South China (Jiang et al., 2000; Wang et al., 2005; Yan et al., 2013; Chen et al., 2015), Qinling areas (Lai, 1992), Tibet (Xia and Zhang, 2005) and western USA (Clark et al., 1979; Solien, 1979). *Pachycladina* and *Hadrodontina* are common in the Dinarides (Perri, 1991; Kolar-Jurkovšek and Jurkovšek, 2015; Kolar-Jurkovšek et al., 2017), whereas *Parachirognathus* is not very frequent. This zone corresponds to the *Pachycladina-Parachirognathus* Assemblage Zone in the Beibei Area, Chongqing (Jiang, 1982) and the Bianyang Section, Guizhou (Yan et al., 2013), South China, and is also equivalent to the *Parachirognathus-Fumishius* Assemblage Zone and upper *Parachirognathus ethingtoni* Zone in the Great Basin, western USA (Clark et al., 1979; Solien, 1979), where they were all assigned to the Smithian Substage.

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

Discussion

Global geographical distribution of Early Triassic platform-bearing gondolellid conodonts.—Ten platform-bearing gondolellid conodont genera (*Clarkina*, *Neoclarkina* Henderson, *Borinella* Budurov and Sudar, *Scythogondolella*, *Neogondolella* Bender and Stoppel, *Gladigondolella* müller, *Paullella* Orchard, *Columbitella* Orchard, *Magnigondolella* Golding and Orchard, *Spathogondolella* Jiang) occur in the Early Triassic. The evolution of platform-bearing gondolellids in Early Triassic remains controversial. Klets and Kopylova (2007) suggested an evolutionary lineage consisting of: - *Mesogondolella* - *Clarkina* - *Neospathodus* - *Neogondolella* - *Scythogondolella*. However, we consider that *Neogondolella* is unlikely to have evolved from *Neospathodus*. The opinion we tentatively support is as follows: *Clarkina* survived the end-Permian mass extinction in low abundance until disappearing in the late Griesbachian. A few *Neogondolella*, *Neoclarkina* and *Borinella* species evolved from *Clarkina* during this time. *Clarkina*, *Neogondolella* and *Neoclarkina* have very similar P1 elements, but the latter two can be distinguished from *Clarkina* with their different S_0 elements (Henderson and Mei, 2007). In this paper, *Clarkina* is used for those conodonts that originated in the Permian and extended into Early Triassic. As for *Scythogondolella*, Orchard (2007) proposed an evolutionary lineage consisting of: - *Cl. nassichuki* - *Cl. krystyni* - *Cl. discreta* - *Sc.*? sp. A - Smithian *Scythogondolella*. *Sc.*? sp. A in the early Dienerian (Orchard, 2007, Orchard and Zonneveld, 2009) and *Ng*. sp. B in the late Dienerian (Hatleberg and Clark, 1984, pl. 1, fig. 3) might be the ancestor of Smithian *Scythogondolella*. Its multielement apparatus of 15 elements differs from *Neogondolella* in both the P and S elements (Orchard, 2005, 2007; Goudemand et al., 2012). However, since the multielement apparatuses have not been completely established, the genera of some species might be corrected in the future.

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

Griesbachian.—Some *Clarkina* species [*Cl. carinata* (Clark), *Cl. planata* (Clark), *Cl. orchardi* (Mei), *Cl. kazi* (Orchard), *Cl. meishanensis* Zhang et al., *Cl. zhejiangensis* (Mei), *Cl. nassichuki* (Orchard), *Cl. taylorae* (Orchard), *Cl. tulongensis* (Tian), *Cl. deflecta* (Wang and Wang), *Cl. changxingensis* (Wang and Wang), *Cl. prediscreta* Wu et al., *Cl. postwangi* (Tian), *Cl. hauschkei* Kozur] survived the end-Permian mass extinction and lived alongside newly evolved species [*Neogondolella griesbachensis* (Orchard), *Ng. lehrmanni* (Chen et al.) and *Neoclarkina krystyni* (Orchard), *Nc. discreta* (Orchard and Krystyn)] in the Griesbachian. They have been reported from northern low-latitude regions: South China (e.g., Zhang et al., 2007; Jiang et al., 2007, 2011; Chen et al., 2009; Zhao et al., 2013), western USA (Clark et al., 1979); northern high-latitude areas: British Columbia (Mosher, 1973; Henderson, 1997; Orchard and Zonneveld, 2009; Golding et al., 2014), Canadian Arctic (Mosher, 1973; Henderson, 1997; Orchard, 2007; Orchard, 2008), Svalbard (Nakrem et al., 2008), Greenland (Teichert and Kummel, 1976); south margin of Neo-Tethys: Oman (Krystyn et al., 2003), West Pakistan (Sweet, 1970a), Kashmir (Sweet, 1970b), India (Krystyn and Orchard, 1996; Goel, 1977; Orchard and Krystyn, 1998; Krystyn et al., 2004), Nepal (Hatleberg and Clark, 1984), Tibet (Tian, 1982; Orchard et al., 1994; Wang and Wang, 1995; Orchard and Krystyn, 1998; Wu et al., 2014); Panthalassa: Japan (Igo, 1989; Koike, 1996). *Borinella megacuspa* Orchard that originated in the late Griesbachian has been reported from Canadian Arctic (Orchard, 2008).

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

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

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

Smithian.—Orchard et al. (2007) considered the middle Smithian to be the heyday of Early Triassic conodonts. In additon to *Borinella*, three new genera *Scythogondolella*, *Neogondolella* and *Paullella*, probably evolved in the late Dienerian or early Smithian have been found in Smithian. Amongst these, *Scythogondolella* was a dominant and cosmopolitan genus (Orchard, 2008; Klets, 2008). In contrast, other platform-bearing gondolellids were rarer and less widespread. *Scythogondolella* is represented by seven species [*Sc. mosheri*, *Sc. milleri*, *Sc. phryna*, *Sc. lachrymiformis* Orchard, *Sc. rhomboidea* Orchard and Zonneveld, *Sc. ellesmerensis* Orchard, *Sc. crenulata* (Mosher)] and five other species in open nomenclature (*Sc*.? sp. A Orchard and *Sc.* B-E Orchard), distributed across northern high-latitude regions: Siberia (Dagis, 1984; Klets and Yadrenkin, 2001; Konstantinov, 2013), Canadian Arctic (Mosher, 1973; Kozur and Mostler, 1976; Orchard, 2007, 2008 and Orchard and Zonneveld, 2009; Beranek et al., 2010), British Columbia (Mosher, 1973; Orchard, 2008; Orchard and Zonneveld, 2009; Golding et al., 2014, 2015; Henderson et al., 2018), Svalbard (Weitschat and Lehmann, 1978; Hatleberg and Clark, 1984; Nakrem et al., 2008), South Primorye (Kozur and Mostler, 1976; Buryi, 1979; Bondarenko et al., 2015), Qinghai, China (part of the Tarim Plate, Fang et al., 2013); the south margin of Neo-Tethys: Tibet (Tian, 1982; Tian et al., 1983; Zhao and Zhang, 1991; Wang and Wang, 1995; Zou et al., 2006), India (Matsuda, 1984), Timor Island (Nogami, 1968; Berry et al., 1984), West Pakistan and Nepal (Kozur and Mostler, 1976; Hatleberg and Clark, 1984). Some also occurred in relatively low-latitude (about 10N°) regions: western USA (Müller, 1956; Clark and Mosher, 1966; Solien, 1979; Clark et al., 1979; Orchard, 2008), Chaohu, South China (Liang et al., 2011), Qinling Basin, northwestern China (this paper) and Panthalassa: Japan (Nogami, 1968).

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

Spathian.—The bloom of *Scythogondolella* species was terminated in the late Smithian extinction along with *Borinella* and *Paullella*, leaving *Neogondolella* as the sole platform-bearing gondolellid survivor (although no species of this genus are known to have survived). The Spathian saw several new *Neogondolella* species appear [*Ng. jubata* Sweet, *Ng. amica* Klets, *Ng. captica* Klets, *Ng. taimyrensis* Dagis, *Ng. paragondolellaeformis* Dagis, *Ng. shevyrevi* (Kozur and Mostler), *Ng. dolpanae* Balini, Gavrilova and Nicora]. They were joined by another four genera [*Gladigondolella* (*Gl. malayensis* Nogami, *Gl. carinata* Bender), *Columbitella* (Sweet), *Magnigondolella regalis* Golding and Orchard and *Spathogondolella jiarongensis* Jiang and Chen] that originated in the late Spathian and ranged into Middle Triassic.

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

Controls on the evolution of Early Triassic platform-bearing gondolellid conodonts.—Some platform-bearing gondolellids were a deep-water, nektobenthic group, such as *Clarkina* and *Neogondolella* (Lai et al., 2001), but others possibly prefer pelagic environments, such as *Borinella* and *Gladigondolella* (Orchard, 2007; Kozur et al., 2009; Zhang et al., 2017). The former are likely to have been affected by the substantial temperature and seafloor oxygenation fluctuations known to have affected Early Triassic marine habitats, and the latter have probably been mainly affected by the seawater temperature. In particular, the diversity and evolution of platform-bearing gondolellids appear to have closely followed the temperature record of the time (Sun et al., 2012). The disappearance in late Griesbachian of *Clarkina* that was dominant in end Permian strata coincides with a temperature rise that began at the Permo-Triassic boundary and peaked at the late Griesbachian. The rise saw the platform-bearing gondolellids of low diversity and abundance contract to relatively high latitude regions in the Dienerian (Fig. 8). The subsequent cooling trend in the Dienerian, that peaked at the Dienerian/Smithian boundary, coincided with the appearance of new taxa including *Scythogondolella*, *Paullella* and several *Neogondolella* species. Temperature then rose again through the Smithian, peaking late in the substage. It appears that many conodonts could not cope with these high temperatures, especially in tropical latitudes, causing genera such as *Neogondolella* and *Borinella* to become restricted to high-latitude regions (Fig. 8). In contrast *Scythogondolella* was tolerant of a broad range of temperatures and was found in all latitudes. However, the latest Smithian temperature peak coincides with the extinction of all platform-bearing gondollelids, except for *Neogondolella* that saw a turnover amongst its constituent species. Finally, platform-bearing gondolellids returned to the equatorial regions and achieved global distribution again during late Spathian cooling.

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

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

Conclusions

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

The fluctuating fortunes of the platform-bearing gondolellids closely follow the seawater temperature record with low diversity related to peaks of temperature in Early Triassic seas. Compilation of global platform-bearing gondolellid occurrences show that high temperatures in the late Griesbachian-early Dienerian and in the Smithian saw their retreat to higher, cooler latitudes. *Scythogondolella* is shown to be both a thermophilic and eurythermic genus which was successful during the high temperatures of the Smithian, when other platform-bearing gondolellids disappeared from tropical latitudes. However, the peak temperatures late in the Smithian may have been too much for even *Scythogondolella* to survive.

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

Systematic paleontology

Class Conodonta Eichenberg, 1930

Order Conodontophorida Eichenberg, 1930

Family Ellisoniidae Clark, 1972

Genus *Parafurnishius* Yang et al., 2014

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

Parafurnishius xuanhanensis Yang et al., 2014

Figure 4.1–4.21

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

Holotype.—NIGP161300, from the Feixianguan Formation at the Panlongdong Section in Xuanhan County, northeastern Sichuan Province, southwest China (Yang et al., 2014, pl. 3, fig. J).

Occurrence.—from the Zhalishan Formation at the Yiwagou Section in Tewo County, Gansu Province, northwestern China, in Dienerian or Smithian.

Description.—The P1 element has a variable shape platform with the width:length ratio about 1:2. In upper view, a relatively small cusp lies in the centre, surrounded by 8–10 high and strong irregularly distributed denticles. Generally, it has an anterior process with 1–2 denticles and a roughly triangular posterior process with 3–4 denticles, between which there is a broad platform with 2–7 denticles and a cusp. In lateral view, the basal margin is almost straight, but sometimes upturned posteriorly in juvenile elements. Denticles generally erect or inclined posteriorly in the posterior part. In lower view, a large basal cavity is approximately diamond-shaped with a basal pit located in the centre. A basal furrow extends from the basal pit to the anterior end, but always no furrow or a very shallow one to the posterior end.

Materials.—71 specimens.

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

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

Order Ozarkodinida Dzik, 1976

Family Gondolellidae Lindström, 1970

Subfamily Scythogondolellinae Orchard, 2007

Genus *Scythogondolella* Kozur, 1989

Type species.—Gondolella milleri Müller, 1956 from the Lower Triassic *Meekoceras* bed, Dinner Springs Canyon, northeastern Nevada, USA.

Remarks.—Compared with *Neogondolella*, *Scythogondolella* is characterized by a very prominent blade-carina which extends beyond the posterior end to form a free blade in most cases.

Scythogondolella mosheri (Kozur and Mostler, 1976)

Figure 5.1–5.21

1973 *Neogondolella nevadensis* Clark in Mosher, p. 169, pl. 19, figs. 17, 18, 24.

1973 *Neogondolella elongata* Sweet in Mosher, p. 166, pl. 19, fig. 19.

1976 *Gondolella mosheri* Kozur and Mostler, p. 8, pl. 1, figs. 9–12.

1978 *Neogondolella planata* Clark in Weitschat and Lehmann, pl. 14, figs. 1–5.

1978 *Neogondolella nevadensis* Clark in Weitschat and Lehmann, pl. 14, figs. 6–10.

1982 *Neogondolella elongatus* Sweet in Tian, pl. 1, 11.

1983 *Neogondolella elongatus*; Tian et al., pl. 94. fig. 1.

1984 *Neogondolella nevadensis*; Berry et al., pl. 1, figs. 22–25.

1984 *Neogondolella nevadensis*; Hatleberg and Clark, pl. 2, figs. 14, 15.

1991 *Neogondolella nevadensis*; Zhao and Zhang, pl. 1, figs. 17, 18.

2005 *Scythogondolella mosheri*; Orchard, p. 97–98, fig. 23A–H.

2008 *Scythogondolella mosheri*; Orchard, p. 410, pl. 5, figs. 1–4.

2008 *Scythogondolella mosheri*; Nakrem et al., pl. 5, figs. 4–6, 12, 13.

2014 *Scythogondolella mosheri*; Golding et al., p. 173, pl. 1, figs. 7–9.

2015 *Scythogondolella mosheri*; Golding et al., p. 167–168, pl. 12, figs. 19–21.

2018 *Scythogondolella mosheri*; Henderson et al., pl. 1. figs. 35–37.

Holotype.—from Dolpo, Nepal (Kozur and Mostler, 1976, pl. 1, figs. 9–12).

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

Description.—This species has a wedge-shaped platform, with the maximum width occurring posteriorly. The posterior margin is typically constricted and indented inwards from the large cusp which projects posteriorly beyond the platform margin. Consequently, some specimens have a heart-shaped plan view. The platform with smooth upturned margins tapers progressively to the anterior end, leaving a free blade of variable length. The blade-carina is typically high with relatively large, discrete denticles, of uniform height in lateral view. In lower view, the rounded expanded basal cavity loop surrounds a small basal pit. Juvenile specimens typically have a more developed carina than platform, with a very prominent cusp projecting posteriorly beyond the platform margin.

Materials.—30 specimens.

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

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

Scythogondolella cf. *milleri* (Müller, 1956)

Figure 5.22–5.23

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

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

Description.—This large broken specimen has subparallel upturned platform margins ornamented with small nodes. The carina is relatively low with fused denticles. The moderate-sized cusp projects posteriorly beyond the platform margin. In the lower view, the keel with basal groove is broad.

Material.—One specimen.

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

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

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

Scythogondolella phryna Orchard and Zonneveld, 2009

Figure 5.24–5.26

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

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

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

Holotype.—GSC 132549 from GSC loc. no. C-103866 (213E), in the Toad Formation on Toad River, northeast British Columbia (Orchard and Zonneveld, 2009, pl. 16, figs. 16, 23, 24).

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

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

Material.—One specimen.

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

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Figure captions

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

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

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

Figure 4. SEM photos of conodonts obtained from the Yiwagou Section. **(1–21)** *Parafurnishius xuanhanensis* Yang et al., 2014: **(1–6)** from sample ZLS-6, registration nos. ZLS17006001–17006002; **(7–12)** from sample ZLS-7, registration nos. ZLS17007001–17007002; **(13–21)** from sample ZLS-13, registration nos.

ZLS17013001–17013003. **(22–36)** *Eurygnathodus costatus* Staesche, 1964, from sample ZLS-9, registration nos. ZLS17009001–17009005. **(37–45)** *Eurygnathodus hamadai* (Koike, 1982), from sample ZLS-9, registration nos. ZLS17009006–17009008. Scale bar = 100 µm.

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

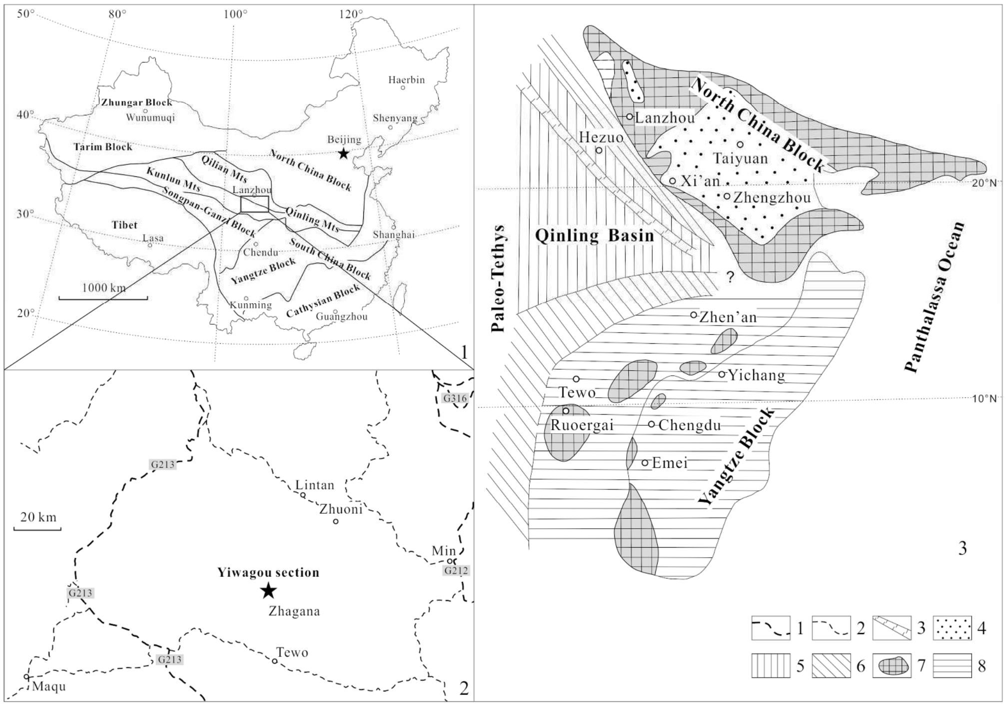
Figure 6. SEM photos of conodonts obtained from the Yiwagou Section. **(1–6)** *Novispathodus waageni waageni* (Sweet, 1970a), from sample ZLS-30, registration nos. ZLS17030039–17030041. **(7–10)** *Novispathodus waageni eowaageni* (Zhao and Orchard in Zhao et al., 2007), from sample ZLS-30, registration nos. ZLS17030042–17030043. **(11–12)** *Parachirognathus* n. sp. A, from sample ZLS-82, registration nos. ZLS17082001–17082002. **(13)** *Pachycladina obliqua* Staesche, 1964, S_2 element, from sample ZLS-42, registration nos. ZLS17042001. **(14–19)** *Pachycladina qinlingensis* Lai, 1992: **(14)** P_2 element, from sample ZLS-88, registration nos. ZLS17088001; **(15)** P_2 element, from sample ZLS-85, registration nos. ZLS17085001; **(16)** P_2 element, from sample ZLS-74, registration nos. ZLS17074001; **(17)** P_2 element, from sample ZLS-53, registration nos. ZLS17053001; **(18)** S_1 element, from sample

ZLS-98, registration nos. ZLS17098001; **(19)** S_2 element, from sample ZLS-67, registration nos. ZLS17067001. **(20–22)** *Parachirognathus semicircnelus* Tian and Dai in Tian et al., 1983: **(20)** S_2 element, from sample ZLS-88, registration nos. ZLS17088002; **(21, 22)** S_1 elements, from sample ZLS-88, registration nos. ZLS17088003–17088004. Scale bar = 100 μm.

Figure 7. SEM photos of conodonts obtained from the Yiwagou Section. **(1–7)** *Pachycladina qinlingensis*: **(1)** M element, from sample ZLS-83, registration nos. ZLS17083001; **(2)** M element, from sample ZLS-91, registration nos. ZLS17091001; **(3)** $S_{3\text{-}4}$ elements, from sample ZLS-98, registration nos. ZLS17098002; **(4)** S_3 element, from sample ZLS-50, registration nos. ZLS17050001; **(5)** S_1 element, from sample ZLS-50, registration nos. ZLS17050002; **(6)** S_3 element, from sample ZLS-67, registration nos. ZLS17067002; **(7)** S_2 element, from sample ZLS-82, registration nos. ZLS17082003. **(8–10)** *Pachycladina obliqua*: **(8)** M element, from sample ZLS-95, registration nos. ZLS17095001; **(9)** $S_{3\text{-}4}$ elements, from sample ZLS-96, registration nos. ZLS17096001; **(10)** S_1 element, from sample ZLS-98, registration nos. ZLS17098003. **(11)** *Parachirognathus delicatulus* Wang and Cao, 1981, S_1 element, from sample ZLS-83, registration nos. ZLS17083002. **(12, 13)** *Hadrodontina anceps* Staesche, 1964: **(12)** P_1 element, from sample ZLS-96, registration nos. ZLS17096002; **(13)** P_1 element, from sample ZLS-67, registration nos. ZLS17067003. Scale bar = 200 μm.

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

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



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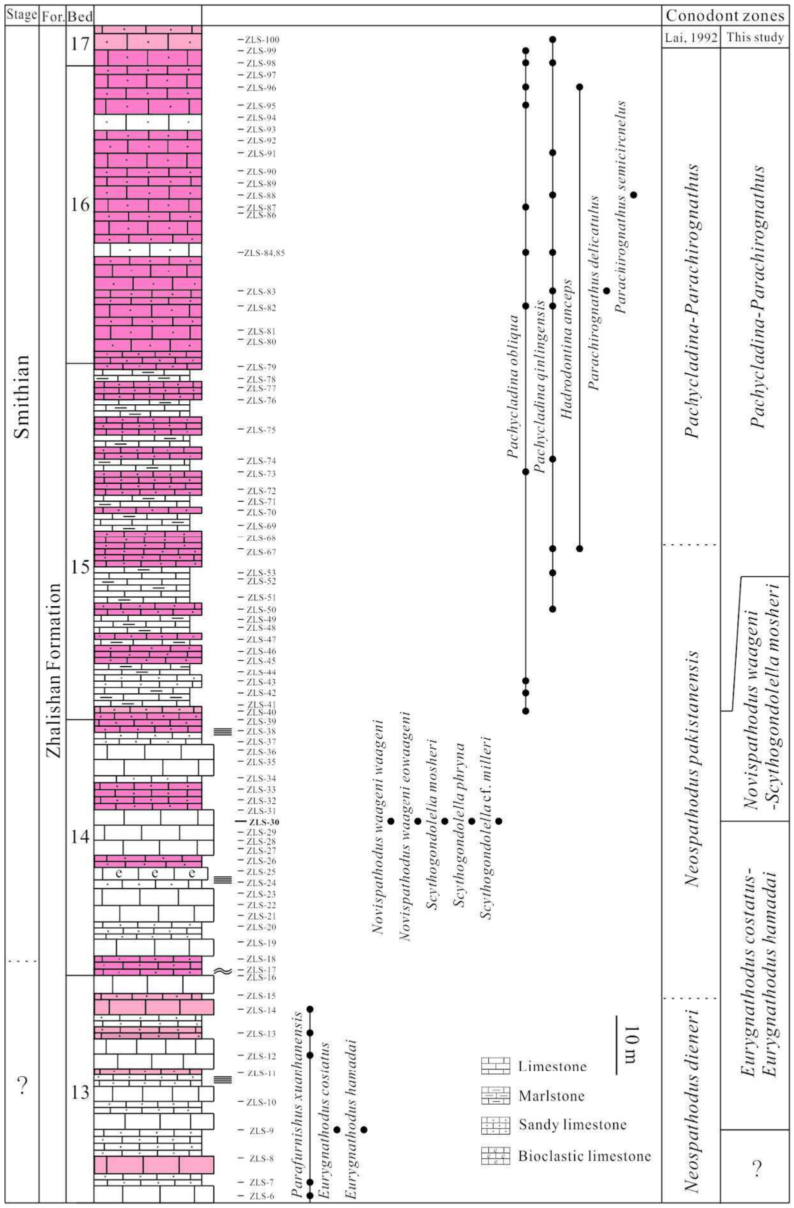

Figure 3. Conodont distribution in the Lower Triassic strata at the Yiwagou Section, Tewo, northwestern China. Scale bar = 10 m.

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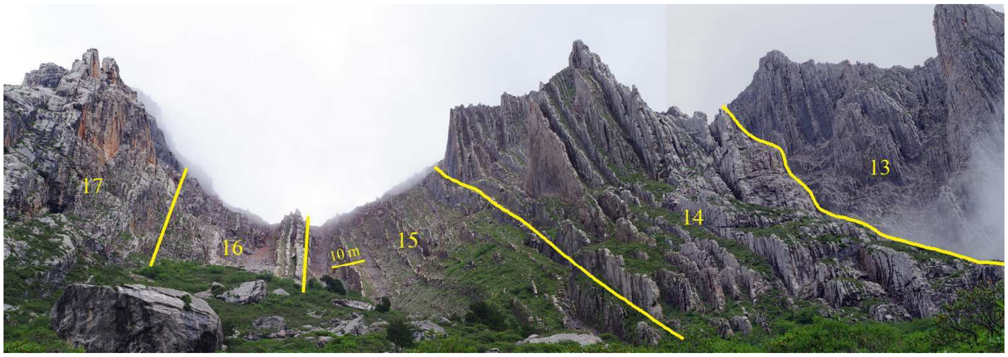

Figure 2. Photographs of marine red beds in Zhalishan Formation from Dienerian to Smithian, Yiwagou Section. 13–17. Bed numbers. Scale bar = 10 m.

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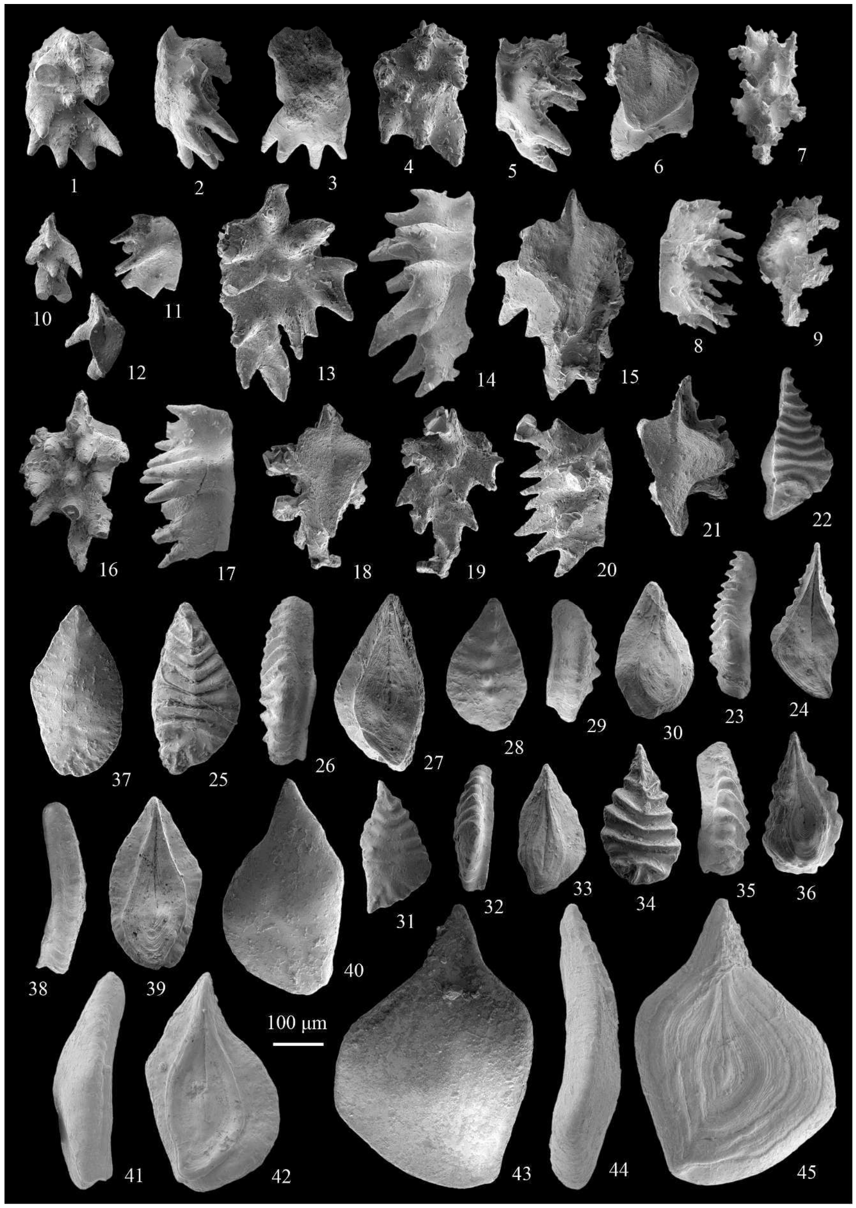

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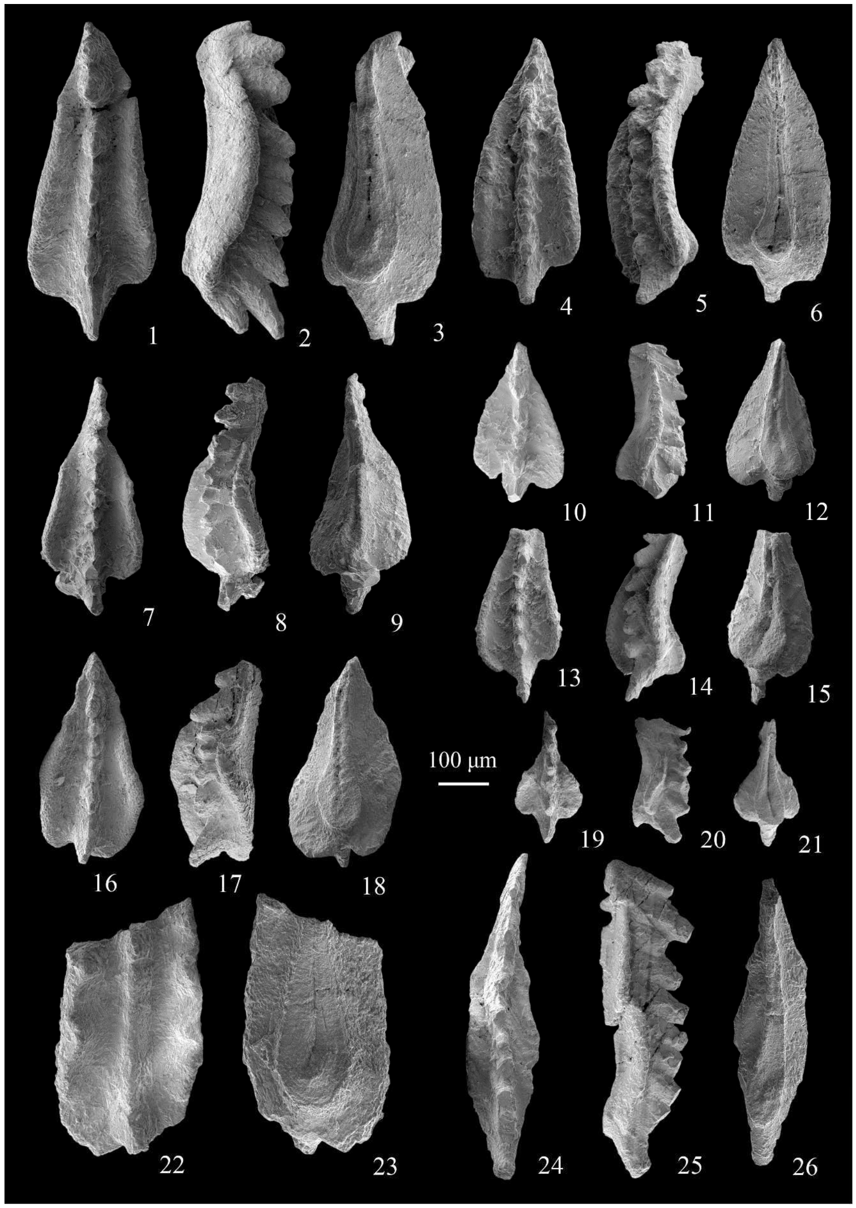

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209x297mm (300 x 300 DPI)

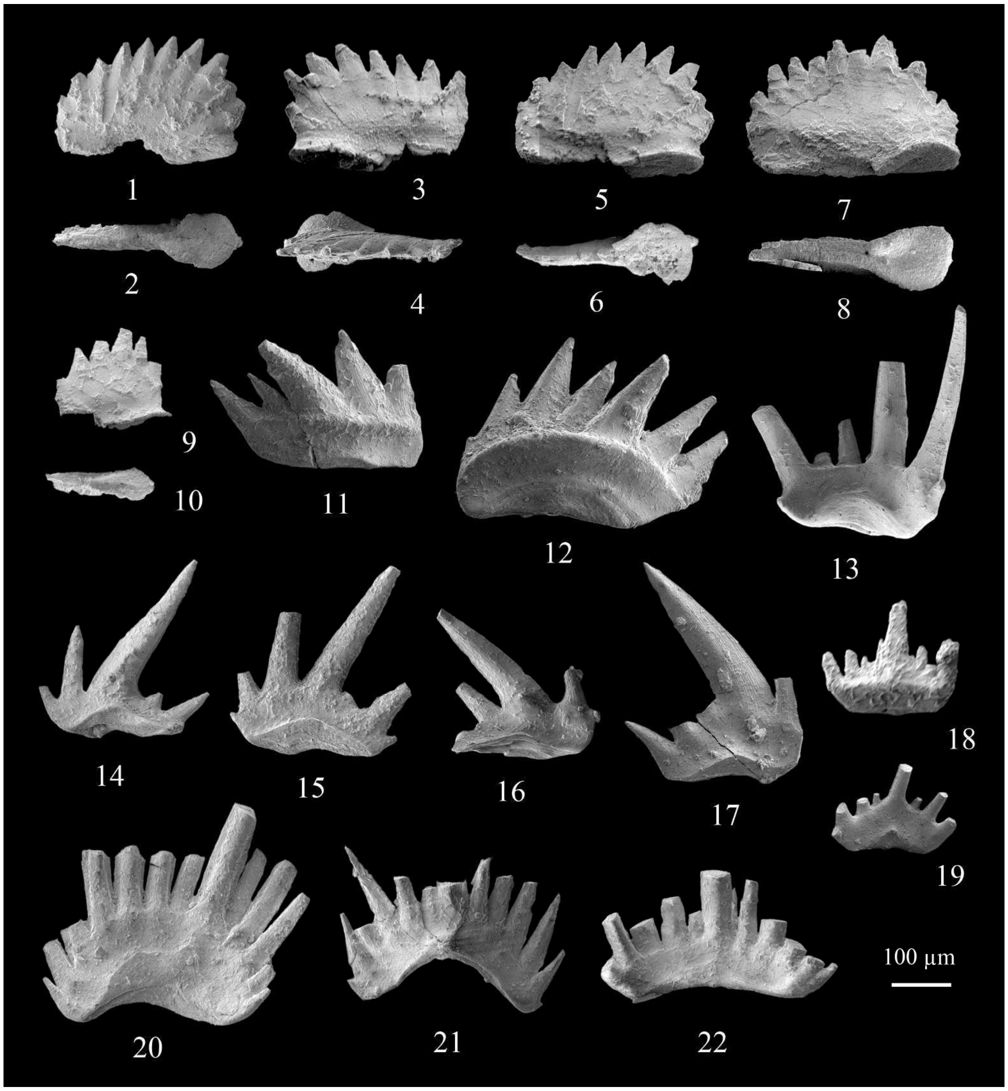

Figure 6. SEM photos of conodonts obtained from the Yiwagou Section. (1–6) Novispathodus waageni waageni (Sweet, 1970a), from sample ZLS-30, registration nos. ZLS17030039–17030041. (7–10) Novispathodus waageni eowaageni (Zhao and Orchard in Zhao et al., 2007), from sample ZLS-30, registration nos. ZLS17030042–17030043.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

209x227mm (300 x 300 DPI)

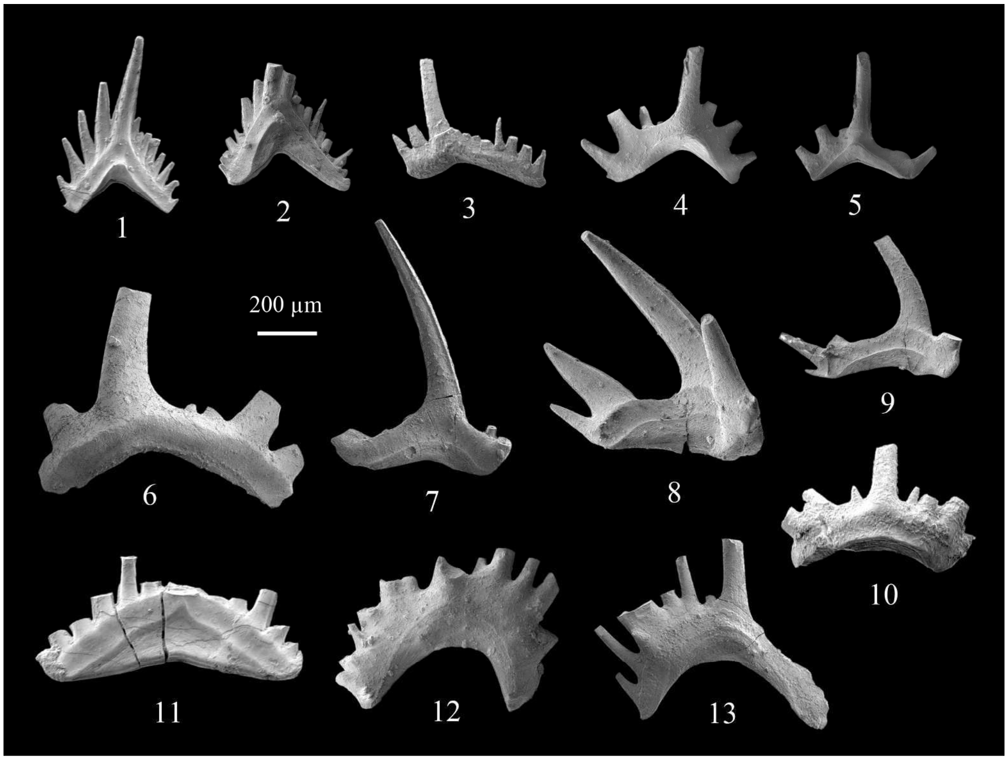

Figure 7. SEM photos of conodonts obtained from the Yiwagou Section. (1–7) Pachycladina qinlingensis: (1) M element, from sample ZLS-83, registration nos. ZLS17083001; (2) M element, from sample ZLS-91, registration nos. ZLS17091001; (3) S3-4 elements, from sample ZLS-98, registration nos. ZLS17098002;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

209x158mm (300 x 300 DPI)

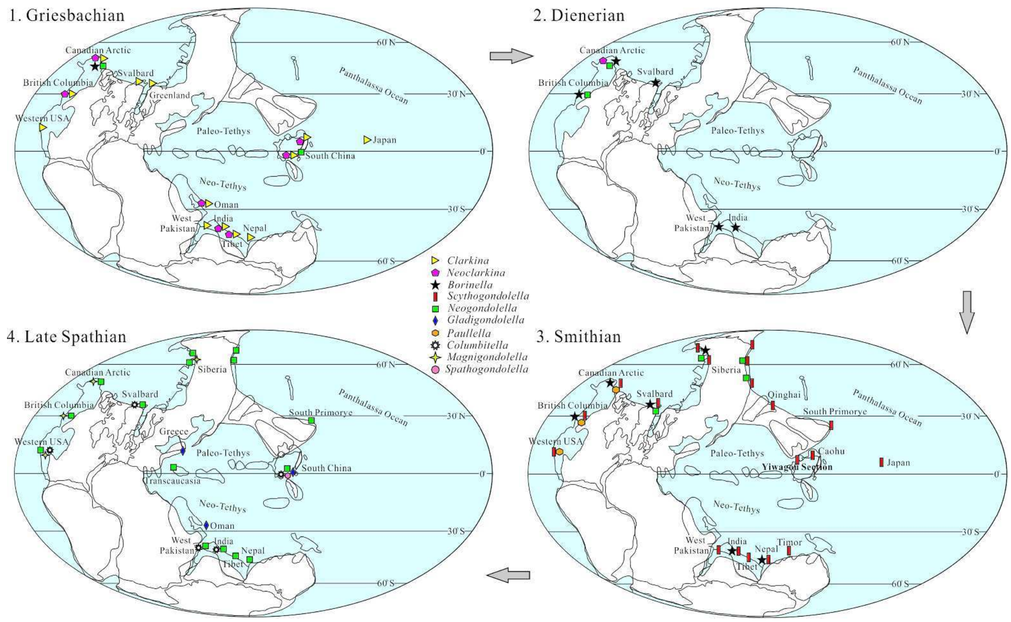

Figure 8. Global distribution of platform-bearing gondolellid conodonts in the Early Triassic (palaeogeographic map is modified after Muttoni et al., 2009 and Sun et al., 2012; occurrences are given in the text).

230x140mm (300 x 300 DPI)