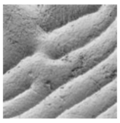
Conodont biostratigraphy of the Nalai section (Guangxi) and new data on the age of the *Zdimir* beds in South China

Jianfeng Lu, José Ignacio Valenzuela-Ríos, Xiuqin Chen & Jau-Chyn Liao



The conodont biostratigraphy of the lower part of the Beiliu Formation at the Nalai, Guangxi is described. The association of *Polygnathus serotinus*, *P. cooperi cooperi*, *P. cracens*, *P. linguiformis bultyncki* and *Bipennatus* cf. *B. montensis* indicates that this stratigraphic interval, in which one *Zdimir* bed crops out, can be assigned to the *serotinus* Zone. *Bipennatus* cf. *B. montensis*, which closely resembles *B. montensis* from the Eifelian *costatus* Zone, is recorded from a relatively lower level in the Emsian *serotinus* Zone. The stratigraphic distribution of *Zdimir* in South China is further reviewed at seven sections where abundant specimens of *Zdimir* have been reported. Several *Zdimir* beds which were previously correlated with the *patulus* Zone are assigned to the *serotinus* Zone herein. The zonal correlation of these seven sections suggests that the *Zdimir* beds in South China belong to the *serotinus* Zone and to the *partitus* Zone. • Key words: *Zdimir*, Beiliu Formation, *serotinus* Zone, Emsian, conodont.

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The genus *Zdimir* is represented by a group of large, thick-shelled and strong costate brachiopods that has been widely reported in the upper Emsian and the lower Eifelian in Spain, France, Belgium, Germany, Austria, Czech Republic, Poland, Urals, Kuznetsk Basin, South Tian-Shan, Mongolia, Japan and Australia (Andronov 1961, Boucot & Siehl 1962, Ivanova 1962, Krilova 1962, Malygina & Sapelnikov 1973, Rzhonsnitskaia 1975, Tazawa 1988, Talent & Mawson 1994, Chen & Tazawa 2003, Chen & Liao 2006, Yolkin *et al.* 2008, Suttner & Chen 2009, Suttner personal communication). In South China, *Zdimir* has also been recorded from the Dafengmen section at Beiliu (Wang *et al*. 1965, Hou & Xian 1975, Wang & Zhu 1979, Yu & Kuang 1982), Liujing section at Hengxian (Kuang *et al*. 1989), Qinjia section at Debao (Wu & Yan 1980, Xian *et al*. 1980), Bahe section at Tiandeng (Bai & Bai 1988, Bai *et al*. 1994, Bai *et al*. 1998), Guanziyao section at Pu'an (Hou & Xu 1964, Hou & Xian 1975, Wang & Zhu 1979, Xiong 1987) (Fig. 1), and Guixi-Shawozi section at Longmenshan (Yoh 1956, Hou *et al*. 1988).

Bai & Bai (1988), and Bai *et al*. (1998) demonstrated that the stratigraphic distribution of *Zdimir* in South China ranges from the upper Emsian (the *serotinus* Zone) to the lower Eifelian (the *costatus* Zone). Moreover, Bai *et al*. (1998) also noted that the *Zdimir* beds in Guangxi, Yunan, Guizhou and Sichuan could be further assigned to the *serotinus*, *patulus* and *partitus* zones. However, the assignation of some *Zdimir* beds by Bai *et al*. (1998) to the *patulus* Zone and *partitus* Zone at the Bahe, Dafengmen, and Qinjia sections has to be revised, because several important conodont and rugose coral studies (Yu *et al.* 1979; Xiong 1981, 1987) related to these sections were not taken into consideration. The rugose coral researches also play an important role in the stratigraphic correlation herein when detailed conodont researches at some studied sections are pending. The main goals of this paper are to study the age of the *Zdimir* bed at the Nalai section by means of conodonts and to review the age assignations of the *Zdimir* beds in relevant sections from South China.

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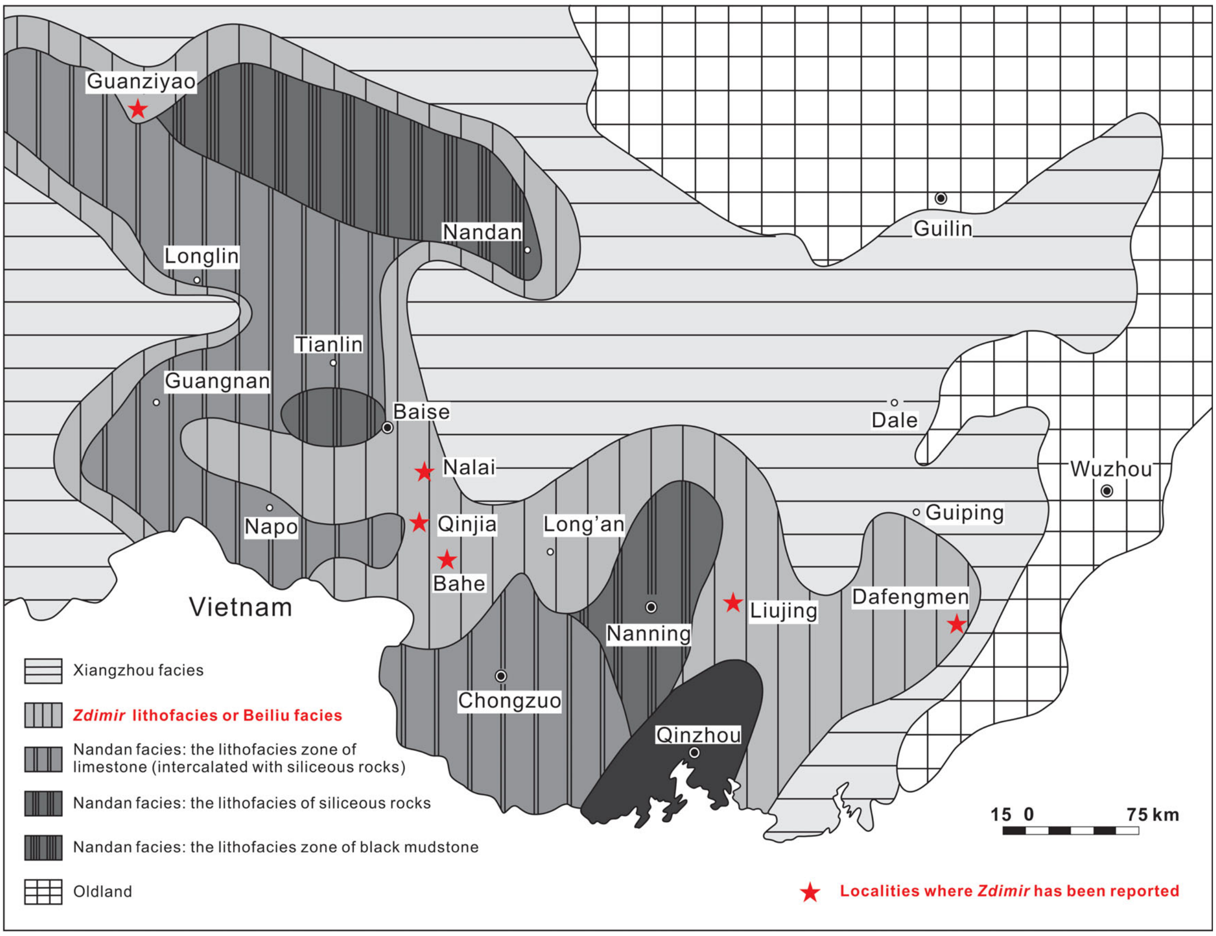


Figure 1. The geographical distribution of *Zdimir* in South China during the late Emsian to early Eifelian (modified after Xian *et al.* 1980). The red stars represent the localities where the *Zdimir* beds have been reported.

Geological setting

A continuous succession of strata from the Lower Devonian Huangjingshan Formation to the Lower-Middle Devonian Beiliu Formation is well exposed along the country road (Fig. 2A) at the Nalai section (Figs 1, 3; 23° 34´ 56˝ N, 106° 46´ 32˝ E). This section is situated about 1.5 km northeast of the Nalai Village, Pohong Town, Baise. Wang *et al.* (1965) named the Beiliu Formation and subdivided it into the Huangjingshan, Guitang, and Yarang members in ascending order. Later, Wang *et al.* (1974) formally raised the rank of the Huangjingshan Member to a formation, leaving the Guitang and Yarang as members of the Beiliu Formation. Subsequently, Zhong *et al.* (1992) further raised the Beiliu Formation to a group consisting of the Guitang and Yarang formations. However, due to the great difficulty in differentiating the Guitang and Yarang formations because of similar development in the Pohong area, the stratigraphic subdivision of Wang *et al.* (1974) is followed herein. The lower part of the Beiliu Fm. at the Nalai section conformably overlies the Huangjingshan Fm. (thick-bedded dolomite in the upper part). The Beliu Fm. is about 72.5 m thick and is composed of black and dark grey, thin to thick-bedded limestone. Twenty-one conodont samples were collected at this section (Fig. 4).

Methods

The limestone samples, weighing between 1.645 kg and 6.020 kg, were reduced mechanically to a size of approximately 5 cm in diameter and then dissolved in dilute acetic acid (5–10%). The insoluble residues were washed, air-dried and concentrated by sodium polytungstate heavy-liquid separation. Concentrated residues were hand-picked under a stereo microscope. Selected gold-coated specimens were photographed using a Scanning Electron Microscope (SEM) in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. Only thirteen limestone samples yielded conodont elements and five species or subspecies were identified from fifty-two relatively intact Pa elements (Table 1).

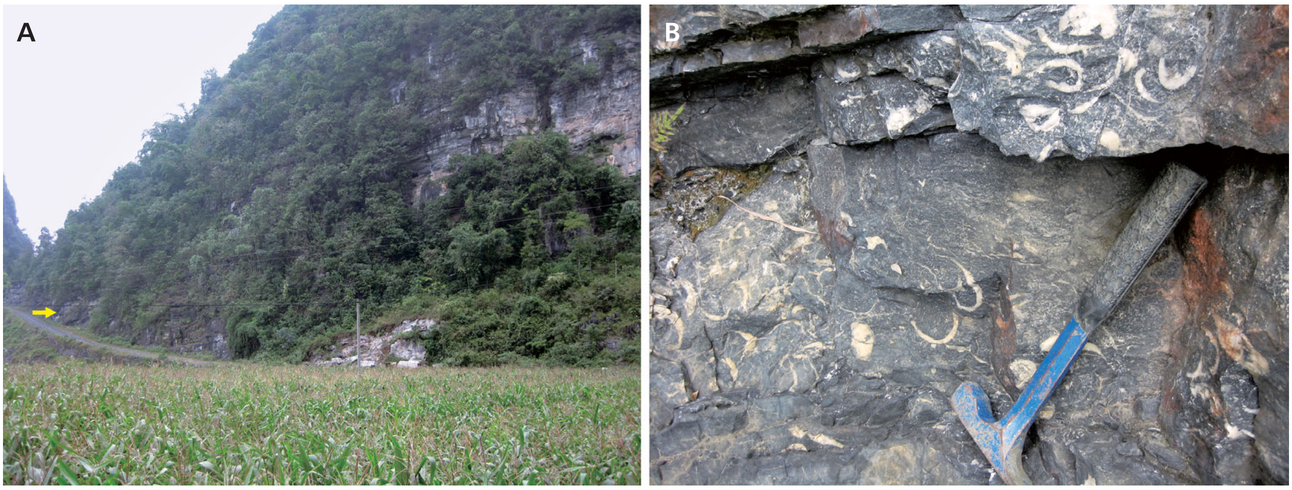


Figure 2. Outcrop view of the Nalai section with an arrow indicating the level of the *Zdimir* bed (A). The *Zdimir* bed in the upper part of bed 10 of the Beiliu Formation (B); the length of geological hammer is about 31.5 cm.

Figure 3. Locality of the Nalai section (red star mark) in Guangxi, South China.

Results

Polygnathus serotinus has its lowest occurrence in sample NL-10-5 in the middle part of Bed 10 (Figs 4, 8M, N) and ranges up to sample NL-13-3 in the middle part of Bed 13 (Figs 4, 8O–R, 9A–R). *Bipennatus* cf. *B. montensis* (Fig. 7A–C), a morphologically unique specimen that closely resembles *B. montensis* generally recorded from the Eifelian *costatus* Zone (Narkiewicz & Narkiewicz 2010; Narkiewicz 2013), is collected in sample NL-10-6 that belongs here to the Emsian *serotinus* Zone. However, *B.* cf. *B. montensis* differs slightly from the holotype of *B. montensis* (Weddige 1977, pl. 6, fig. 95) in the position of the basal cavity and the development of the characteristic sulcus on the narrow platform, thus, probably representing a phylogenetically early form of *B. montensis*. The upper half of Bed 10 also recorded the successively first entries of *P. cooperi cooperi* (Fig. 7D–K), *P. linguiformis bultyncki* (Fig. 8A–L) and *P. cracens* (Fig. 7L–Q); the former two taxa range higher into the upper part of Bed 12 and the lower part of Bed 13 respectively, whereas the latter one has its last appearance in sample NL-12-1 in the basal part of Bed 12. *Polygnathus linguiformis bultyncki* and *P. cooperi cooperi* are common taxa in the *serotinus* Zone, and both can reach into the *costatus* Zone together with *P. serotinus*. *Polygnathus cracens* has a worldwide distribution but is restricted to the *serotinus* Zone. In summary, the lower part of the Beiliu Formation at the Nalai section

Table 1. Distribution of conodont species and richness at the Nalai section.

Samples	NL-9-1	NL-10-1	NL-10-2	NL-10-3	NL-10-4	NL-10-5	NL-10-6	NL-10-7	NL-10-8	NL-10-9	NL-10-10
Sample weight(kg)	1,645	3,63	2,605	2,744	3,512	6,02	2,065	3,782	2,175	3,635	3,895
Polygnathus serotinus						1		1	2	3	1
Bipennatus cf. *B. montensis*							1				
Polygnathus cooperi cooperi								1		3	
Polygnathus linguiformis bultyncki									3	8	2
Polygnathus cracens											1
Number of elements						1	1	2	5	14	4

Samples	NL-11-1	NL-12-1	NL-12-2	NL-12-3	NL-12-4	NL-12-5	NL-13-1	NL-13-2	NL-13-3	NL-13-4
Sample weight(kg)	3,365	4,158	3,645	3,115	2,93	3,51	1,735	3,9	3,445	3,651
Polygnathus serotinus							5	2	3	
Bipennatus cf. *B. montensis*										
Polygnathus cooperi cooperi					1					
Polygnathus linguiformis bultyncki		3		3		4	1		1	
Polygnathus cracens		2								
Number of elements		5		3	1	4	6	2	4	

covering an interval from the middle part of Bed 10 to the lowermost part of Bed 12 is assigned to the *serotinus* Zone, whereas the precise zonal assignation of the interval ranging from samples NL-12-2 to NL-13-4 still needs a further study (Fig. 4).

One *Zdimir* bed was recognized from the upper part of Bed 10 in the lower part of the Beiliu Formation at the Nalai section (Figs 2B, 4). Additionally, few specimens of *Zdimir* were also collected at the base of Bed 13, just below sample NL-13-13. The study of the conodont biostratigraphy indicates that the *Zdimir* bed close to sample NL-10-10 belongs to the *serotinus* Zone.

Conodont biostratigraphy of the *Zdimir* beds in South China

Zdimir and *Megastrophia* are usually recorded together in South China and have important palaeoenvironmental and palaeoecological significances. Based on the lithology and faunal compositions, Wang *et al.* (1974) subdivided the marine Devonian strata in South China into the Xiangzhou facies and the Nandan facies. The former is mainly represented by bioclastic limestone, marlstone, and dolomite hosting rich benthic fossils, corresponds to an oxygen-rich and shallow sea environment, and could roughly be compared to the Rhenish facies in Europe; the latter mainly consists of black and dark grey mudstone and shale with abundant pelagic fossils, represents a deeper and quite sea environment, and can be compared to the Bohemian facies in Europe. Xian *et al.* (1980) subsequently broadened the concept of the Nandan facies by further classifying it into four lithofacies zones: the lithofacies zone of black mudstone, the lithofacies zone of limestone (intercalated with siliceous rocks), the lithofacies of siliceous rocks, and the lithofacies zone of limestone (with *Zdimir*) (Fig. 1). Characterized by yielding abundant specimens of *Zdimir* and *Megastrophia*, the lithofacies zone of limestone (with *Zdimir*), or the *Zdimir* lithofacies, is viewed as a transitional facies between the Xiangzhou facies and the Nandan facies and is suggested to represent a reef or reef mound environment (Xian *et al.* 1980, Bai & Bai 1988, Bai *et al.* 1998). Later, Zhong *et al.* (1992) formally named this transitional lithofacies as the Beiliu facies. In the present paper, the Nandan facies is restricted to the other three lithofacies zones proposed by Xian *et al.* (1980) (*Zdimir* lithofacies is excluded). To study the stratigraphic distribution of *Zdimir* in South China, we have analyzed the conodont biostratigraphy of the *Zdimir* beds at six other sections that belong to the Beiliu facies or the *Zdimir* lithofacies (Fig. 5).

Bahe section at Tiandeng

Bai & Bai (1988, fig. 2), Bai *et al.* (1994, fig. 10-5), and Bai *et al.* (1998) reported three *Zdimir* beds in the Najiao-Zuozhou Formation at the Bahe section, Tiandeng (Fig. 1). The lowest *Zdimir* bed that contains the brachiopods *Zdimir kueichouensis* and *Megastrophia* sp. is located in the basal part of bed 1c; the second *Zdimir* bed with the same brachiopod taxa as the first one is situated in the lower part of bed 3; and the highest one hosting *Z. kueichouensis*, *Z. contractus* and *Megastrophia* sp. is close to the top of bed 11. Conodont succession of the Najiao-Zuozhou

Formation suggests that the first and second *Zdimir* beds can be assigned to the *serotinus* Zone, whereas the third one belongs to the *partitus* Zone (Bai & Bai 1988, Bai *et al*. 1994, 1998). However, when correlating the conodont biostratigraphy of the *Zdimir* beds at different sections in South China, Bai *et al*. (1998, tab. 1) correlated the second *Zdimir* bed at the Bahe section with the *patulus* Zone, an opinion that is inconsistent with the description in their paper (Bai *et al*. 1998, p. 374). Additionally, the joint occurrence of the rugose corals including *Dohmophyllum beiluensis*, *Siphonophrentis* cf. *longiseptata* and *Tryplasma* sp. with the brachiopods *Z. kueichouensis* and *Megastrophia* sp. in bed 3 indicates that this rugose coral fauna is assignable to the *serotinus* Zone.

Dafengmen section at Beiliu

Wang *et al.* (1965) first reported extraordinarily abundant specimens of the genus *Zdimir* (which was previously assigned to the genus *Conchidiella*) in the Guitang Formation (the previous Guitang Member of the Beiliu Formation) at the Dafengmen section (Fig. 1) and ascribed them to the Middle Devonian. Later, a comprehensive study on the brachiopods at this section was carried out by Wang & Zhu (1979), who recognized three main *Zdimir* beds in the Guitang Formation (Fig. 6). The lowest *Zdimir* bed, located in bed BD634 in the lower half of the Guitang Formation, contains *Zdimir gorezkii*, *Z. pseudobaschkiricus* and *Megastrophia uralensis*; the second one is situated in the upper half of the Guitang Formation (bed BD643) and yields abundant specimens of *Z. triangulicostatus*, *Z. gorezkii*, *Z. contractus*, *Z. baschkiricus*, *Z. pseudobaschkiricus*, *Z. strachovi*, *Z. beiliuensis*, *Z. quitangensis*, *M. uralensis* and *Carinatina arimaspa*; the highest *Zdimir* bed is positioned in bed BD 646 close to the upper boundary of the Guitang Formation and hosts *Z. triangulicostatus*, *Z. baschkiricus*, *Z. pseudobaschkiricus*, *Z. beiliuensis*, *M. uralensis* and *Eifelatrypa superplana*. The strata at the Dafengmen section are characterized by containing abundant brachiopods and rugose corals, but no conodonts have ever been reported.

According to Yu & Kuang (1982, pp. 44, 45), the rugose corals in the Guitang and the overlying Yarang formations at the Dafengmen section can be subdivided into three assemblages (Fig. 6. I–III). The first rugose coral assemblage (I) ranges from beds BD626 to 9-3 in the upper part of the lower half of the Guitang Formation and corresponds to the first *Zdimir* bed of Wang & Zhu (1979). The second rugose coral assemblage (II) is situated in the upper part of the Guitang Formation; it ranges from beds BD643 to BD647 and includes the second and third *Zdimir* beds of Wang & Zhu (1979). The third assemblage (III) includes rugose corals from beds BD652 to BD655 in the upper part of the Yarang Formation. Yu *et al.* (1979, pp. 98, 99), and Yu & Kuang (1982, p. 46) made a detailed comparison of the rugose coral faunas between the Dafengmen and Dale sections (Xiangzhou) and noted that the first rugose coral assemblage in the Guitang Formation at the Dafengmen section could be correlated with the T assemblage (or the *Trapezophyllum cystosum* assemblage) in the lower part of the Liuhui Member of the Sipai Formation at the Dale section in having *Trapezophyllum cystosum*, *Thamnophyllum uniense*, *Tryplasma devoniana* and

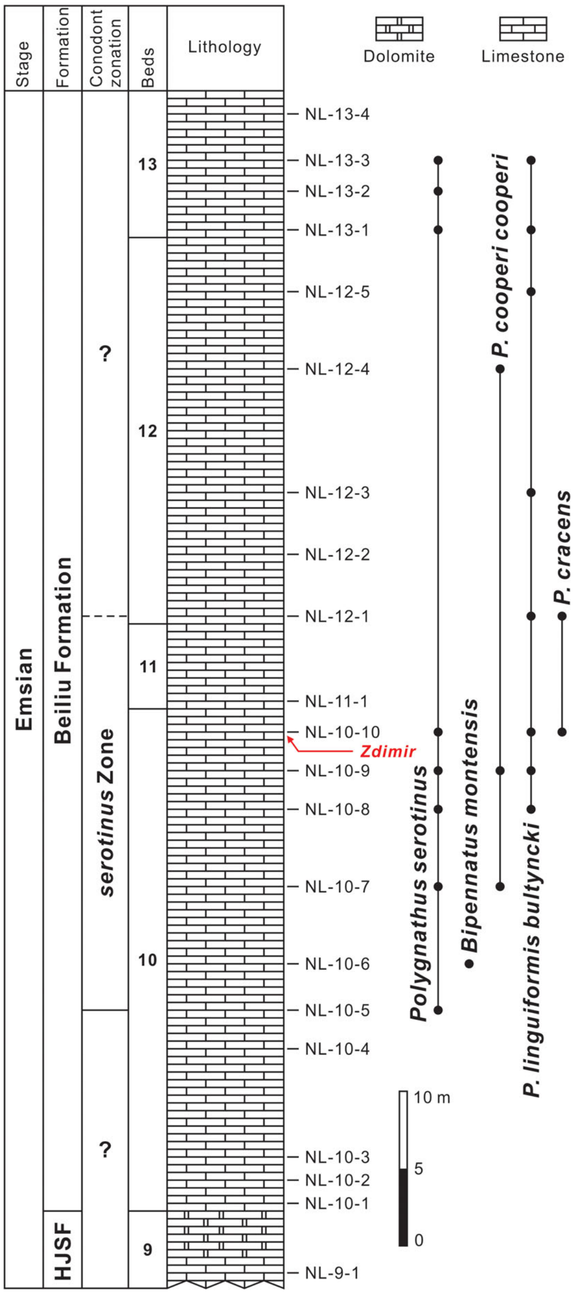


Figure 4. Stratigraphical column of the Emsian succession at the Nalai section with position of samples, conodont ranges and location of the *Zdimir* beds. HJSF, Huangjingshan Formation.

Stage	**Conodont zonation** (Sandberg & Ziegler 1996)	**Nalai** (This paper)	**Bahe** (Bai & Bai 1988, Bai *et al.* 1998)	**Qinjia** (Wu & Yan 1980)	**Dafengmen** (Wang & Zhu 1979)	**Guangziyao** (Wang & Zhu 1979)	**Liujing** (Kuang *et al.* 1989)	**Longmenshan** (Hou *et al.* 1988)
Eifelian	***partitus***		***Zdimir***					***Zdimir***
Emsian	***patulus***							
	serotinus	***Zdimir***	***Zdimir***	***Zdimir***	***Zdimir***	***Zdimir***	***Zdimir***	

Figure 5. Zonal correlation of the *Zdimir* beds in relevant sections of South China.

Embolophyllum. In addition to Dale section in the Xianzhou area, the T assemblage was only reported in the Luzhai and Wuxuan (Yu *et al.* 1979, p. 99; Yu & Kuang 1982, p. 46), both of which are geographically close (approximately ninety kilometres, respectively) to the Dale section. According to Wang (1979), the conodont *Polygnathus declinatus*, a species initially thought to be transitional between *P. inversus* and *P. serotinus* by Wang (1979) but viewed as a junior synonym of *P. serotinus* by Klapper & Vodrážková (2013) and present paper, was reported from the uppermost part of the Shipeng Member to the lowermost part of the Liuhui Member of the Sipai Formation. In addition, *P. serotinus* together with *P. inversus* and *Nowakia holynensis* was also obtained by Bai *et al.* (1982, p. 14) and Bai *et al.* (1994, p. 142) from the middle part of the Liuhui Member at the Dale section. The conodont evidences suggest that the lower and middle parts of the Liuhui Member of the Sipai Formation in the Xiangzhou area can be assigned to the *serotinus* Zone. Accordingly, the first rugose coral assemblage at the Dafengmen section, to which the first *Zdimir* bed of Wang & Zhu (1979) corresponds, also belongs to the *serotinus* Zone (Fig. 5).

Yu & Kuang (1982, p. 46) temporarily correlated the second rugose coral assemblage at the Dafengmen section with that from the Dingshanling Member of the Sipai Formation to the lower part of the overlying Yingtang Formation in the Xiangzhou area. However, rugose coral fauna reported by Bai *et al.* (1982, p. 14) and Bai *et al.* (1994, p. 141) in bed 36b of the Dingshangling Member at the Dale section is somewhat similar to the second rugose coral assemblage at the Dafengmen section in containing only *Tryplasma guangxiensis*, whereas fauna in the Yingtang Formation is completely not. According to Wang *et al.* (1979, p. 309) and Wang & Ziegler (1983, p. 81), the Dingshanling Member of the Sipai Formation and the overlying lower part of the Yintang Formation are roughly assigned to the *serotinus* Zone and *costatus* Zone, respectively. However, due to the scarcity of conodonts from the upper part of the Dingshanling Member of the Sipai Formation, the precise levels of the *patulus* Zone and the *partitus* Zone at the Dale section remain unknown.

As aforementioned, the rugose corals including *Dohmophyllum beiluensis*, *Siphonophrentis* cf. *longiseptata* and *Tryplasma* sp. were only reported in the second *Zdimir* bed at the Bahe section (Bai & Bai 1988; Bai *et al.* 1994, 1998). At the Dafengmen section, *D. beiluensis* was collected from bed BD646; *S. longiseptata* ranged from the middle to upper parts of the Guitang Formation; and the genus *Tryplasma* was common in the first and second rugose coral assemblages (Yu & Kuang 1982; herein, Fig. 6). As a result, the second rugose coral assemblage at the Dafengmen section can be roughly correlated with the rugose coral fauna in bed 3 at the Bahe section and belongs to the *serotinus* Zone. Additionally, the correlation of the rugose coral taxa between the Dafengmen and Guanziyao sections (discussed further down in this paper) also strongly suggests the assignation of the second rugose coral assemblage in the Guitang Formation to the *serotinus* Zone. Accordingly, all three main *Zdimir* beds in the Guitang Formation at the Dafengmen section belong to the *serotinus* Zone (Fig. 5).

Qinjia section at Debao

Zdimir was recorded from beds 25 and 26 in the lower part of the Qunping Member of the Debao Formation at the Qinjia section (Fig. 1) (Wu & Yan 1980, Xian *et al.* 1980). Wu & Yan (1980, pp. 206, 207) compared the brachiopod and coral faunas between the Qinjia and Guixi-Shawozi sections, and suggested a rough correlation of the Qunping Member with the upper part of the Yangmaba Formation in the Longmenshan area that was assigned to the *partitus* Zone. They further stressed that the lower part of the Qunping Member was correlative with the *Nowakia holynensis* Zone, whereas the upper part was referred to the upper *N. sulcata* Zone. This opinion was later adopted by Bai

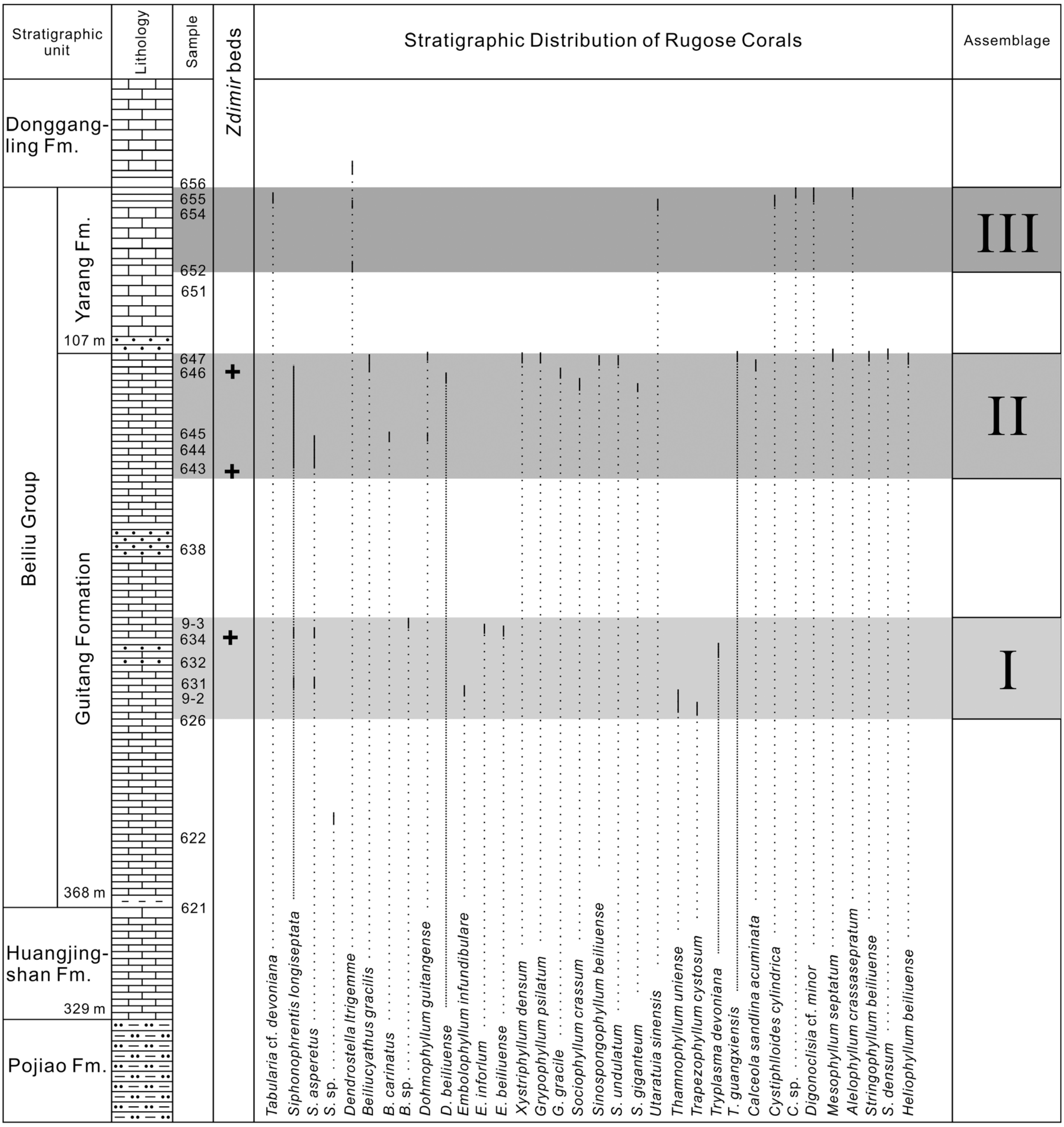


Figure 6. Stratigraphical distribution of rugose corals in the Beiliu Group at Dafengmen section, Guangxi (modified after Yu & Kuang 1982). I–III represent the three rugose coral assemblages. The black crosses correspond to the three main *Zdimir* beds.

et al. (1998), who assigned the lower part of the Qunping Member to the *patulus* Zone. The interval containing only *Megastrophia uralensis* in the upper part of Qunping Member was viewed as the second *Zdimir* bed and they assigned it to the *partitus* Zone.

According to the conodont study conducted by Xiong (1981) at the Qinjia section, *Polygnathus inversus*, which commonly ranges from the *inversus* Zone to the *serotinus* Zone, was recorded in bed 25 in the basal part of the Qunping Member. Taking into consideration that *Nowakia holynensis* first appeared in the upper part of the underlying Duobang Member, the lower part of the Qunping Member should be assigned to the lower rather, than the upper, part of the *N. holynensis* Zone. Accordingly, as suggested by

Xiong (1987, tab. 1), *Zdimir* in beds 25 and 26 in the lower part of the Qunping Member belongs to the *serotinus* Zone (Fig. 5). The second *Zdimir* bed proposed by Wu & Yan (1980), and Bai *et al*. (1998) in the upper part of the Qunping Member should better be named the *Megastrophia* bed. However, its precise position regarding conodont biozones is unknown because of the absence of diagnostic taxa.

Guanziyao section at Pu'an

A preliminary study about the genus *Zdimir* (which was also previously assigned to the genus *Conchidiella*) in the Guanziyao Formation at the Guanziyao section (Fig. 1) was first conducted by Hou & Xu (1964). They described three new species of this genus and correlated the Guanziyao Formation with the middle part of the Middle Devonian in the Urals and Kuznetsk Basin on the basis of the correlation of the brachiopod taxa. Later, when restudying the brachiopod fauna at the Guanziyao section, Wang & Zhu (1979, p. 15) reported abundant specimens of *Zdimir* in the lower half of the Guanziyao Formation at the Guanziyao section. Subsequently, Yu & Kuang (1982, p. 48) made a detailed study of the rugose corals co-occurring with *Zdimir* in the Guanziyao Formation. They corroborated that many species or genera of rugose corals at the Guanziyao section such as *Beiliucyathus gracilis*, *Dohmophyllum guitangense*, *Tryplasma guangxiense*, *Siphonophrentis*, *Stringophyllum* and *Sociophyllum* can also be (or only be) observed in the second rugose coral assemblage at the Dafengmen section. As a result, the *Zdimir* bed in the Guanziyao Formation at the Guanziyao section can be directly correlated with the *Zdimir* beds in the upper part of the Guitang Formation at the Dafengmen section, which suggests that the stratigraphic level of the former cannot be lower than the *serotinus* Zone. Moreover, conodonts including *Polygnathus cooperi secus*, *P. linguiformis* alpha morphotype (= *P. linguiformis bultyncki*), *P. foliformis* (= *P. serotinus*) and *Caudicriodus culicellus* were obtained in the uppermost part of the Guanziyao Formation by Xiong (1987), indicating that the uppermost part of the Guanziyao Formation belongs to the *serotinus* Zone. Thus, the *Zdimir* bed at the Guanziyao section is assigned to the *serotinus* Zone (Fig. 5).

It is worthy to note that Bai *et al*. (1998) also agreed with the correlation of the rugose coral biostratigraphy between the Guanziyao and Dafengmen sections made by Yu & Kuang (1982). Although the *Zdimir* bed at the Guanziyao section was correlated with the *serotinus* Zone by Bai *et al*. (1998), these *Zdimir* beds in the upper part of the Guitang Formation at the Dafengmen section were assigned to the *patulus* Zone.

Other sections in South China

Kuang *et al*. (1989, pp. 8, 71, fig. 13) reported the first appearance of *Zdimir* sp. together with *Atrypa* sp. and *Megastrophia* sp. in the upper part of bed 43 of the Najiao Formation at the Liujing section (Fig. 1). *Polygnathus serotinus* first appears in the lower part of bed 43, whereas *P. costatus patulus* has its first appearance in sample Nj17 in the middle or upper part of bed 44. As a result, the *Zdimir* bed that was initially assigned to the *patulus* Zone by Kuang *et al*. (1989, p. 57) is correlated with the *serotinus* Zone in the present paper (Fig. 5).

Abundant specimens of *Zdimir* were also collected by Hou *et al*. (1988) from bed B93 in the Shiliangzi Member of the Yangmaba Formation at the Guixi-Shawozi section, Longmenshan (in the northwest part of the South China Block). The joint occurrence of *Polygnathus costatus partitus*, *Bipennatus bipennatus* and *B. montensis* with *Zdimir* permits the assignation of beds B93–B94 of the Shiliangzi Member to the *partitus* Zone (Hou *et al*. 1988; herein, Fig. 5).

Summary

On the basis of the conodont succession at the Nalai section, one *Zdimir* bed in the lower part of the Beiliu Formation is assigned to the *serotinus* Zone. Taking into account the rugose coral biostratigraphy associated to *Zdimir*, the conodont biostratigraphy of the *Zdimir* beds at the Dafengmen, Liujing, Qinjia, Bahe, Guangziyao and Guixi-Shawozi sections in South China are also reviewed. Several *Zdimir* beds which were previously correlated with the *patulus* Zone at the Dafengmen, Bahe and Qinjia sections by Bai *et al*. (1998) in fact belong to the *serotinus* Zone. Accordingly, the *Zdimir* beds in South China can only be assigned to the upper Emsian *serotinus* Zone and to the lower Eifelian *partitus* Zone.

Systematic Palaeontology

All specimens described and illustrated herein are deposited in the collections of the Nanjing Institute of Geology and Palaeontology (NIGP). Only Pa elements are described. Nomenclature of the Pa elements proposed by Murphy & Valenzuela-Ríos (1999) is followed.

Class Conodonta Pander, 1856
Order Ozarkodinida Dzik, 1976
Family Polygnathidae Bassler, 1925

Genus *Bipennatus* Mawson, 1993

Type species. – *Spathognathodus bipennatus* Bischoff & Ziegler, 1957.

***Bipennatus* cf. *B. montensis* (Weddige, 1977)**
Figures 7A–C

cf. 1966 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler. – Bultynck, pp. 202–203, pl. 2, figs 6–7 (only).
cf. 1970 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler. – Bultynck, p. 134, pl. 19, figs 2, 4 (only).
cf. 1974 *Eognathodus bipennatus* (Bischoff & Ziegler). – Perry *et al*., pp. 1084, 1086, pl. 6, figs 14–15.
cf. 1977 *Eognathodus bipennatus montensis* n. ssp.; Weddige, p. 324, pl. 6, figs 95–96.
cf. 1983 *Eognathodus bipennatus montensis* Weddige. – Wang & Ziegler, pp. 92, 93, pl. 1, figs 15–16.
cf. 1988 *Eognathodus bipennatus montensis* Weddige. – Xiong *in* Hou *et al*., p. 314, pl. 123, fig. 3.
cf. 1989 *Eognathodus bipennatus montensis* Weddige. – Wang, p. 41, pl. 6, figs 4–7.
cf. 2010 *Bipennatus bipennatus montensis* (Weddige). – Narkiewicz & Narkiewicz, p. 292, figs 5a–h.
cf. 2013 *Bipennatus montensis* (Weddige). – Narkiewicz, pp. 3, 5–6, figs 3a–v.

Material. – One Pa element from sample NL-10-6 (1).

Description. – The anterior fourth of the blade is composed of four almost equal, tip-free and very low denticles, slightly higher than the flat and smoothly descending middle blade. The anterior end is slightly bent. Posterior blade tapers posteriorly, gently bowed downwards and markedly descending with six broad, transversely elongated and very low denticles with the posterior one being the lowest. The lower margin is weakly concave with both anterior and posterior margins rising slowly from the end to the middle point of the blade. The blade is longitudinally straight. A flat, smooth and narrow upper platform is developed in the middle third of the blade above the basal cavity, tapers anteriorly and remains broad posteriorly; margins of this narrow platform are distinctly smooth and join together with the last denticle of the anterior blade at the anterior end of the platform. Basal lobes are slightly anterior of mid blade, rounded and asymmetrical with the outer one being larger. A small terrace area with brim is developed on both lobes. Basal cavity is completely open and extends anteriorly and posteriorly as a narrow groove.

Discussion. – *Bipennatus montensis* was first named and described as *Eognathodus bipennatus montensis* by Weddige (1977) in the Bergisches Land and Eifel Mountains, Germany. Later, when investigating the morphological variability and phylogenetic affinity of this taxon, Narkiewicz (2013) ascribed it to the genus *Bipennatus* and raised it to species level. The taxonomic treatment of Narkiewicz (2013) is followed in the present paper.

Bipennatus montensis closely resembles *B. pennatus* in the blade outline, but differs in having a shallow trough restricted to the middle part of the blade and flanked by two smooth marginal ridges, a more centrally located basal cavity, a relatively lower anterior blade, and a longitudinally straight blade. In contrast, *B. pennatus* has a clear trough or sulcus on the upper surface that nearly extends to the posterior termination and is bordered by two nodose marginal ridges; the basal cavity is somewhat more anteriorly located; the denticles in the anterior part of the blade are remarkably higher than the upper margin of the posterior part; and the posterior blade is clearly deflected inward.

The holotype of *Bipennatus montensis* (Weddige 1977, pl. 6, fig. 95) is characterized by a shallow sulcus on the narrow platform in the middle third of the blade, a basal cavity situated slightly posterior to the mid-length, and two lateral, semi-circular lobes without terrace on the upper surface. However, the Nalai specimen slightly differs from the holotype of *B. montensis* in having a flat, smooth and narrow upper platform surface in the absence of the characteristic shallow sulcus, a slightly anteriorly located basal cavity, and two terraced lobes. As a result, the Nalai specimen, provisionally identified as *B.* cf. *B. montensis* herein, probably represents a phylogenetically early form of this species.

Narkiewicz & Narkiewicz (2010), and Narkiewicz (2013) pointed out that *Bipennatus montensis* was generally reported from the Eifelian *costatus* Zone in Germany, Poland and Russia. However, *B.* cf. *B. montensis* is described in the upper Emsian *serotinus* Zone at the Nalai section, a level which is much lower than the previously recorded. As a result, the Nalai's record challenges Narkiewicz's (2013) opinion about the phylogenetic position of *B. montensis* being derived from the ozarkodinids near the Emsian–Eifelian boundary. Compared with the Eifelian *B.* aff. *B. montensis* and *Ozarkodina* sp. A described by Narkiewicz (2013) from the Holy Cross Mountains, the Nalai material resembles more closely the holotype or the representative specimens of *B. montensis*, suggesting that *B. montensis* do not evolve from *Ozarkodina* sp. A via *B.* aff. *B. montensis* near the Emsian-Eifelian boundary.

Occurrence. – *Bipennatus montensis* has been widely recorded in the *costatus* Zone, but *B.* cf. *B. montensis* in the present study is reported from the *serotinus* Zone.

Genus *Polygnathus* Hinde, 1879

Type species. – *Polygnathus dubius* Hinde, 1879.

***Polygnathus cooperi cooperi* Klapper, 1971**
Figures 7D–K

1968 *Polygnathus webbi* Stauffer. – Đurđanović, pp. 100–101, pl. 1, fig. 10 (only).

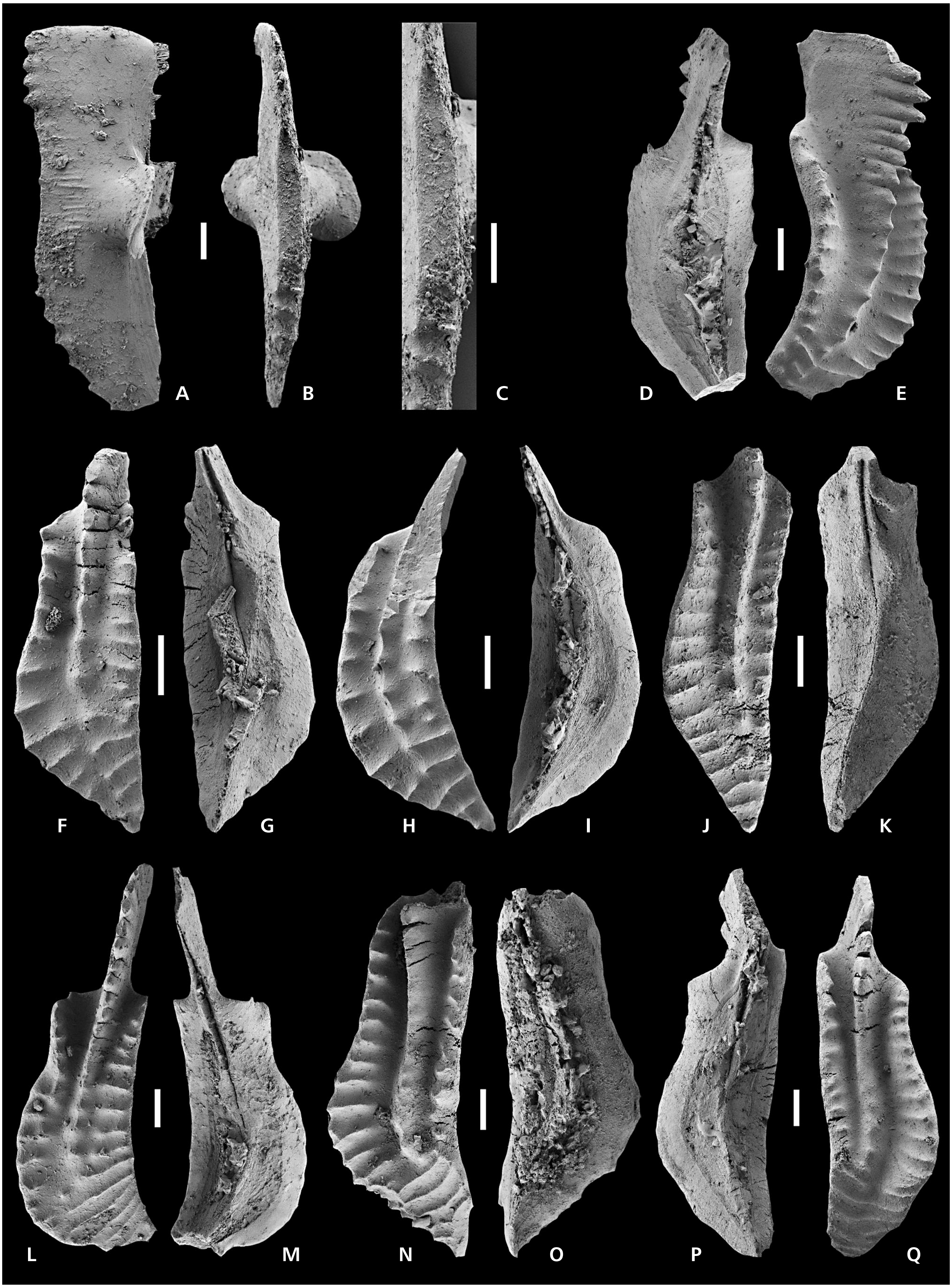
1970 *Polygnathus linguiformis linguiformis* Hinde. – Bultynck, pp. 125–127, pl. 9, figs 8–11.
1971 *Polygnathus linguiformis cooperi* n. ssp.; Klapper, p. 64, pl. 1, figs 12–22; pl. 2, fig. 21.
non 1975 *Polygnathus linguiformis cooperi* Klapper. – Telford, pp. 44–48, pl. 8, figs 6–15.
1977 *Polygnathus linguiformis cooperi* Klapper. – Klapper *in* Ziegler, pp. 471–472, *Polygnathus*-pl. 9, figs 2–3.
1977 *Polygnathus linguiformis cooperi* Klapper. – Weddige, pp. 314–315, pl. 5, figs 93–94.
non 1978 *Polygnathus linguiformis cooperi* Klapper. – Apekina & Mashkova *in* Kim *et al*., p. 47, pl. 77, figs 3, 9.
1978 *Polygnathus cooperi cooperi* Klapper. – Klapper *et al*., p. 108, pl. 2, figs 21–22, 29–30.
1979 *Polygnathus cooperi* Klapper. – Lane & Ormiston, pp. 76, 77, pl. 3, fig. 27.
1980 *Polygnathus cooperi cooperi* Klapper. – Klapper & Johnson, p. 452.
1980 *Polygnathus linguiformis cooperi* Klapper. – Bultynck & Hollard, p. 43, pl. 2, figs 17, 19; pl. 3, figs 14–15 (only).
1985 *Polygnathus cooperi cooperi* Klapper. – Bultynck, pp. 282, 283, pl. 7, figs 5–6, 14?
1987b *Polygnathus cooperi cooperi* Klapper. – Mawson, pp. 264, 265, pl. 1, fig. 6 (only).
non 1989 *Polygnathus cooperi cooperi* Klapper. – Mawson & Talent, pp. 248, 249, pl. 3, fig. 8.
1992 *Polygnathus cooperi cooperi* Klapper. – Bardashev, pp. 62, 63, , pl. 1, fig. 2 (only).
non 1992 *Polygnathus cooperi cooperi* Klapper. – Bardashev & Ziegler, pp. 28, 29, pl. 6, figs 26, 29.
? 1994 *Polygnathus cooperi cooperi* Klapper. – Mawson & Talent, pp. 54, 55, pl. 2, fig. 4.
non 1994 *Polygnathus cooperi cooperi* Klapper. – Talent & Mawson, pp. 78, 79, pl. 2, fig. 18.
2002 *Linguipolygnathus cooperi cooperi* (Klapper). – Bardashev *et al*., p. 421, text-figs 10, 15.42.
2009 *Polygnathus cooperi cooperi* Klapper. – Berkyová, p. 680, figs 7a–d.
2012 *Polygnathus cooperi cooperi* Klapper. – Saydam-Demiray & Çapkinoğlu, p. 15, pl. 2, figs 17, 22 (only).

Material. – Five Pa elements from samples NL-10-7 (1), NL-10-9 (3) and NL-12-4 (1).

Description. – Free blade about $^1/_4$ to $^1/_3$ of the total length with 7–9 close, palisade denticles (Fig. 7D, E), decreasing gradually in height posteriorly. Carina, flanked by narrow and somewhat shallow adcarinal grooves in the anterior part of the platform, varies from stout fused denticles in the anterior half of the platform to a row of discrete denticles in the middle part; it does not reach the posterior tip and isolated denticles fuse with tongue transverse ridges. Platform is symmetrical or slightly asymmetrical with the carina being centrally positioned (Fig. 7E, F, H) or near the inner side (Fig. 7J). Anterior platform margins meet the blade at straight or acute angles; in most specimens the inner one meets the blade at a more anterior position. Platform margins in the anterior part are at same height and ornamented by short transverse ridges that grow longer posteriorly, mainly in the outer flank. In some specimens (Fig. 7F–K) the anterior part of the platform is marked by a clear constriction, forming a concave outer margin anteriorly; these specimens show an almost straight inner margin, and the carina reflects this shape by a clear inner deflection in the posterior half. Other specimens (Fig. 7D, E) develop subparallel margins, and the carina gently curves inward. The posterior part of the platform has a short and triangular tongue covered by 4–5 semi-crossed transverse ridges. On the lower side a large or medium-sized, symmetrical basal pit is situated in the anterior half. It continues anteriorly in an open anterior through that tapers distally. Narrow posterior through is with appressed flanks. Platform bows with posterior third clearly bent downwards.

Discussion. – In the type specimens of *Polygnathus cooperi cooperi* (Klapper 1971 pl. 1, figs 12–22; pl. 2, fig. 21), the apparently or weakly constricted anterior platform is relatively flat and ornamented by short transverse ridges which are separated from the carina by shallow adcarinal grooves; the inner margin is at same height with the rounded and smooth outer one; the small tongue is ornamented by one to three crossed or semi-crossed transverse ridges; and the basal pit is located in the anterior part of the platform. One specimen illustrated here (Fig. 7F) has a small tongue whose transverse ridges on the outer side are interrupted except for the last and continuous one. A similar development of the transverse ridges on the tongue is also observed in two specimens of *P. cooperi cooperi* (Klapper 1971, pl. 1, figs 18, 19). The specimens figured by Berkyová (2009, figs 7a, c, d) also possess one continuous or

Figure 7. A–C – *Bipennatus* cf. *B. montensis* (Weddige 1977), Pa element: lateral, upper and enlarged views of NIGP 164918, sample NL-10-6. • D–K – *Polygnathus cooperi cooperi* Klapper, 1971, Pa elements; D, E – lower and upper views of NIGP 164919, sample NL-10-7; F, G – upper and lower views of NIGP 164920, sample NL-10-9; H, I – upper and lower views of NIGP 164921, sample NL-10-9; J, K – upper and lower views of NIGP 164922, sample NL-12-4. • L–Q – *Polygnathus cracens* Klapper, Ziegler & Mashkova, 1978, Pa elements; L, M – upper and lower views of NIGP 164923, sample NL-10-10; N, O – upper and lower views of NIGP 164924, sample NL-12-1; P, Q – lower and upper views of NIGP 164925, sample NL-12-1. Scale bars = 100 μm. All the specimens are deposited at the NIGP.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semi-crossed transverse ridge at the posterior end of the platform. Another specimen from the Nalai section (Fig. 7D, E) is similar to one of the original specimens (Klapper 1971, pl. 1, figs 20, 21) in having parallel inner and outer margins in the anterior part of the platform. The specimens reported as *P. cooperi cooperi* from Australia by Mawson & Talent (1989, pl. 3, fig. 8; 1994, pl. 3, fig. 6), and Talent & Mawson (1994, pl. 2, fig. 18) are characterized by interrupted transverse ridges at the posterior-end of the platform and a carina running to the posterior end.

Polygnathus cooperi cooperi differs from *P. linguiformis butyncki* by its weakly developed transverse ridges of which few completely cross the tongue, and the shallow adcarinal grooves only restricted to the anterior part. *Polygnathus cooperi cooperi* is highly differentiable by its distinctly straight, rather than serrate, anterior platform margin, whereas the anterior platform margin is strongly serrated in *P. cooperi secus*. *Polygnathus costatus patulus* has a carina extending to the posterior termination of the platform without the development of a tongue.

Occurrence. – This subspecies ranges from the *serotinus* Zone to the *costatus* Zone.

Polygnathus cracens **Klapper, Ziegler & Mashkova, 1978**

Figures 7L–Q

1978 *Polygnathus cracens* n. sp.; Klapper, Ziegler & Mashkova, p. 109, pl. 1, figs 17–20, 24–25.
1978 *Polygnathus* sp. H Klapper. – Apekina & Mashkova *in* Kim *et al*., p. 46, pl. 76, figs 6–7.
1978 *Polygnathus linguiformis* Hinde alpha forma Bultynck. – Apekina & Mashkova *in* Kim *et al*., p. 47, pl. 77, fig. 8.
1978 *Polygnathus linguiformis cooperi* Klapper. – Apekina & Mashkova *in* Kim *et al*., p. 47, pl. 77, figs 3, 9.
1980 *Polygnathus cracens* Klapper, Ziegler & Mashkova. – Klapper & Johnson, p. 452.
1985 *Polygnathus cracens* Klapper, Ziegler & Mashkova. – Bultynck, pp. 282, 283, pl. 7, fig. 1.
1992 *Polygnathus cracens* Klapper, Ziegler & Mashkova. – Bardashev & Ziegler, pp. 28, 29, pl. 6, figs 5, 18?
1992 *Polygnathus cracens* Klapper, Ziegler & Mashkova. – Bonceva, p. 37, pl. 1, figs 5–6.
2002 *Linguipolygnathus cracens* (Klapper, Ziegler & Mashkova). – Bardashev *et al*., p. 421, text-figs 10, 15.37.
2009 *Polygnathus linguiformis linguiformis* Hinde. – Berkyová, pp. 682, 683, fig. 8i.
2012 *Polygnathus cooperi cooperi* Klapper. – Saydam-Demiray & Çapkinoğlu, p. 15, pl. 2, fig. 16.

Material. – Three Pa elements from samples NL-10-10 (1) and NL-12-1 (2).

Description. – High free blade is about $^1/_4$ of the total length and bears several laterally compressed denticles (Fig. 7L, M); its height gradually decreases posteriorly. Carina, located near the inner margin, varies from strongly fused denticles in the anterior part of the platform to a row of discrete denticles in the middle part. Platform is asymmetrically developed with a much wider and deeper outer adcarinal groove. Anterior platform margins commonly meet the blade at the same position with straight or acute angles (Fig. 7L–O). Anterior inner and outer platform margins are at same height and ornamented by short or slightly longer transverse ridges. Outer platform margin clearly constricted anteriorly. The posterior part of the platform is deflected inward and ornamented with numerous continuous transverse ridges; it represents about $^1/_3$ of the platform The outer margin at the conjunction of tongue and anterior platform is angular in most specimens, but in some specimens it continues in a rounded curve (Fig. 8C–H). On the lower side a small and symmetrical basal pit is situated anterior of the inward deflection of the posterior keel. It continues anteriorly in an open anterior through that tapers distally. Platform bows with posterior third clearly bent downwards.

Discussion. – Specimens from the Nalai section are characterized by an anteriorly constricted platform with the inner and outer margins having the same height, a well-developed tongue bearing numerous crossed transverse ridges, and a small, somewhat anteriorly situated basal pit. This combination of features is consistent with that shown in the representative specimens of *Polygnathus cracens*. However, the posterior part of the platform in the type specimens of *P. cracens* (Klapper *et al*. 1978, pl. 1, figs 17–20,

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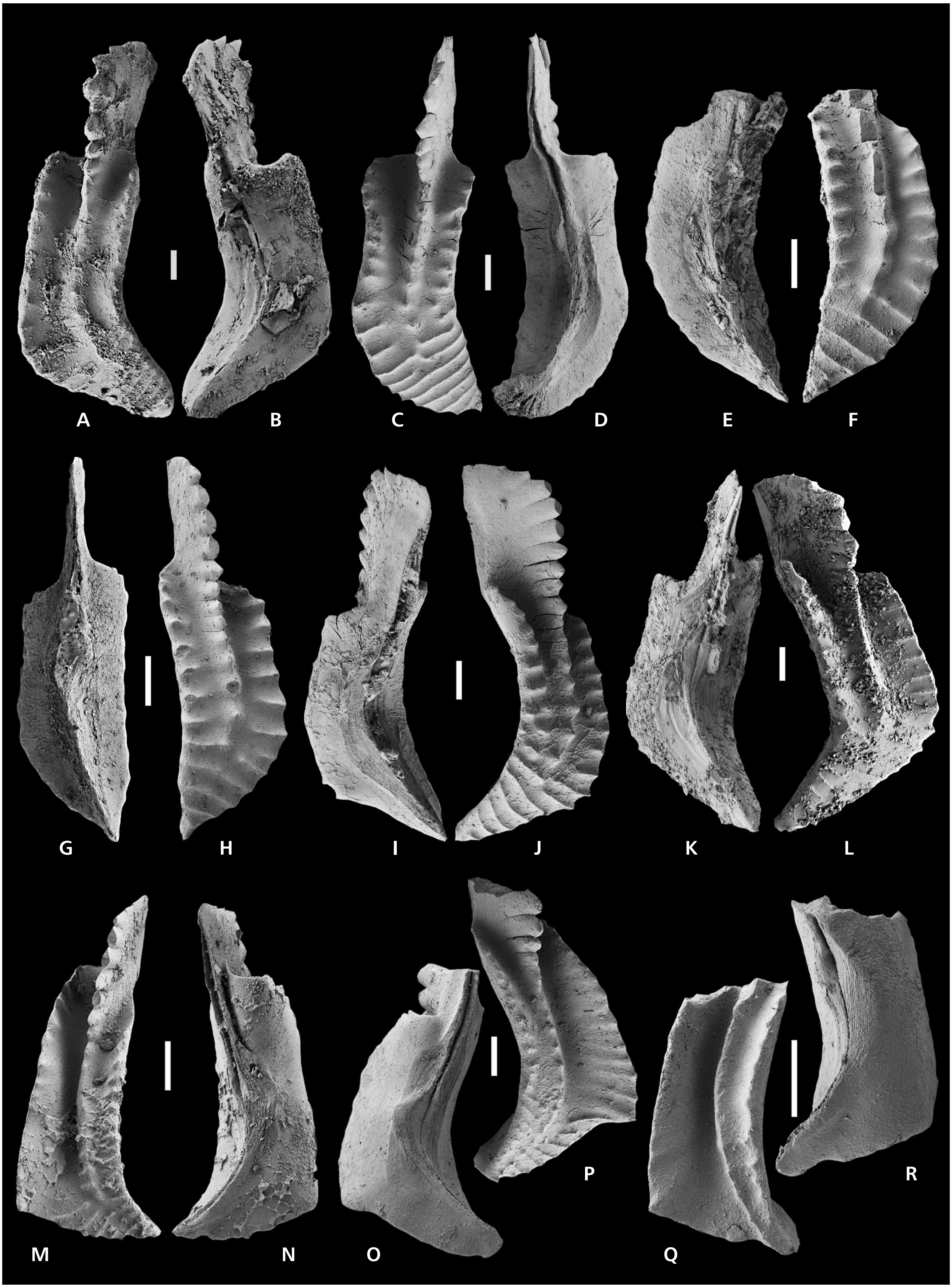
Figure 8. A–L – *Polygnathus linguiformis bultyncki* Weddige, 1977, Pa elements; A, B – upper and lower views of NIGP 164926, sample NL-10-8; C, D – upper and lower views of NIGP 164927, sample NL-10-9; E, F –lower and upper views of NIGP 164928, sample NL-10-9; G, H –lower and upper views of NIGP 164929, sample NL-10-9; I, J – lower and upper views of NIGP 164930, sample NL-10-10; K, L – lower and upper views of NIGP 164931, sample NL-13-1. • M–R – *Polygnathus serotinus* Telford, 1975, Pa elements; M, N – upper and lower views of NIGP 164932, sample NL-10-5; O, P – lower and upper views of NIGP 164933, sample NL-10-8; Q, R – upper and lower views of NIGP 164934, juvenile specimen, sample NL-10-9. Scale bars = 100 µm. All the specimens are deposited at the NIGP.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24, 25) is sharply deflected inward, whereas some of the Nalai specimens (Fig. 7N–Q) have a moderately deflected posterior part of the platform with an almost straight inner margin and a rounded outer one. Bultynck (1985, pl. 7, fig. 1) reported a similar specimen from Morocco.

Polygnathus inversus has a more or less parallel anterior inner and outer margins and a basal pit just anterior of the inward deflection of the keel; besides *P. cracens* has an anteriorly constricted platform and a more anteriorly situated basal pit. *Polygnathus linguiformis bultyncki* closely resembles *P. cracens* in the height of the anterior inner and outer margins and the position of the basal pit, but mainly the development of parallel anterior margins distinguishes *P. linguiformis bultyncki* from *P. cracens*.

Occurrence. – *Polygnathus cracens* is only recorded in the *serotinus* Zone.

Polygnathus linguiformis bultyncki Weddige, 1977
Figures 8A–L

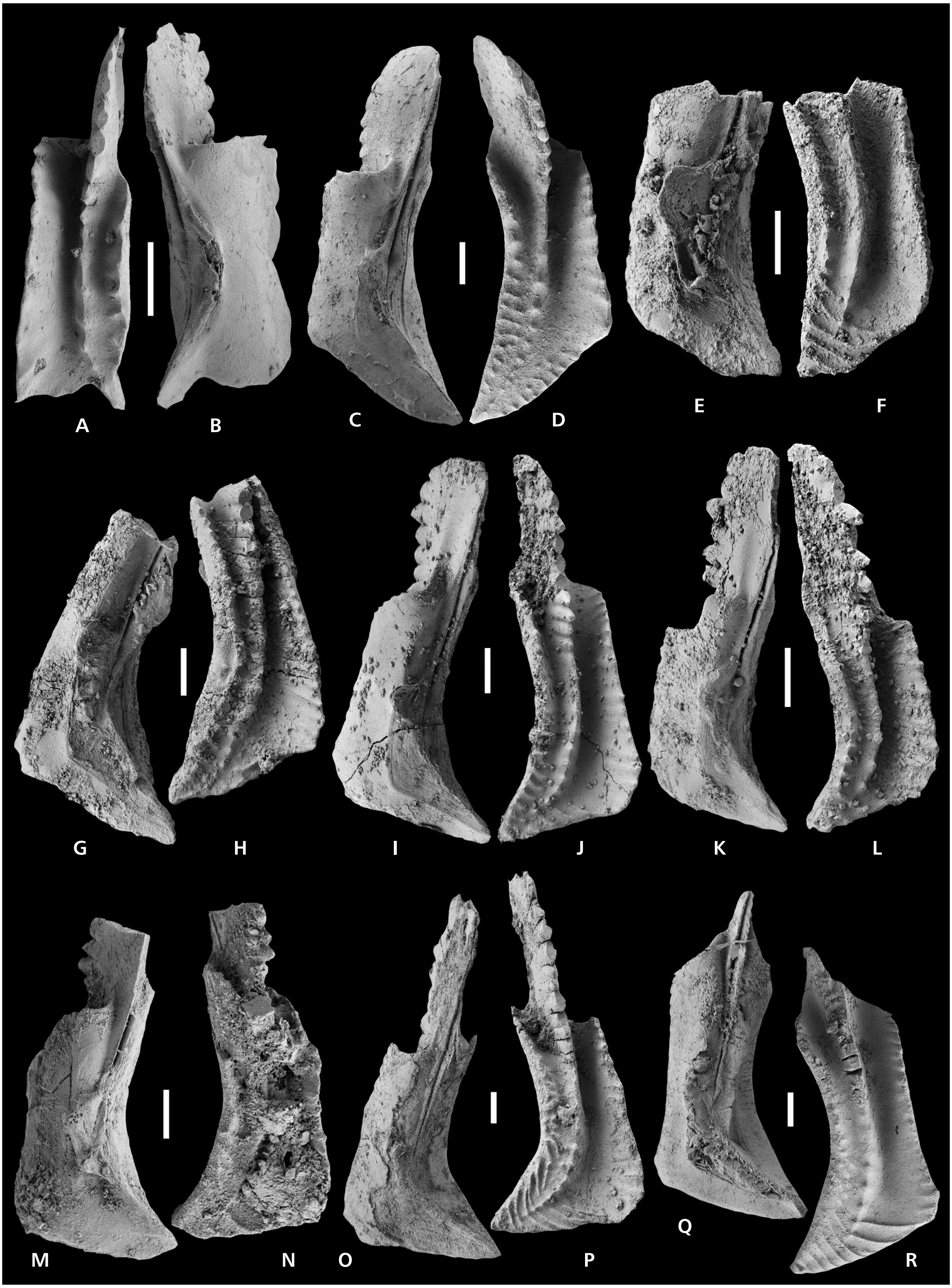
1975 *Polygnathus linguiformis* Hinde. – Snigireva, pp. 22, 23, pl. 4, fig. 5.
1977 *Polygnathus linguiformis bultyncki* n. ssp.; Weddige, pp. 313–314, pl. 5, figs 90–91; text-fig. 4.20 (only).
1982 *Polygnathus linguiformis bultyncki* Weddige. – Bai *et al*., p. 68, pl. 3, fig. 5; pl. 7, fig. 18.
1983 *Polygnathus linguiformis bultyncki* Weddige beta morphotype. – Wang & Ziegler, p. 89, pl. 5, fig. 18.
1985 *Polygnathus linguiformis linguiformis* Hinde. – Ziegler & Wang, pp. 30, 31, pl. 1, fig. 32.
1991 *Polygnathus linguiformis bultyncki* Weddige. – Uyeno, pp. 156, 157, pl. 3, fig. 7.
1995 *Polygnathus bultyncki* Weddige. – Furey-Greig, pp. 230, 231, pl. 1, fig. 4.
1997 *Polygnathus linguiformis* cf. *l. bultyncki* Weddige. – Savage & Soja, p. 127, figs 3.3–3.5.
2003 *Polygnathus linguiformis bultyncki* Weddige. – Daniell, pp. 352, 353, pl. 4, figs 10–12.
2005 *Polygnathus linguiformis bultyncki* Weddige. – Jin *et al*., pp. 59–60, pl. 2, figs 3–4,13–14, 17–18.
2012 *Polygnathus linguiformis bultyncki* Weddige beta morphotype. – Saydam-Demiray & Çapkinoğlu, p. 16, pl. 2, figs 9–10, 20 (only).
2013 *Polygnathus bultyncki* Weddige. – Klapper & Vodrážková; pp. 164–167, text-figs 1a–f, 6a–f (further synonymy).
2013 *Polygnathus linguiformis bultyncki* Weddige. – Lu, pp. 316, 317, pl. 2, figs 2–3.
2015 *Linguipolygnathus bultyncki* (Weddige). – Aboussalam *et al*., pp. 946–949, figs 15v, 16a–b, h–j.

Material. – Twenty-five Pa elements from samples NL-10-8 (3), NL-10-9 (8), NL-10-10 (2), NL-12-1 (3), NL-12-3 (3), NL-12-5 (4), NL-13-1 (1) and NL-13-3 (1).

Description. – High free blade composed of 5–7 palisade denticles occupying about $^1/_5$ to $^1/_4$ of the total length (Fig. 8A–D, G–L); its height gradually decreases posteriorly. Carina, flanked by wide and deep adcarinal grooves, varies from strongly fused and stout denticles in the anterior half of the platform to a row of small discrete denticles in the middle part; carina ends at the beginning of the tongue. In most specimens, the anterior platform margins meet the blade at the same position with straight or acute angles. Platform is somewhat asymmetrical with a much deeper outer adcarinal groove. Anterior inner and outer platform margins have the same height and are ornamented by short transverse ridges. The posterior part of the platform is deflected inward and forms a well-developed triangular tongue that bears numerous continuous transverse ridges; it represents about $^1/_3$ of the platform. The outer margin at the conjunction of tongue and anterior platform is angular in most specimens, but in some specimens it continues in a rounded curve (Fig. 8C–H). On the lower side, a small to medium-sized and symmetrical basal pit is located anterior of the inward deflection of the keel. It continues anteriorly in an open anterior through that tapers distally. In slightly smaller specimen whose tongue is only ornamented by three or four continuous transverse ridges, the medium-sized basal pit is positioned more anteriorly between the mid-length and the anterior end of the platform (Fig. 8E–H). Platform bows with posterior third clearly bent downwards.

Discussion. – The Nalai specimens are similar to the type specimens of *Polygnathus linguiformis bultyncki* (Weddige 1977, pl. 5, figs 90–91) in the platform outline, tongue ornamentation, and position of the basal cavity. This taxon

Figure 9. A–R – *Polygnathus serotinus* Telford, 1975, Pa elements; A, B – upper and lower views of NIGP 164935, juvenile specimen, sample NL-10-9; C, D – lower and upper views of NIGP 164936, sample NL-10-10; E, F – lower and upper views of NIGP 164937, sample NL-13-1; G, H – lower and upper views of NIGP 164938, sample NL-13-1; I, J – lower and upper views of NIGP 164939, sample NL-13-1; K, L – lower and upper views of NIGP 164940, sample NL-13-1; M, N – lower and upper views of NIGP 164941, sample NL-13-2; O, P – lower and upper views of NIGP 164942, sample NL-13-3; Q, R – lower and upper views of NIGP 164943, sample NL-13-3. Scale bars = 100 μm. All the specimens are deposited at the NIGP.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was initially depicted as the alpha morphotype of *P. linguiformis linguiformis* by Bultynck (1970). Differing from other six morphotypes (beta, gamma, delta, epsilon, zeta and eta) of *P. linguiformis linguiformis* which were summarized by Klapper *in* Ziegler (1977), *P. linguiformis bultyncki* is distinctly differentiable by the well-developed tongue that bears numerous continuous transverse ridges, the more or less parallel anterior inner and outer margins without the prominent flange-like development of the outer margin, and the deep adcarinal grooves (especially the outer one). *Polygnathus linguiformis bultyncki* shows a close similarity in the platform outline with *P. inversus*, from which it differs by the more anteriorly situated basal pit on the lower side.

Occurrence. –*Polygnathus linguiformis bultyncki* ranges from the *serotinus* Zone to *costatus* Zone (Klapper & Vodrážková 2013).

***Polygnathus serotinus* Telford, 1975**
Figures 8M–R, 9A–R

1975 *Polygnathus foveolatus serotinus* n. ssp.; Telford, pp. 43–44, pl. 7, figs 1–8.
1976 *Polygnathus foveolatus* n. ssp. Telford. – Fordham, pp. 80, 81, pl. 5, figs 5–8, 29, 30.
1978 *Polygnathus linguiformis linguiformis* Hinde. – Wang & Wang, p. 341, pl. 41, figs 15–17, 21–23.
1979 *Polygnathus serotinus* Telford. – Bai *et al*., p. 69, pl. 3, figs 7–10.
1979 *Polygnathus serotinus* Telford. – Lane & Ormiston, p. 63, pl. 7, figs 13, 37; pl. 8, figs 2, 6, 8–10, 10–13, 19–22, 32–35.
1981 *Polygnathus serotinus* Telford. – Xiong, p. 194, pl. 1, figs 27–28.
1982 *Polygnathus serotinus* Telford. – Bai *et al*., p. 60, pl. 3, figs 7–10; pl. 8, figs 9–15.
1985 *Polygnathus serotinus* Telford. – Bultynck, pp. 278–281, pl. 5, figs 17–18; pl. 6, figs 3–4.
1987a *Polygnathus serotinus* Telford 'delta morphotype'. – Mawson, pp. 278, 280, 282, pl. 33, figs 9–12; pl. 36, fig. 10.
1987a *Polygnathus pseudoserotinus* sp.; Mawson, pp. 277–278, pl. 35, figs 10–12; pl. 36, fig. 5.
1988 *Polygnathus serotinus* Telford. – Bai & Bai, pp. 532, 533, pl. 1, fig. 7.
1992 *Polygnathus falcatus* sp.; Bonceva, p. 42, pl. 5, figs 1–3.
1992 *Polygnathus pseudoserotinus* Mawson. – Bonceva, pp. 40–41, pl. 6, figs 8–9.
1994 *Polygnathus serotinus* Telford. – Talent & Mawson, pp. 78, 79, pl. 2, figs 15–17.
1997 *Polygnathus serotinus* Telford. – Savage & Soja, p. 127, figs 3.11–3.22.
2005 *Polygnathus pseudoserotinus* Mawson. – Jin *et al*., pp. 63, 64, pl. 4, figs 12–17; pl. 13, figs 3–4, 11, 12.
2005 *Polygnathus serotinus* Telford gamma morphotype. – Jin *et al*., p. 65, pl. 5, figs 7–14, 17; pl. 6, fig. 1.
2005 *Polygnathus serotinus* Telford delta morphotype. – Jin *et al*., pp. 65–67, pl. 5, figs 15–16; pl. 6, figs 2–9; pl. 12, figs 15, 16; pl. 13, figs 13–16.
2012 *Polygnathus serotinus* Telford delta morphotype. – Saydam-Demiray & Çapkinoğlu, pp. 16, 17, pl. 2, figs 1–8.
2013 *Polygnathus serotinus* Telford. – Klapper & Vodrážková, pp. 158–159, 161, 164, text-figs 3a–g, 4a–h, 5a–f (further synonymy).
2013 *Polygnathus serotinus* Telford. – Lu, pp. 319, 320, pl. 4, figs 3–6.
2015 *Linguipolygnathus serotinus* (Telford). – Aboussalam *et al*., pp. 946, 947, figs 15w–x.

Material. – Eighteen Pa elements from samples NL-10-5 (1), NL-10-7 (1), NL-10-8 (2), NL-10-9 (3), NL-10-10 (1), NL-13-1 (5), NL-13-2 (2) and NL-13-3 (3).

Description. – High free blade composed of 6–7 palisade denticles decreasing gradually in height posteriorly and about $^{1}/_{5}$ to $^{1}/_{4}$ of the total length in adult specimens (Figs 8M, N, 9C, D, I, J, O, P), whereas it takes about $^{1}/_{3}$ in juvenile specimens (Fig. 9A, B, K, L). Asymmetrical platform with the carina near the inner margin. Carina varies from strongly fused denticles in the anterior part of the platform to a row of small discrete denticles in the posterior part, and may run to the posterior termination of the platform (Figs 8M, P, 9D, H, J, L) or just end before the tongue (Fig. 9F, P, R). Juvenile specimens may even have a carina extending one to two denticles posterior of the platform termination (Figs 8Q, R, 9A, B). Adcarinal grooves are asymmetrically developed, the outer one being much wider, deeper and extending far more posteriorly than the inner one. Platform margins in the anterior part are more or less parallel, and the outer margin is remarkably higher than the carina and inner margin due to its prominent flange-like development. Anterior platform margins meet the blade at straight or acute angles; in some specimens the inner one meets the blade at a slightly different position (Figs 8M, N, 9A, B, M–P). The outer platform is strongly deflected inward posteriorly, forming a rounded, quadrate or angular outline. On the lower side, a small basal pit is situated just anterior of the sharply inward deflection of the keel. A shelf-like protuberance or bulge with variable outlines is developed on the outer side of the pit, but it may be barren or weakly developed in some juvenile specimens (Figs 8Q, R, 9A, B).

Discussion. – *Polygnathus serotinus* easily differs from *P. inversus*, *P. linguiformis bultyncki* and *P. quadratus* in the presence of a shelf-like protuberance or bulge on the outer side of the pit. *Polygnathus vigierei* is distinctly differentiable by the clearly constricted anterior part of the platform and the randomly distributed nodes on the inner platform; *P. apekinae* lacks a shelf-like protuberance or bulge on the outer side of the pit.

Lane & Ormiston (1979) recognized three morphotypes (alpha, beta, and gamma) of *Polygnathus serotinus* mainly on the basis of the different outlines of the tongue on the upper side and the constitutions of the protuberance on the lower side. Later, the alpha or early morphotype of Lane & Ormiston (1979) was formally termed *P. pseudoserotinus* by Mawson (1987a), and *P. serotinus* was only restricted to the beta and gamma morphotypes of Lane & Ormiston (1979). However, Klapper & Vodrážková (2013) treated some supposedly transitional forms between *P. inversus* and *P. serotinus* (Klapper & Johnson 1975, pl. 3, figs 19–22, 24–31; Uyeno & Klapper 1980, pl. 8.1, figs 13–16) as the alpha morphotype of Lane & Ormiston (1979) due to their close similarity on the lower side. As suggested by Uyeno & Klapper (1980, p. 89), and Klapper & Vodrážková (2013, p. 161), the anterior outer and inner margins have the same height in these intermediate forms; whereas Mawson (1987a, p. 277) maintained that the anterior outer margin is higher than the inner margin in *P. pseudoserotinus*. Accordingly, *P. pseudoserotinus* is accepted as a junior synonym of *P. serotinus* herein.

Klapper & Vodrážková (2013) also made a detailed morphological analysis of *Polygnathus serotinus* and recognized three informal morphotypes of this species based on the outline of the shelf-like protuberance on the outer side of the pit. In the present paper, morphotype 1 (Figs 8N, 9E, K, M, O) and morphotype 2 (Figs 8O, 9C, G, I) of Klapper & Vodrážková (2013) are both collected, whereas one juvenile specimen (Fig. 9B) with an incipient shelf-like bulge on the outer side of the pit extending farther to the posterior end corresponds to morphotype 3 of Klapper & Vodrážková (2013).

Occurrence. – This taxon ranges from the *serotinus* Zone to the lower part of the *costatus* Zone (Klapper & Vodrážková 2013).

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