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Polygnathids (Conodonta) around the Pragian/Emsian boundary from the Dacun-1 section (central Guangxi, South China)

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Abstract.—The base of the Emsian, which is defined by the first appearance of the conodont *Polygnathus kitabicus*, has never been successfully demonstrated in the South China Block (including Guangxi and eastern Yunnan). As a result, we studied conodonts from the lowermost part of the Shizhou Member of the Yukiang Formation at the Dacun-1 section in the Liujing area, Guangxi. This new investigation has revealed a conodont fauna only consisting of *Polygnathus pireneae*, *P. sokolovi*, *P. kitabicus*, *P.* sp. and *Pandorinellina exigua philipi*, which can be assigned to the uppermost part of the *pireneae* Zone and the lowermost part of the *kitabicus* Zone in ascending order. The Pragian/Emsian boundary at the Dacun-1 section is located in the highest thick-bedded limestone bed that can be observed in the lowermost part of the Shizhou Member. Therefore, this is the first time that the lower boundary of the Emsian defined by the lowest occurrence of *P. kitabicus* is reported in the South China Block. However, the scarcity of suitable limestone samples for conodont analysis in the middle and upper parts of the Shizhou Member precludes definitive identification of the upper boundary of the *kitabicus* Zone in the Liujing area.

Introduction

Due to the Caledonian orogeny, the lowest part of the Lower Devonian in the South China Block (including Guangxi and eastern Yunnan) is predominately represented by non-marine siliciclastic rocks. An epicontinental sea started to dominate the southern margin of the South China Block during the Pragian age, and mixed lime-mud units were the dominant deposits on the shallow shelf (Hou, 2000). Widespread and massive deposition of Devonian carbonates in the South China Block did not occur until the time of the lower Emsian *excavatus* Zone (Lu and Chen, 2016). In the past forty years, the Emsian conodonts from Guangxi and southeastern Yunnan had been extensively studied. Since the first Early Devonian (mainly Emsian) conodont research in the South China Block by Wang and Wang (1978), numerous records of Early Devonian conodonts have been reported in the South China Block. Wang and Ziegler (1983), Wang (1989), and Bai et al. (1994) successively recognized a relatively complete Pragian and Emsian conodont zonation including the *sulcatus*, *dehiscens*, *perbonus*, *inversus*, *serotinus*, and *patulus* zones, in ascending order. However, the scheme of the standard conodont zonation of the uppermost Pragian and lower Emsian has been changed significantly (Yolkin et al., 1994, table 1). Moreover, owing to the taxonomic revision of *Polygnathus dehiscens* Philip and Jackson, 1967, *P. kitabicus* Yolkin et al., 1994 has been viewed as the direct descendant of *P. pireneae* Boersma, 1973 and chosen to define the base of the Emsian by its lowest occurrence (Yolkin et al., 1997).

When reviewing the base of the Emsian in the South China Block that was previously defined by the first appearance of *P. dehiscens*, Lu and Chen (2016) pointed out that most specimens previously reported as *P. dehiscens* in Guangxi and southeastern Yunnan actually belong to *P. excavatus excavatus* Carls and Gandl, 1969 or *P. excavatus* ssp. 114 Carls and Valenzuela-Ríos, 2002. They further suggested that the *kitabicus* Zone in the South China Block probably was located in strata mainly compromising marine siliciclastic rocks. Recently, Lu et al. (2016, 2017) restudied the famous Liujing section in Guangxi and successfully recognized the uppermost part of the *pireneae* Zone from the lowermost part of the Shizhou Member of the Yukiang (Yujiang) Formation, and the *nothoperbonus* Zone from the Daliancun and Liujing members of the Yukiang Formation. Later, the middle and upper subzones of the *excavatus* Zone were also reported from the uppermost part of the Shizhou Member at the nominate section of this member (Lu et al., 2018). As a result, the *pireneae*, *excavatus* (part), and *nothoperbonus* zones have already been recognized from the Yukiang Formation in the Liujing area, whereas the precise level of the Pragian/Emsian boundary or of the base of the *kitabicus* Zone is still unknown.

In order to establish a biostratigraphically well-documented sequence within the Pragian and Emsian strata of the Liujing area, the lowermost part of the Shizhou Member at the Dacun-1 section was sampled for conodonts. These data contribute to a better regional or global stratigraphic correlation with contemporaneous strata in the South China Block or other continents around the world.

Geological setting

The Yukiang Formation is widely distributed in the area between Nanning and Liujing along the Yukiang (Yujiang) River, Guangxi, South China (Fig. 1.1, 1.2). Wang et al. (1964) first subdivided this formation in this area into four lithological units, in ascending order: the Xiayiling, Shizhou, Daliancun, and Liujing members. According to the original description given by Wang et al. (1964), the Shizhou Member is represented by alternating mudstone and thin- to medium-bedded limestone in the Liujing area, and has a total of thirty-nine limestone beds cropping out near the Shizhou village, which is located ∼3.6 km west of the Liujing section and after which Wang et al. (1964) first named the Shizhou Member. However, the Yukiang Formation in the area between Nanning and Liujing today is commonly covered by farmland, devastated by railway construction, or eroded by the Yukiang River. Consequently, the lower part of the Shizhou Member is often poorly exposed.

Situated at a small hill close to the railway, the Dacun-1 section is located ∼300 m northwest of Dacun Village and 1.8 km east of the Liujing section. The lowermost part of the Shizhou Member at this section is composed of thin- to medium-bedded limestone alternating with mudstone and has twenty-nine limestone beds, thus differing greatly from the largely covered lower part of the Shizhou Member at Liujing section, where only seven limestone beds can be sampled. The investigated strata at the Dacun-1 section are 6.84 m thick (Fig. 2). It is hard to detect the lithological boundary between the underlying Xiayiling Member, which is represented by sandstone, mudstone, and siltstone, and the Shizhou Member at the Dacun-1 section because this lithological boundary was probably destroyed by railway construction. The uppermost part of the investigated interval is mainly composed of thick-bedded limestone (Fig. 1.3), which, however, is severely weathered. The strata overlying the studied interval mainly consist of mudstone and siltstone, with no exposed limestone beds.

Materials and methods

Twenty-five limestone samples, weighing 2.85–15.78 kg, were collected in 2015 and 2016 from the lowermost part of the Shizhou Member of the Yukiang Formation at the Dacun-1 section (Table 1). They were crushed mechanically into small pieces (∼2–5 cm diameter) and dissolved in dilute acetic acid (5–10%). The insoluble residues were then washed, air-dried, and finally concentrated by heavy-liquid separation using sodium polytungstate. Specimens coated with gold were photographed using a Scanning Electron Microscope (SEM) in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS).

In order to show the cross-sections of platforms in different parts of the basal cavity, we scanned specimens NIGP 169979, 169970, and 169985 at the micro-CT lab of NIGPAS, using a 3D X-ray microscope (3D-XRM), Zeiss Xradia 520 versa. Unlike conventional micro-CT, which relies on maximum geometric magnification and flat panel detector to achieve high resolution, 3D-XRM uses CCD-based objectives to get higher spatial resolution. Depending on the size of the fossil specimen, a CCD-based 4X objective was used, providing isotropic voxel sizes of 1.0699 µm for specimen NIGP 169979, 1.4784 µm for specimen NIGP 169970, and 1.5014 µm for specimen NIGP 169985. During the scan, the running voltage for the X-ray source was set to be 60 kV for specimens NIGP

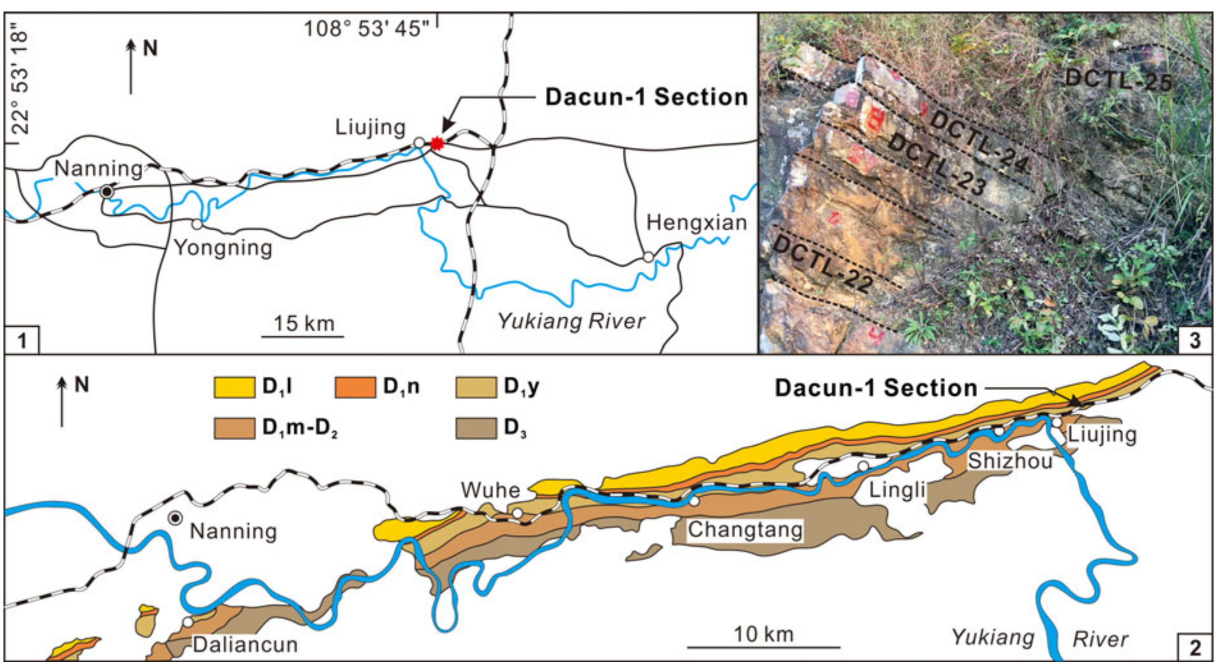

Figure 1. (**1**) Location of the study area, with star showing the site of Dacun-1 section in the Liujing area, Guangxi, South China (modified from Lu et al., 2018). (**2**) Geological map showing the exposed Devonian strata in the area between Nanning and Liujing along the Yukiang River. D_1l: Lianhuashan Formation; D_1n: Nahkaoling (Nagaoling) Formation; D_1y: Yukiang (Yujiang) Formation; D_1m-D_2: Lower Devonian Moding Formation and the Middle Devonian; D_3: Upper Devonian. (**3**) Outcrop view of the lowermost part of the Shizhou Member of the Yukiang Formation exposed at the Dacun-1 section.

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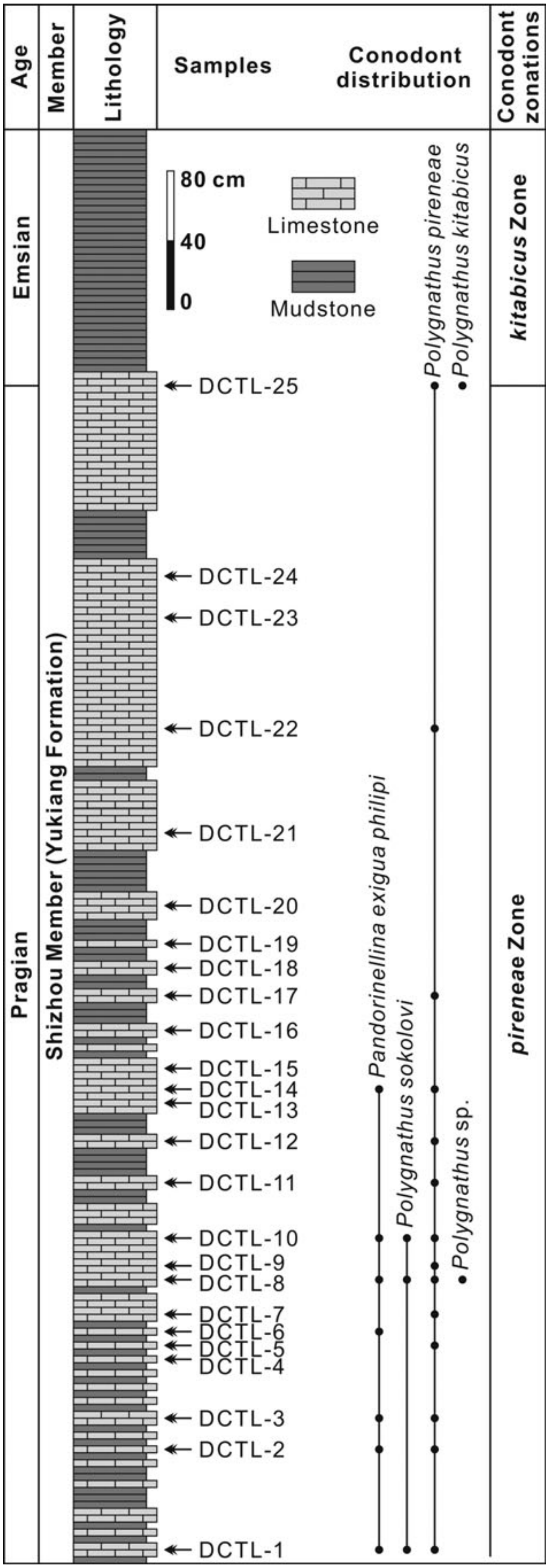

Figure 2. Stratigraphic column of the uppermost Pragian to lowermost Emsian succession at the Dacun-1 section with conodont ranges.

169979 and 169970, and 50 kV for specimen NIGP 169985, and a thin filter (LE2) was used to avoid beam hardening artifacts. To get a high signal-to-noise ratio, 3001 projections over 360° were collected and the exposure time for each projection was set as 3s. Volume data processing was performed using software Vgstudio Max (version 3.0, Volume Graphics, Heidelberg, Germany).

Repository and institutional abbreviation.—All specimens described and illustrated herein are deposited in the collections of the Nanjing Institute of Geology and Palaeontology (NIGP), Chinese Academy of Sciences.

Systematic paleontology

Only Pa elements of *Polygnathus* are described.

Order Ozarkodinida Dzik, 1976
Family Polygnathidae Bassler, 1925
Genus *Polygnathus* Hinde, 1879

Type species.—*Polygnathus dubius* Hinde, 1879

Polygnathus kitabicus Yolkin et al., 1994
Figures 3.1–3.4, 5.7–5.12

non 1977 *Polygnathus dehiscens* Philip and Jackson; Savage, p. 59, pl. 1, figs. 29–36.
?1985 *Polygnathus dehiscens* Philip and Jackson; Schönlaub, pl. 3, figs. 8, 9.
non 1992 *Polygnathus pireneae* Boersma; Mawson et al., figs. 7A–F.
1994 *Polygnathus kitabicus* Yolkin et al., p. 150, pl. 1, figs. 1–4 [with synonymy list].
2011 *Polygnathus kitabicus* Yolkin et al.; Izokh et al., p. 51, pl. 1, figs. 7–10 [with synonymy list].
non 2014 *Polygnathus kitabicus* Yolkin et al.; Baranov et al., p. 666, figs. 14A–G.
2014 *Polygnathus kitabicus* Yolkin et al.; Martínez-Pérez and Valenzuela-Ríos, p. 146, figs. 9e–g.
2018 *Eocostapolygnathus kitabicus* (Yolkin et al.); Wang et al., figs. 6A, B.

Holotype.—CSGM 976/C1 from the Lower Zinzilban Beds of the Khodzha-Kurgan Formation, Zinzilban Gorge, Uzbekistan (Yolkin et al., 1994, pl. 1, figs. 1, 2).

Description.—Free blade is broken and lost in all specimens. Platform narrows anteriorly and is widest at the point where the posterior part starts to deflect inwards to form a rounded curvature of the outer platform margin. The upper platform surface is slightly flat and has weakly developed and shallow adcarinal troughs, which extend to the posterior part of the platform (Figs. 3.1, 3.3, 5.9–5.12). Carina, consisting of laterally compressed and fused denticles in the anterior part of the platform and rounded and discrete nodes in the middle and posterior parts, is situated longitudinally along the center line of the platform and reaches the posterior termination. However, the outer trough in the posterior half of the platform

Table 1. Occurrence of conodont species from the lowermost Shizhou Member of the Yukiang Formation at the Dacun-1 section.

Sample no. (DCTL)	1	2	3	5	6	7	8	9	10	11	12	14	17	22	25	Total number
Sample weight (kg)	8.07	4.32	4.57	3.03	4.06	3.69	15.78	4.23	8.60	4.53	5.43	7.91	7.27	3.96	8.93	
Pandorinellina exigua philipi	3	1	9		2		15		7			1				38
Polygnathus sokolovi	2						2		1							5
P. pireneae	16	1	1	1		3	20	6	7	2	2	1	1	1	7	69
P. sp.							1									1
P. kitabicus															3	3
Total number	21	2	10	1	2	3	38	6	15	2	2	2	1	1	10	116

is somewhat wider than the inner one (Fig. 5.11, 5.12). Nodes and short transverse ribs developed on the inner and outer platform margins are separated from the carina by adcarinal troughs. On the lower side, the large and clearly asymmetrical basal cavity has its broad flanks reaching platform margins. It is deeply excavated and V-shaped in cross-section with steep flanks in the anterior part (Fig. 5.10), but progressively shallows in the posterior part with almost flat flanks at the posterior end (Fig. 5.11, 5.12).

Materials.—Three specimens.

Remarks.—According to Yolkin et al. (1994) and Izokh et al. (2011), characteristic features of *Polygnathus kitabicus* include a narrow platform with weak to shallow adcarinal grooves anteriorly, a rounded outer platform margin, and a large and deep basal cavity whose flanks reach the platform margins. These features make it highly distinguishable from its precursor, *P. pireneae*, and another almost contemporaneously occurring species, *P. sokolovi* Yolkin et al., 1994. Moreover, the equally developed adcarinal troughs and centrally situated carina in *P. kitabicus* also differ greatly from the corresponding features in *P. excavatus excavatus*. Specimens from the Dacun-1 section show a close similarity to the representative specimens of *P. kitabicus* from the Zinzilban Gorge (Yolkin et al., 1994, pl. 1, figs. 1–4; Izokh et al., 2011, pl. 1, figs. 7–10) in outline of the outer platform margin, development of adcarinal troughs, and shape of the basal cavity, but mainly differ from the latter by the comparatively wider platform. Moreover, attention is specifically paid to the various and changing depth of the basal cavity in different parts of our specimen. The median cross section in our specimen (Fig. 5.10) is almost identical to that of *P. kitabicus* illustrated by Yolkin et al. (1994, text-fig. 2); however, the morphologies of the basal cavity in the posterior part have been never illustrated. Comparison of the basal cavity between *P. pireneae* and *P. kitabicus* from the Dacun-1 section indicates that the former usually still has a relatively deep and V-shaped basal cavity, even in the posterior part, whereas the latter has an extremely shallow or even flat posterior basal cavity (compare Fig. 5.5, 5.6 with Fig. 5.11, 5.12).

Polygnathus pireneae Boersma, 1973
Figures 3.5–3.18, 4.1–4.4, 5.1–5.6

1972 *Polygnathus lenzi* Klapper; McGregor and Uyeno, pl. 5, figs. 10–12.

1973 *Polygnathus pireneae* Boersma, p. 287, pl. 2, figs. 1–12.

1979 *Polygnathus pireneae* Boersma; Lane and Ormiston, p. 62, pl. 3, figs. 15–17; pl. 5, figs. 2, 3, 9, 10, 27–34, 37.

1982 *Polygnathus pireneae* Boersma; Murphy and Matti, p. 41, pl. 1, figs. 33–38.

1983 *Polygnathus pireneae* Boersma; Wang and Ziegler, pl. 6, fig. 8.

1985 *Polygnathus pireneae* Boersma; Mastandrea, pl. 1, fig. 5 (non fig. 6).

1985 *Polygnathus pireneae* Boersma; Schönlaub, pl. 3, fig. 7.

1990 *Polygnathus pireneae* Boersma; Olivieri and Serpagli, p. 72, pl. 3, figs. 2–6.

1994 *Polygnathus pireneae* Boersma; Valenzuela-Ríos, p. 73, pl. 9, figs. 27, 28, 30.

non 1998 *Polygnathus pireneae* Boersma; Mawson, pl. 4, figs. 6, 7.

2001 *Polygnathus pireneae* Boersma; Slavík, p. 264, pl. 1, fig. 17.

2016 *Polygnathus pireneae* Boersma; Lu et al., p. 289, figs. 5E–N, 6O–R, 7A–J [with synonymy list].

2016 *Polygnathus pireneae* Boersma; Lu and Chen, figs. 4.6, 4.7.

2017 *Polygnathus pireneae* Boersma; Lu et al., figs. 3p–s, 4a–f, k–r, 5a–d.

2018 *Polygnathus pireneae* Boersma; Wang et al., figs. 6R, S.

Holotype.—Specimen 06-035 from the lowermost part of the Basibé Formation at Castells, Spanish Central Pyrenees (Boersma, 1973, pl. 1, figs. 1–3).

Description.—Free blade consisting of five to six high and laterally compressed denticles is approximately one-fourth to one-third of the total length of the unit. Platform, which is broad in adult specimens (Fig. 3.8, 3.11, 3.16, 3.18) but relatively narrow in juvenile or immature specimens (Fig. 3.6, 3.10, 4.4), slightly deflects inwards posteriorly to form a rounded outer platform margin. The upper platform surface is remarkably flat (Fig. 5.3–5.6); adcarinal troughs are commonly undeveloped even at the anterior end of the platform. Consisting of fused denticles in the anterior part of the platform and rounded and discrete nodes in the middle and posterior parts, the carina is situated longitudinally along the center line of the platform and extends to the posterior termination. However, in some specimens (Fig. 3.6, 3.10, 3.11, 3.13, 3.16), the carina in the anterior third part of the

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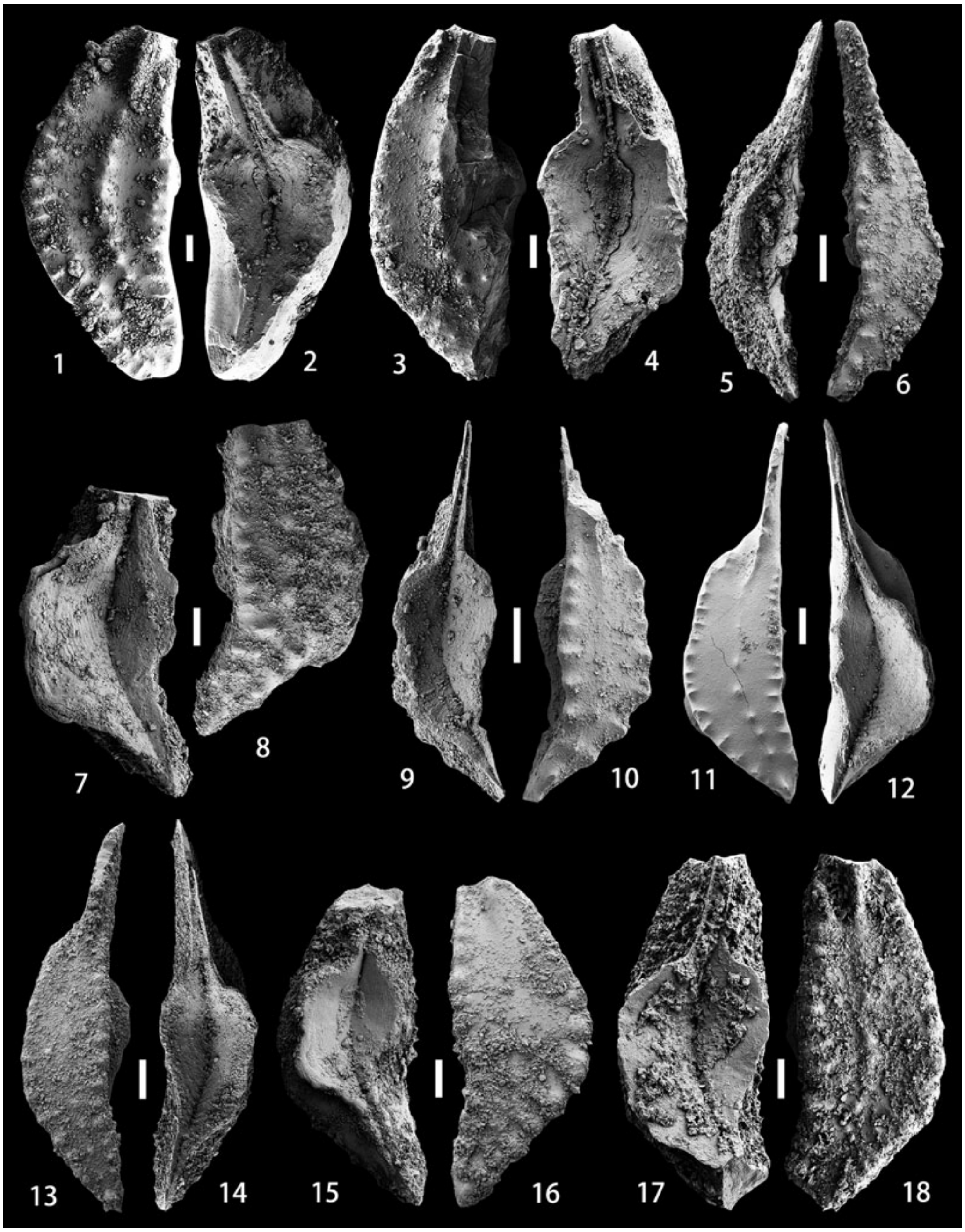

Figure 3. (**1–4**) *Polygnathus kitabicus* Yolkin et al., 1994; (**1, 2**) upper and lower views, NIGP 169970, sample DCTL-25; (**3, 4**) upper and lower views, NIGP 169971, sample DCTL-25. (**5–18**) *Polygnathus pireneae* Boersma, 1973; (**5, 6**) lower and upper views, NIGP 169972, sample DCTL-1; (**7, 8**) kitabiformis morph, lower and upper views, NIGP 169973, sample DCTL-1; (**9, 10**) kitabiformis morph, lower and upper views, NIGP 169974, sample DCTL-7; (**11, 12**) upper and lower views, NIGP 169975, sample DCTL-8; (**13, 14**) upper and lower views, NIGP 169976, sample DCTL-9; (**15, 16**) lower and upper views, NIGP 169977, sample DCTL-10; (**17, 18**) lower and upper views, NIGP 169978, sample DCTL-12. All scale bars represent 100 μm.

platform is specifically indistinct or weakly developed. Joining the free blade at the same position anteriorly, the inner and outer margins are ornamented by nodes or short transverse ridges, with which the carina at the posterior end of the platform may connect to form few semi-crossed transverse ridges (Fig. 3.8, 3.10). On the lower side, the basal cavity is large, clearly asymmetrical, and deeply excavated, with steep and broad flanks just reaching platform margins (Figs. 3.5, 3.12, 3.14, 3.15, 3.17, 4.2) or even visibly protruding beyond platform margins (Figs. 3.7, 3.9, 4.3).

Materials.—69 specimens.

Remarks.—According to Izokh et al. (2011, p. 51), *Polygnathus pireneae* can be subdivided into the sokoloviformis and kitabiformis morphs mainly on the basis of the different outline of the outer platform margin. The sokoloviformis morph has an angular outer platform margin at the point of the inward deflection of the posterior platform, whereas the kitabiformis morph is characterized by the rounded outer platform margin. Several specimens illustrated herein belong

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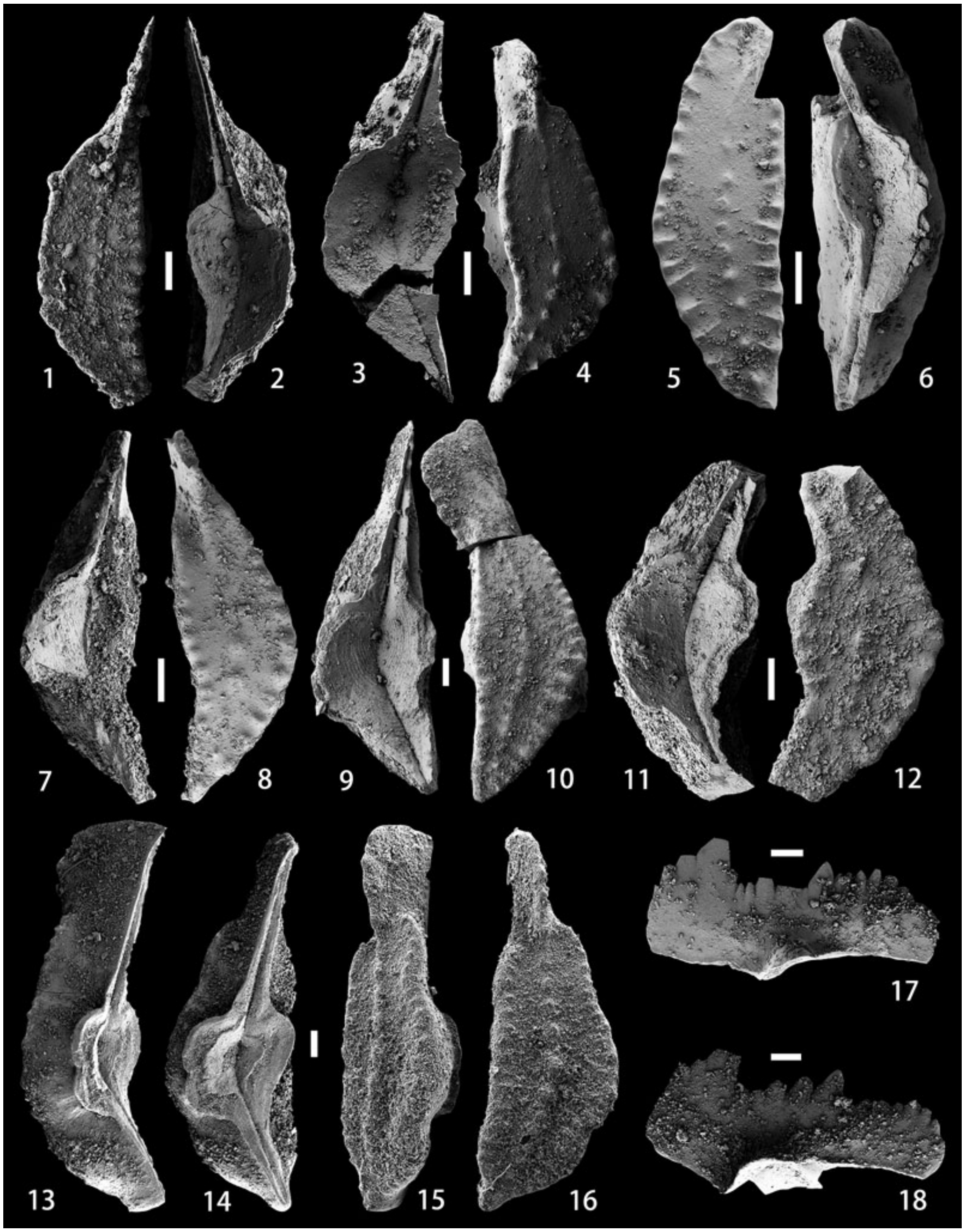

Figure 4. (**1–4**) *Polygnathus pireneae* Boersma, 1973; (**1, 2**) upper and lower views, NIGP 169979, sample DCTL-22; (**3, 4**) kitabiformis morph, lower and upper views, NIGP 169980, sample DCTL-25. **(5–12)** *Polygnathus sokolovi* Yolkin et al., 1994; (**5, 6**) upper and lower views, NIGP 169981, sample DCTL-1; (**7, 8**) lower and upper views, NIGP 169982, sample DCTL-1; (**9, 10**) lower and upper views, NIGP 169983, sample DCTL-8; (**11, 12**) lower and upper views, NIGP 169984, sample DCTL-10. (**13–16**) *Polygnathus* sp., lower-lateral, lower, upper-lateral, and upper views, NIGP 169985, sample DCTL-8. (**17, 18**) *Pandorinellina exigua philipi* (Klapper, 1969); (**17**) lateral view, NIGP 169986, sample DCTL-8; (**18**) lateral view, NIGP 169987, sample DCTL-10. All scale bars represent 100 μm.

to the kitabiformis morph (Figs. 3.7–3.10, 4.3, 4.4), which possesses an extraordinarily large and wide basal cavity whose flanks protrude beyond the platform margins. In contrast, the remaining specimens possess a comparatively narrower basal cavity with steep flanks just reaching platform margins (Figs. 5.5, 5.6, 3.11–3.18, 4.1, 4.2). Similar specimens were also reported at the Liujing section (Lu et al., 2016, figs. 5E–N).

Specimens from the Dacun-1 section differ from the representative specimens of *Polygnathus pireneae* in the following aspects. Compared with the adult specimens figured by Izokh et al. (2011, pl. 1, figs. 1–6), the platform in our adult specimens is much broader (Fig. 3.8, 3.16, 3.18). Secondly, representative specimens of *P. pireneae* commonly bear a well-developed carina running from the anterior end to the posterior end of the platform, whereas in some of our specimens the carina in the anterior third part of the platform is indistinct or weakly developed (Fig. 3.6, 3.10, 3.11, 3.13, 3.16). Additionally, in contrast to the specimens from the Spanish Central Pyrenees that have a more anteriorly shifted outer anterior platform

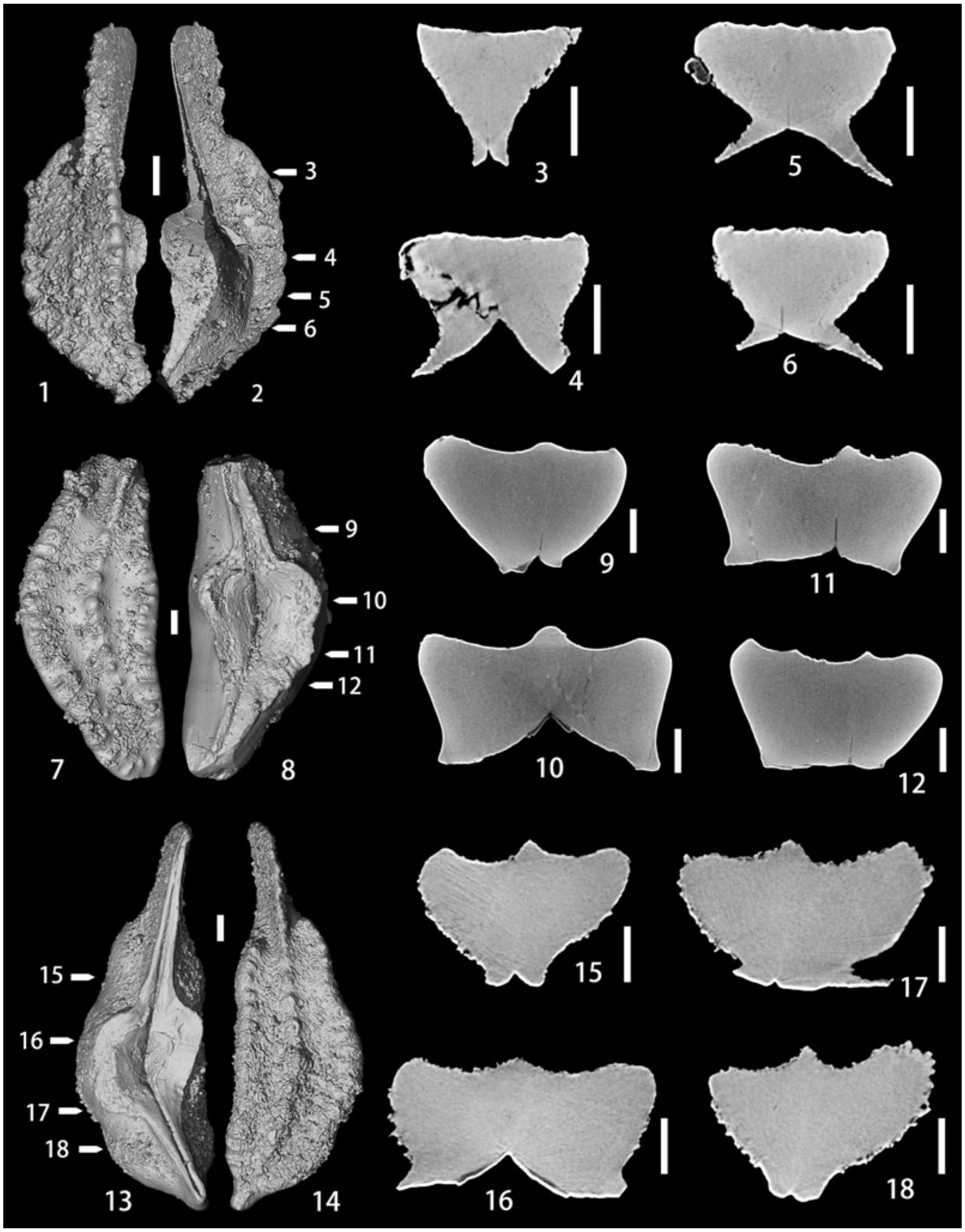

Figure 5. (**1–6**) Scanned specimen of *Polygnathus pireneae* Boersma, 1973 using micro-CT; (**1, 2**) upper and lower views, NIGP 169979, sample DCTL-22; (**3–6**) cross-sections of platform at different part of basal cavity in *P. pireneae*. (**7–12**) Scanned specimen of *Polygnathus kitabicus* Yolkin et al., 1994 using micro-CT; (**7, 8**) upper and lower views, NIGP 169970, sample DCTL-25; (**9–12**) cross-sections of platform at different part of basal cavity in *P. kitabicus*. (**13–18**) Scanned specimen of *Polygnathus* sp. using micro-CT; (**13, 14**) lower and upper views, NIGP 169985, sample DCTL-8; (**15–18**) cross-sections of platform at different part of basal cavity in *P.* sp. All scale bars represent 100 µm.

margin in respect to the inner one (Boersma, 1973, pl. 2, figs. 1–3, 7–9; Martínez-Pérez and Valenzuela-Ríos, 2014, figs. 9a–d.), our juvenile and adult specimens have inner and outer anterior platform margins joining the free blade at the same position.

Specimens initially figured as *Polygnathus lenzi* Klapper, 1969 by McGregor and Uyeno (1972, pl. 5, figs. 10–12) and those as *P. pireneae* by Lane and Ormiston (1979, pl. 5, figs. 27, 37) were later re-identified by Yolkin et al. (1994, p. 149) as *P. kitabicus* without taking their stratigraphic information into further consideration. Specimens depicted as *P. lenzi* by McGregor and Uyeno (1972, pl. 5, figs. 10–12) were collected from a level 185 feet above the base of the Stuart Bay Formation together with *Spathoganthodus sulcatus* (Philip, 1965), strongly indicating that this level belongs to the Pragian and that specimen of *P. lenzi* could not be identified as *P. kitabicus* because *P. kitabicus* first occurs at the base of the Emsian. The specimen figured as *P. pireneae* by Lane and Ormiston (1979, pl. 5, figs. 27, 37) was obtained from sample 3-29 at the Linear Ridge outcrop together with *Eognathodus sulcatus* *kindlei* Lane and Ormiston, 1979, a taxon whose stratigraphic distribution is restricted to the Pragian. In view of above-mentioned facts, taxonomic assignments of these specimens proposed by Klapper and Johnson (1980, p. 454) are followed herein.

Polygnathus sokolovi Yolkin et al., 1994
Figure 4.5–4.12

1994 *Polygnathus sokolovi* Yolkin et al., p. 152, pl. 1, figs. 5–8 [with synonymy list].
2014 *Polygnathus sokolovi* Yolkin et al.; Martínez-Pérez and Valenzuela-Ríos, p. 152, fig. 9h.
2016 *Polygnathus sokolovi* Yolkin et al.; Lu et al., p. 291, figs. 7K–Q.
2016 *Polygnathus sokolovi* Yolkin et al.; Lu and Chen, fig. 4.2.
2017 *Polygnathus sokolovi* Yolkin et al.; Lu et al., figs. 4g–j.
2018 *Polygnathus sokolovi* Yolkin et al.; Wang et al., figs. 6E, F.

Holotype.—CSGM 976/C5 from the Lower Zinzilban Beds of the Khodzha-Kurgan Formation, Zinzilban Gorge, Uzbekistan (Yolkin et al., 1994, pl. 1, figs. 7, 8).

Description.—Free blade consisting of five high and laterally compressed denticles is approximately one-fourth of the total length of the unit (Fig. 4.9, 4.10). The flat and relatively broad platform deflects inwards posteriorly to form a distinct angularity of the outer platform margin just behind midlength (Fig. 4.5, 4.8, 4.10, 4.12). In contrast, the inner margin is more or less straight, but one specimen has its inner platform laterally expanded to form a rounded and convex inner margin in the middle part of the platform (Fig. 4.12). Adcarinal troughs are not developed even at the anterior end of the platform. Carina, which consists of fused denticles in the anterior part of the platform and discrete nodes in the middle and posterior parts, is situated longitudinally along the center line of the platform and extends to the posterior termination. However, some specimens possess an indistinct or weakly developed carina in the anterior third part of the platform (Fig. 4.5, 4.8). Joining the free blade at the same position anteriorly, inner and outer margins are ornamented by nodes in the anterior half of the platform and short transverse ridges in the posterior half of the platform. On the lower side, the basal cavity is large, clearly asymmetrical, and deeply excavated, whose steep and broad flanks just reach platform margins (Fig. 4.6, 4.7, 4.9, 4.11).

Materials.—Five specimens.

Remarks.—*Polygnathus sokolovi* is characterized by a flat and narrow platform, a distinct angularity of the outer platform margins, and sometimes a few nodes scattered between carina and platform margins (Yolkin et al., 1994, p. 152). Based on the marginal ornamentation on the upper platform surface, Yolkin et al. (1994) subdivided this species into the Early and Late forms. The former has discrete marginal nodes, whereas the latter is characterized by short transverse marginal ridges. Specimens from the Dacun-1 section have a comparatively broader platform that do not bear any discrete nodes between carina and margins, and a weakly developed carina in the anterior third of the platform in some specimens, both of which differ greatly from the representative specimens of this species from Uzbekistan (Yolkin et al., 1994, pl. 1, figs. 6s–8; Izokh et al., 2011, pl. 2, figs. 1–6). However, our specimens (Fig. 4.5, 4.10. 4.12) show a close similarity in the platform ornamentation to one specimen from Uzbekistan that was suggested by Yolkin et al. (1994, pl. 1, fig. 5) to be a Late form of *P. sokolovi*. They all have numerous short transverse marginal ridges and are totally barren of the characteristic nodes intercalated between the outer marginal rim and carina. Accordingly, these specimens from the Dacun-1 section are suggested to be Late forms of *P. sokolovi*. A similar specimen was also figured by Wang et al. (2018, fig. 6E) from the Alengchu Formation in western Yunnan. The broad platform also makes our specimens resemble closely *P. hindei* Mashkova and Apekina, 1980, which, however, is highly differentiable by its numerous nodes intercalated between marginal rims and carina.

Polygnathus sp.
Figures 4.13–4.16, 5.13–5.18

Description.—Free blade consisting of five high and laterally compressed denticles is about one-fourth of the total length of the unit. Platform narrows anteriorly and is widest at the point where the posterior half starts to deflect inwards to form a rounded curvature of the outer platform margin. The upper platform surface is slightly flat and has weakly developed and shallow adcarinal troughs, which extend to the posterior part of the platform (Figs. 4.15, 4.16, 5.14–5.18). Carina, which consists of rounded and discrete nodes, is situated longitudinally along the center line of the platform and extends to the posterior end. Nodes and short transverse ribs developed on the inner and outer platform margins are separated from the carina by adcarinal troughs. Compared with the inner anterior margin, the outer one meets the free blade a bit more anteriorly. On the lower side, basal cavity is large, asymmetrical, and relatively shallow, with flanks reaching platform margins (Figs. 4.13, 4.14, 5.13). It is slightly V-shaped in cross-section with a flat rim in the anterior part (Fig. 5.16); the posterior part of basal cavity is remarkably flat and shallow (Fig. 5.17, 5.18).

Materials.—One specimen.

Remarks.—*Polygnathus* sp. closely resembles *P. kitabicus* in having a rounded outer platform margin, weakly developed and shallow adcarinal troughs, and flanks of the basal cavity just reaching rather than protruding beyond the platform margins. However, *P. kitabicus* is characterized by a greatly excavated and V-shaped basal cavity with steep flanks, whereas the basal cavity in *P.* sp. is quite shallow with an almost flat rim (compare Fig. 5.10 with Fig. 5.16). The different outline of the basal cavity probably represents one of the intraspecific variations of *P. kitabicus*; however, a further study with more specimens is needed.

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Conodont biostratigraphy

Only 15 of 25 samples yielded conodont elements, and most samples from the severely weathered upper part of the investigated interval were completely barren. Five species or subspecies were identified from 116 specimens of the Pa element (Table 1). Most of these specimens are assigned to the genus *Polygnathus*, and only a few specimens to *Pandorinellina*. Based on the stratigraphic ranges of conodont species, the uppermost Pragian through lowermost Emsian succession at the Dacun-1 section is subdivided into two conodont phylogenetic-zones (Fig. 2).

The pireneae *Zone*.—This Zone is defined by the lowest occurrence of *Polygnathus pireneae* at the base and by the lowest occurrence of *P. kitabicus* at the top (Yolkin et al., 1994). At the Dacun-1 section, the *pireneae* Zone is recognized in the lowermost part of the Shizhou Member of the Yukiang Formation where samples DCTL-1 to DCTL-24 were collected. The co-occurrence of *P. sokolovi* and *P. pireneae* is only demonstrated in samples DCTL-1, DCTL-8, and DCTL-10; in contrast, in the Spanish Central Pyrenees (Martínez-Pérez and Valenzuela-Ríos, 2014) and Kitab State Geological Reserve Area (Yolkin et al., 1994; Izokh et al., 2011), *P. sokolovi* has a much higher extension into the overlying *kitabicus* Zone. Attention is specifically paid to one specimen provisionally termed *P.* sp. from sample DCTL-8. Although its outline of basal cavity differs greatly from that in *P. kitabicus*, the upper platform surface bears shallow adcarinal troughs, which can be only observed in *P. kitabicus*.

The kitabicus *Zone*.—According to Yolkin et al. (1994), the lower limit of this zone is defined by the lowest occurrence of *Polygnathus kitabicus* and its upper limit by the lowest occurrence of *P. excavatus excavatus*. The lowermost part of the *kitabicus* Zone is recognized from the highest limestone bed at the Dacun-1 section, a level ∼0.92 m above the bed where sample DCTL-24 was collected. Accordingly, the Pragian/Emsian boundary at this section is located at the level of sample DCTL-25. This is the first time that the Pragian/Emsian boundary has been successfully demonstrated in the South China Block.

Discussion

When studying the conodont biostratigraphy of the Yukiang Formation at the Liujing section, Lu et al. (2016) made a detailed report about the conodont fauna from the basal part of the Shizhou Member, which is marked by the co-occurrence of *Polygnathus pireneae* and *P. sokolovi*. As a result, the basal part of the Shizhou Member in the Liujing section was assigned to the *pireneae* Zone (Lu et al., 2017). At both the Liujing and Dacun-1 sections, *P. sokolovi* has a much shorter stratigraphic distribution than *P. pireneae* and is restricted to the *pireneae* Zone. The kitabiformis and sokoloviformis morphs of *P. pireneae* co-occur in sample AGP-LJ-78 from the basal part of the Shizhou Member at the Liujing section, whereas only the kitabiformis morph of *P. pireneae* was recovered from the Dacun-1 section. The kitabiformis morph of *P. pireneae* extends upwards into the base of the Emsian (sample DCTL-25) together with another unofficially defined morph of *P. pireneae*, which is characterized by a slightly narrower basal cavity whose flanks just reach rather than visibly protrude outside platform margins. Moreover, it is noteworthy that the kitabiformis morph of *P. pireneae* is usually restricted to the *pireneae* Zone and lower part of the *kitabicus* Zone (Lane and Ormiston, 1979; Murphy and Matti, 1982; Savage et al., 1985; Schönlaub, 1985; Yolkin et al., 1989, 2011; Olivieri and Serpagli, 1990; Bardashev and Ziegler, 1992; Valenzuela-Ríos, 1994, 2002; Slavík, 2001; Erina in Kim et al., 2007; Izokh et al., 2011), but can range upwards into the middle *excavatus* Subzone in the Spanish Central Pyrenees (Martínez-Pérez and Valenzuela-Ríos, 2014, figs. 4, 9c, 9d), whereas the sokoloviformis morph of *P. pireneae* was only recorded in the uppermost part the *pireneae* Zone and lower part of the *kitabicus* Zone in the Kitab State Geological Reserve Area (Izokh et al., 2011; Yolkin et al., 2011; N.G. Izokh, personal communication, 2019). Nevertheless, the morphological variation of *P. pireneae* and stratigraphic distribution of different morphs of *P. pireneae* in the Liujing area still need to be further studied in detail.

Recently, Wang et al. (2018) described the Lower Devonian conodont biostratigraphy of the Alengchu section in western Yunnan Province, an area probably belonging to the Indochina (or Annamia) Terrane (Zhou et al., 2001). They provisionally placed the lower boundary of the Emsian at the base of the Alengchu Formation due to the fact that no index taxa were collected from samples 19-6 to 20-3. Therefore, the precise lower boundary of the Emsian at the Alengchu section probably needs further investigation. The *kitabicus* Zone at the Alengchu section contains the lowest occurrences of *Polygnathus kitabicus*, *P. pireneae*, *P. sokolovi*, and *P. pannonicus* Mashkova and Apekina, 1980 from the lower part of bed 20 to the upper part of bed 23 in the Alenchu Formation. In the Zinzilban Gorge, the lower part of the *kitabicus* Zone also retains the early diversification of the genus *Polygnathus* including the origination of *P. hindlei*, *P. pannonicus*, and *P. tamara* Apekina, 1989 (Yolkin et al., 1994, 2011). Unfortunately, because of the middle and upper parts of the Shizhou Member of the Yukiang Formation in the Liujing area mainly consist of mudstone and siltstone, the scarcity of appropriate limestone samples for conodont analysis precludes a definitive demonstration of the early diversification of *Polygnathus* at the Dacun-1 section for the time being. Moreover, the upper boundary of the *kitabicus* Zone as well as the lower boundary of the middle *excavatus* Subzone defined by the lowest occurrence of *P. excavatus* ssp. 114 in the Liujing area is also unknown.

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