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RESEARCH PAPER

New Middle Devonian conodont data from the Dong Van area, NE Vietnam (South China Terrane)

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Abstract
Middle Devonian conodonts from the Si Phai section in NE Vietnam are described. The section ranges from the Middle Devonian *ensensis* to *timorensis* conodont zones to the Late Devonian *rhomboidea* conodont Zone. A rich overall assemblage is described, including 27 taxa of species or subspecies rank and 11 taxa described in an open nomenclature. Among the dominant *Polygnathus* forms, four new taxa are described: *Polygnathus linguiformis saharicus* subsp. nov., *Polygnathus linguiformis vietnamicus* subsp. nov., *Polygnathus rhenanus siphai* subsp. nov., and *Polygnathus xylus bacbo* subsp. nov. Conodont assemblages are attributed to polygnathid, polygnathid-klapperinid, and klapperinid conodont biofacies representing hemipelagic to pelagic environments. The klapperinid biofacies, unreported in the previous literature, are here attributed to offshore areas of the external shelf. The taxonomic compositions of the studied conodont assemblages, as well as their CAI characteristics (CAI 4–5), suggest a palaeogeographic affinity of the studied strata to the Chinese Devonian Guangxi Basin, and the South China Terrane in general. Furthermore, the conodont biofacies and the palaeogeographic distribution of the fauna are discussed.

Keywords Conodont stratigraphy · Middle Devonian · NE Vietnam · Bắc Bộ Basin · Conodont biofacies

Introduction

A few previous studies of Devonian conodonts from Vietnam have been reported from the Upper Devonian and the Devonian/Carboniferous boundary interval (Ta Hoa 2002; Ta Hoa and Doan 2005, 2007; Komatsu et al. 2014). Middle Devonian conodonts were briefly mentioned by Tồng et al. (2013), who reported *Polygnathus xylus xylus*, *P. varcus*, and *P. linguiformis* from the Bang Ca Formation of the West Bắc Bộ structural unit. As a consequence, the Middle-Upper Devonian stratigraphy was based on macrofauna (mostly brachiopods) and plant remains, which resulted in a rather generalized chronostratigraphy of this long-lasting interval.

Recently, Königshof et al. (2017a) presented new conodont data on the Middle and Upper Devonian from the Si Phai section which is located in the East Bắc Bộ Basin (NE Vietnam). Based on earlier publications (Ta Hoa 2002), the paper by Königshof et al. (2017a) was devoted to answering the question of whether the Si Phai section contains sediments that represent equivalents of Devonian global bioevent levels. The stratigraphic record of this section covers the interval from the Middle Devonian *ensensis* to *timorensis* conodont zones to the Late Devonian *rhomboidea* conodont Zone. Unfortunately, the Si Phai section is not complete and contains covered intervals, hiatuses, and thrusts. Due to the facies setting, macrofauna is generally rare, and the conodont record is likewise limited in some parts, as the distribution of conodonts in the section also strongly depends on the lithology. The highest number of conodonts has been found in Middle Devonian carbonates (Königshof et al. 2017a). Thus, we present a more detailed conodont record from the Middle Devonian of the Si Phai section in NE Vietnam, an area of little-known conodont stratigraphy. The present paper provides systematic descriptions of some new forms

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and discusses selected aspects of conodont biofacies and palaeogeography.

Geological background

The Si Phai section in the Dong Van area is located in the northeasternmost part of the country (N 23°17′00.3″ E 105°22′34.8″), close to the Chinese border (Fig. 1). Structurally, this area belongs to the Early Paleozoic eastern part of the Bắc Bộ Basin (Tri and Khuc 2011). Nam (1995) used the term "NE Block" for the same area. In the East Bắc Bộ Basin, Silurian rocks are conformably overlain by Devonian rocks of the Đồ Sơn Group (Fig. 2). Sediments of the Si Phai section are composed of siliciclastics, carbonates, and argillaceous limestones, suggesting relatively deep offshore conditions. The lithology and the overall lack of macrofauna suggest a basinal facies setting known from other sections in Vietnam and Thailand (e.g., Savage et al. 2006; Königshof et al. 2012; Königshof et al. 2017a). Some parts of the section may represent anoxic conditions which are associated with global bioevents (Königshof et al. 2017a). The section has a thickness of about 13.50 m and ranges stratigraphically from the Middle Devonian (*ensensis* to *timorensis* zones) to the Late Devonian (*rhomboidea* Zone; Fig. 3). An overview of the sedimentological record and stratigraphy of the Si Phai section is given in Königshof et al. (2017a).

The assumed palaeogeographic position of NE Vietnam in the Early and Middle Devonian (Königshof et al. 2017a, fig. 1) close to the western Himalayas is confirmed by faunal similarities between Vietnam and southern China, which were described in a number of papers by Janvier and Ta Hoa (1999), Janvier and Tong-Dzuy (1998), Jones et al. (1997), and Racheboeuf et al. (2005). In a recent paper by Königshof et al. (2017b),

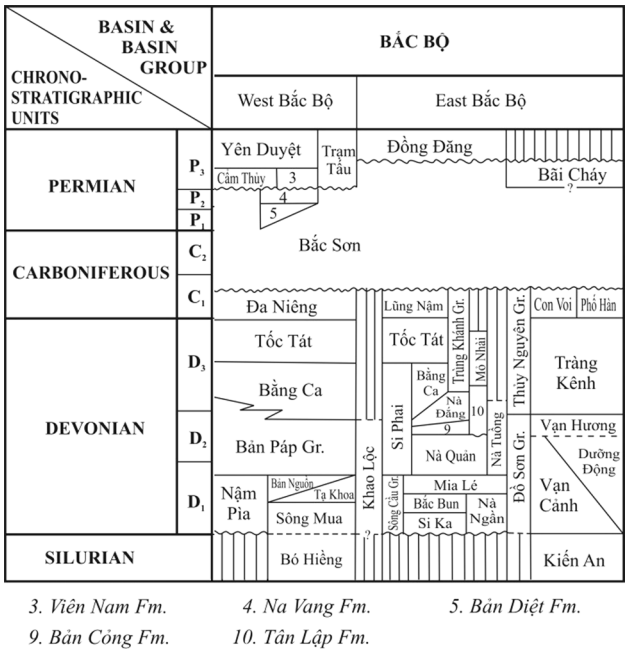


Fig. 2 Subdivision and correlation of stratigraphic units of the Devonian-Upper Permian (Wuchiapingian) Supersequence (Tri and Khuc 2011, with minor adaptions)

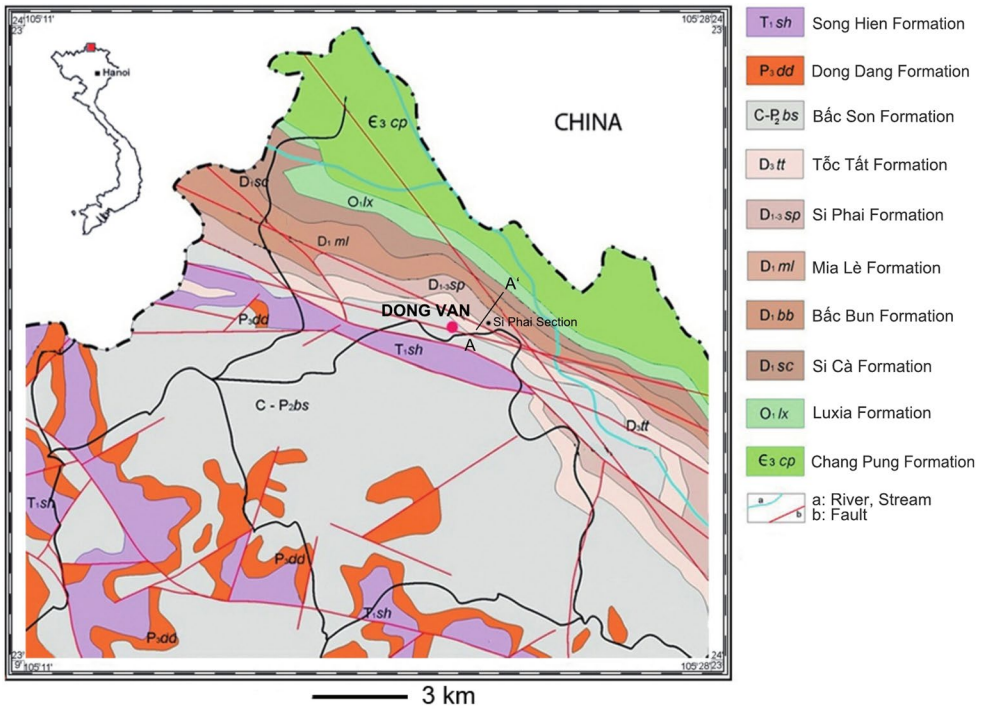


Fig. 1 Geological map of the Dong Van area (NE Vietnam) and position of the Si Phai section (A–A′) Figure reproduced from Königshof et al. (2017a)

the assumed palaeogeographic position is also supported by provenance analysis of detrital zircons. According to this study, the zircon cluster of siliciclastic rocks from the east Bắc Bộ-Basin exhibits similarities to the South China Terrane. More information on plate tectonics, geological background, sample locations, and the lithology of the section, as well as details on sample preparation, are given in the publication by Königshof et al. (2017a), which we refer to.

Materials and methods

The conodont material was obtained from 14 samples from the Si Phai Formation. The studied collection includes 350 P_1 elements. The occurrence and number of elements in particular samples are given in Table 1. In most parts of the Middle Devonian section, the conodont frequency is low—not exceeding 5 specimens per sample in the interval between sample VD-MD-1 and VD-MD-29 (Fig. 3). The most abundant assemblages are from the upper part of the section, in samples VD-MD-33 and VD-MD-35 (more than 100 specimens per sample) and VD-MD-38 (68 specimens). The specimens are moderately well preserved, they are rarely complete, often broken, and covered with sediment, which hampers their taxonomic identification. The thermal maturity is between the conodont CAI 4 for delicate and/or juvenile forms, and CAI 5 for mature forms.

Nevertheless, five genera were identified in the studied material: *Polygnathus*, *Icriodus*, *Klapperina*, *Ozarkodina*, and *Schmidtognathus*. In addition, one form was attributed to an unknown genus. The dominant genus is *Polygnathus*, comprising 76% of the whole collection; the second most important is *Klapperina*, representing 18.5%. The most interesting forms, particularly those described systematically later in this paper, are figured in Figs. 4, 5, and 6.

The biofacies analysis was carried out based on samples with a frequency of platform elements of at least 20 specimens. Moreover, a requirement for those samples was the presence of various ontogenetic stages of the same taxon, which suggests that the assemblage is close to the original biocoenosis (Broadhead et al. 1990; McGoff 1991). In a single case of two closely located samples with the same age (VD-MD-36 and VD-MD-37: 10 cm apart in the section), the frequency data were combined. The analysis was carried out at a generic level, with particular biofacies being defined in cases where the index genus or two dominant genera comprised at least 75% of the total assemblage (Sandberg et al. 1988). Conodonts are stored at the Senckenberg Research Institute and Natural History Museum, Frankfurt, Germany (SMF VD-MD-01–VD-MD-56).

Systematic palaeontology

More detailed analysis of the Si Phai conodont collection revealed greater taxonomic diversity of the species *Polygnathus linguiformis*, *Polygnathus rhenanus*, and *Polygnathus cristatus* than was presented in a previous account (Königshof et al. 2017a). This section initially provides descriptions of new taxa (subspecies) within *Polygnathus linguiformis*, *P. rhenanus*, and *P. xylus*. Moreover, it includes the new form that cannot be attributed to any of the genera described in the literature so far. A few characteristic taxa are also figured in Figs. 4, 5, and 6 with appropriate descriptions.

Special attention should be paid to the occurrence of *Polygnathus eiflius* Bischoff and Ziegler, 1957 (Fig. 5u) in the sample VD-MD-36, dated to the lower part of the Lower *disparilis* Zone (Table 1). This species was last found in the lower Givetian *timorensis* Zone in Morocco (Walliser and Bultynck 2011) and in the lower part of the *ansatus* Zone (middle Givetian) in the Central Pyrenees (Gouwy et al. 2013). The Vietnamese discovery may indicate much a wider stratigraphic range of *P. eiflius* than previously documented. On the other hand, the specimen presented here could be an example of the evolution of the species *Polygnathus eiflius*. The only feature that distinguishes the figured specimen from typical representatives of *P. eiflius* is the anterior inner ridge, which is not diagonal to the carina but parallel. The shape of the platform and ornamentation of the studied specimen are quite similar to some specimens of *Polygnathus dubius* Hinde (1879) from the Huddle material (1980, pl. 138, fig, 8, 11, 12, 17), in which the rostrum is not strongly accentuated. Anterior ridges are typically not seen in *P. dubius*, although a tendency to develop rostral ridges was mentioned by Huddle (1981, p. B29) for a new subspecies, *Polygnathus dubius frons*, appearing in the *hermanni* Zone. It is possible that both the Vietnamese specimen and the *P. dubius frons* subspecies evolved from *P. eiflius*, and that the lineage *P. psedofoliatus-P. eiflius* could lead to the appearance of *P. dubius*. Nevertheless, such a conclusion is tentative and should be confirmed by future studies.

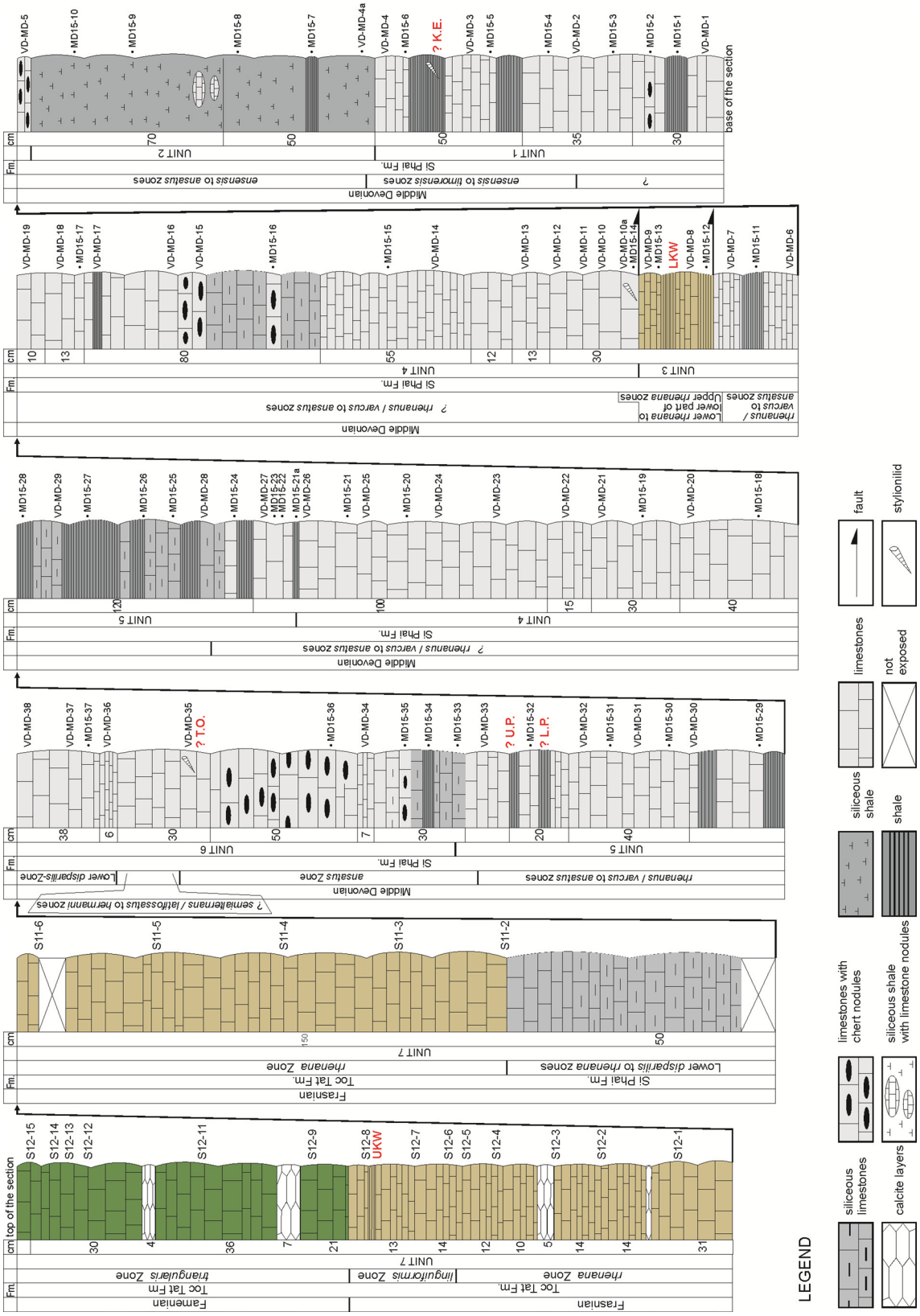
Genus ***Polygnathus*** Hinde, 1879

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

(*Polygnathus linguiformis* group)

Polygnathus linguiformis, a common constituent of the Middle Devonian conodont assemblages, is characterized by exceptional morphological differentiation.

Several lower rank taxa have been erected since the establishment of the species by Hinde (1879), with the


base of the section
top of the section
Middle Devonian
Si Phai Fm.
Frasnian
Famennian
Toc Tat Fm.
UNIT 1
UNIT 2
UNIT 3
UNIT 4
UNIT 5
UNIT 6
UNIT 7
? K.E.
LKW
UKW
? T.O.
? U.P.
? L.P.
ensensis to timorensis zones
ensensis to ansatus zones
? rhenanus / varcus to ansatus zones
rhenanus / varcus to ansatus zones
Lower rhenana to lower part of Upper rhenana zones
? semialternans / latifossatus to hermanni zones
Lower disparilis-Zone
ansatus Zone
rhenana Zone
Lower disparilis to rhenana zones
linguliformis Zone
triangularis Zone
LEGEND
siliceous limestones
calcite layers
limestones with chert nodules
siliceous shale with limestone nodules
siliceous shale
shale
limestones
not exposed
fault
stylonilid

◂ **Fig. 3** Lithology and stratigraphy of the Si Phai section, NE Vietnam (N 23° 17′ 00.3″ E 105° 22′ 34.8″). The section contains rocks from the Middle Devonian (*gray*), Frasnian (*ocher yellow*), and Famennian (*green*). Based on the biostratigraphic data and lithology, it is possible to pinpoint possible equivalents of Devonian events (?=questionable event layer due to limited conodont data): *UKW* Upper Kellwasser Event; *LKW* Lower Kellwasser Event; *T.O.* Taghanic Onlap; *U.P.* Upper pumilio Event; *L.P.* Lower pumilio Event; *K.E.* Kačák Event Figure reproduced from Königshof et al. (2017a)

subspecies *P. linguiformis linguiformis* dominant. Within the latter, four morphotypes were defined by Walliser and Bultynck (2011), including morphotype γ1, corresponding to the earlier described morphotype *P. linguiformis linguiformis* γ (Bultynck 1970; Klapper 1977). In the material analyzed, *P. linguiformis* comprises 30% of all polygnathid elements, and more than half of those belong to *P. linguiformis linguiformis*, for which the morphotypes γ1a and γ2 (Walliser and Bultynck 2011) have been identified; the latter has been defined as a new subspecies.

Polygnathus linguiformis linguiformis Hinde, 1879 (γ1a morphotype Walliser and Bultynck, 2011)
Figure 4b–g

1933 *Polygnathus linguiformis* Hinde—Branson and Mehl: pl. 12, fig. 6 (holotype).
1934 *Polygnathus linguiformis* Hinde—Huddle: pl. 8, figs. 4–5.
1957 *Polygnathus linguiformis* Hinde—Bischoff and Ziegler: pl. 1, figs. 3, 9, 12a, b
1970 *Polygnathus linguiformis linguiformis* Hinde—Bultynck: pl. 11, figs. 1, 2, 3; pl. 12, fig. 6.
1971 *Polygnathus linguiformis linguiformis* γ morphotype Bultynck—Klapper: pl. 2, figs. 24–25, 30, 35, 39–40; pl. 3, fig. 15.
1976 *Polygnathus linguiformis linguiformis* gamma morphotype—Ziegler et al.: pl. 4, figs. 9, 13
1977 *Polygnathus linguiformis linguiformis* Hinde—Weddige: pl. 5, fig. 82.
1978 *Polygnathus linguiformis linguiformis* Hinde, 1879 forma γ Bultynck— Chatterton: pl. 1, fig. 22.
1978 *Polygnathus linguiformis linguiformis* Hinde—Orchard: pl. 114, figs. 24, 31, 33, 35.
1980 *Polygnathus linguiformis linguiformis* Hinde, 1879, gamma morphotype Bultynck—Bultynck and Hollard: pl. 7, fig. 1.
1981 *Polygnathus linguiformis linguiformis* Hinde, form gamma of Bultynck—Huddle: pl. 15, figs. 9–10, 11–12, 18–19, 20–21.
1982 *Polygnathus linguiformis linguiformis* Hinde—Uyeno (in Norris et al.): pl. 31, figs. 30–31; pl. 34, figs. 9, 23–25.
1985 *Polygnathus linguiformis linguiformis* Hinde—Austin et al.: pl. 4.3, fig. 15.
1985 *Polygnathus linguiformis linguiformis* Hinde—Ziegler and Wang: pl. 1, fig. 32.
1986 *Polygnathus linguiformis linguiformis* Hinde—Garcia-Lopez: pl. 13, figs. 3, 5, 8–9.
1989 *Polygnathus linguiformis linguiformis* Hinde—Mawson and Talent: pl. 5, figs. 1–2.
1990 *Polygnathus linguiformis linguiformis* Hinde—Khalymbadzha: pl. 6, figs. 16, 17, pl. 8, fig. 28.
1990 *Polygnathus linguiformis linguiformis* Hinde, form gamma of Bultynck—Lazreq: pl. 1, figs. 14, 15, 16, 17.
1992 *Polygnathus linguiformis linguiformis* Hinde, form gamma of Bultynck—Bardashev: pl. 3, fig. 18 (only).
1994 *Polygnathus linguiformis linguiformis* Hinde, morphotype gamma Bultynck—Bai et al.: pl. 20, figs. 12b, 13.
1999 *Polygnathus linguiformis linguiformis* Hinde, morphotype gamma—Lazreq: pl. 1, fig. 20.
2001 *Polygnathus linguiformis linguiformis* Hinde—Liao et al.: pl. 2, figs. 8–9; 15–16.
2005 *Polygnathus linguiformis linguiformis* Hinde—Woroncowa-Marcinowska: figs. 4E, 4F, 4I, 4K.
2007 *Polygnathus linguiformis linguiformis* Hinde—Benfrika et al.: figure 9L.
2007 *Polygnathus linguiformis linguiformis* Hinde—Narkiewicz and Bultynck: fig. 6A.
2011 *Polygnathus linguiformis linguiformis* Hinde—Narkiewicz: tabl. 3, fig. 1, 12.
2011 *Polygnathus linguiformis linguiformis* Hinde, γ1a morphotype—Walliser and Bultynck: pl. 3, fig. 1.
2012 *Polygnathus linguiformis* Hinde—Woroncowa-Marcinowska: figs. 5B, 5D, 5I; figs. 7A, 7B, 7C.
2011 *Polygnathus linguiformis linguiformis* Hinde, gamma 1a (γ^{1a}) morphotype Walliser and Bultynck—Demiray: pl. 4, figs. 11, 12, 13.

Material. 13 specimens.

Description (after Walliser and Bultynck 2011). The tongue forms about one-third of the total platform length and its surface is crossed by strong, continuous transverse ridges. The width of the tongue decreases progressively from the end of the anterior platform to the end of the tongue. The margin of the outer platform anterior to the tongue is high, flange-like, and its rim is nearly rectilinear. The adcarinal trough is deep and wide. The margin of the narrow inner platform is only slightly raised and can be straight or slightly concave or convex. The inner platform is ornamented with nodes and/or straight or irregular ribs.

Table 1 Conodont occurrences in the Si Phai section

Sample number	VD-MD-1	VD-MD-2	VD-MD-4	VD-MD-4a	VD-MD-6	VD-MD-10	VD-MD-26	VD-MD-28	VD-MD-29	VD-MD-33	VD-MD-35	VD-MD-36	VD-MD-37	VD-MD-38
Zone	?	*ensensis–timorensis*			*rhenanus–ansatus*					*ansatus*		lower part of L. *disparilis*		
Taxa														
Polygnathus pseudoeiflius		1												
Polygnathus eiflius			1									1		
Polygnathus cf. *eiflius*				1										
Polygnathus xylus ensensis						1j				3				
Polygnathus linguiformis aff. *klapperi*	1													
Polygnathus l. mucronatus							1j				4			
Polygnathus l. aff. *mucronatus*											1			
P. l. sensu Liao et al. 2001, pl. 2, fig. 21											2			
Polygnathus l. vietnamicus subsp. nov.								1j	1	2	1			
P. l. vietnamicus→P. l. predelta morphotype										1				
Polygnathus l. saharicus subsp. nov.										17	11			
Polygnathus l. linguiformis γ1a										1	12			
P. l. klapperi s. Clausen et al. pl. 1, fig. 8										1				
Polygnathus linguiformis						1j				2	16			
Polygnathus xylus group									1j					
Polygnathus xylus bacbo subsp. nov.										6				
Polygnathus xylus ensensis→P. ansatus										1				
Polygnathus rhenanus rhenanus								2		15	10			
Polygnathus rhenanus siphai subsp. nov.										8	5			
Polygnathus rhenanus										14	21			
Polygnathus timorensis										1				
Polygnathud parawebbi											22			
Polygnathus cf. *ovatinodosus*											1j			
Polygnathus ansatus											2j			
Polygnathus cf. *ansatus*											1j			
Polygnathus timorensis→P. pollocki												1		
Polygnathus dubius														1
Polygnathus aff. *dengleri sagitta*													1	1
Polygnathus cristatus cristatus													1	1
Polygnathus cristatus ectypus												1	2	2
Polygnathus cristatus												2		5
P. cristatus→Klapperina disparilis												2		2
P. cristata→Klapperina disparata														1
Polygnathus sp. indet.	1	2	1				2j		1j	21	20	2	2	
Icriodus aff. *regularicrescens*				1										
Icriodus brevis											1			
Icriodus difficilis					1									
Icriodus sp. nov.											1			
Ozarkodina brevis		1												
Ozarkodina plana										10				
Klapperina disparilis												8	4	39
Klapperina cf. *disparilis*														13
Klapperina cf. *disparata*												1		
Genus and species indet.												1		
Schmidtognathus wittekindti														3j
Total numbers of P_1 elements	2	4	2	2	1	2	3	3	2	103	131	18	10	68

L lower, *j* juvenile

Stratigraphical distribution. Middle Eifelian to upper Givetian *costatus–hermanni* zones (Narkiewicz and Bultynck 2007; Walliser and Bultynck 2011).

Polygnathus linguiformis sahariacus subsp. nov.
Figure 4j–n

1970 *Polygnathus linguiformis linguiformis* Hinde, γ forma nova—Bultynck: pl. 11, fig. 5.
aff. 1980 *Polygnathus linguiformis mucronatus* Wittekindt—Bultynck and Hollard: pl. 7, fig. 14.
1992 *Polygnathus linguiformis linguiformis*, gamma Bultynck, 1970—Bardashev: pl. 3, fig. 19.
2001 *Polygnathus linguiformis linguiformis* Hinde—Liao et al.: pl. 2; figs. 5, 6–7.
2001 *Polygnathus linguiformis klapperi* Clausen et al. 1979—Liao et al. pl. 2; figs. 27–28.
2003 *Polygnathus linguiformis linguiformis* Hinde—Aboussalam: pl. 17, fig. 4.
2011 *Polygnathus linguiformis linguiformis* Hinde, γ2 morphotype Walliser and Bultynck—Walliser and Bultynck: pl. 3, fig. 3.
2017 *Polygnathus linguiformis linguiformis* Hinde, gama 1a (γ^{1a}) morphotype Walliser and Bultynck—Demiray: pl. 4, fig. 9.
2017 *Polygnathus linguiformis linguiformis* Hinde, gamma 2 (γ^{2}) morphotype Walliser and Bultynck—Demiray: pl. 4, fig. 16.

Etymology. The name is derived from the Sahara Desert area in Morocco, where *Polygnathus linguiformis linguiformis* γ2 morphotype was first described by Walliser and Bultynck (2011).

Type material. Holotype no. 1601-487-L108, the specimen illustrated on pl. 3, fig. 3 from Jebel Mech Irdane section, sample 108, Tafilalt, Anti-Atlas, SE Morocco (Walliser and Bultynck, 2011), housed in the Museum of the Geoscience Center, Göttingen University (GZG).

Material. 28 specimens.

Diagnosis. Representative specimens of *Polygnathus linguiformis sahariacus* have an asymmetrical platform, the anterior (1/3) part of which is narrowed relative to the remaining part. The outer platform forms a characteristic high flange-like development of the margin, being higher in the posterior part of the platform. In the junction between platform and tongue, the outer margin is either gently curved or forms almost a straight angle. The tongue is short, transected by 3–5 distinct transverse ridges. The free blade makes up half of the platform length and has a fan-like shape in a lateral view.

Description. The free blade is built from 6–7 denticles, the highest of which occur in the middle part. The denticles grade into a low carina which forms a ridge in the anterior part, due to completely fused nodes, while posteriorly it is composed of 4–5 isolated nodes. The anterior part of the tongue is nearly as wide as the platform, while posteriorly it progressively narrows into a sharp tip. The morphological variability includes forms in which the outer margin is gently curved (Vietnamese material) or deflected sharply inward (Moroccan material) at the beginning of the tongue. Both varieties were found in the Eastern Ou Driss section in sample no. 21.

Remarks. Walliser and Bultynck (2011) found only one specimen, which they identified as *Polygnathus linguiformis linguiformis* Hinde, 1879, γ2 morphotype. In the present study the morphotype is described as a new subspecies because of its distinct morphology, documented by fairly abundant Vietnamese material and supported by the literature data (compare synonymy). The new subspecies differs from *Polygnathus linguiformis linguiformis* Hinde, 1879, γ1a morphotype in a development of the outer platform margin which is raised posteriorly starting ca. 1/3 along its length and is higher in the posterior part, whereas the platform is elevated uniformly along its length in morphotype γ1a. Moreover, the anterior part of the platform is narrower than its posterior part, whereas it maintains nearly the same width along its entire length in morphotype γ1a.

The juvenile form illustrated in Fig. 4n is similar to the specimen identified as *Polygnathus linguiformis alveolus* by Weddige (1977, pl. 5, fig. 86), which may suggest that the latter taxon is an ancestor of *P. linguiformis sahariacus*.

Occurrence. According to Walliser and Bultynck (2011), in the Moroccan Tafilalt area, *P. linguiformis sahariacus* occurs in the Bou Tchrafine section (sample no. 12; lowermost part of the Eifelian *kockelianus* Zone), in the Jebel Mech Irdane section (sample 108), and in the Eastern Ou Driss section (Ma'der area; samples ODE-8-9 and ODE-8-21, all samples from the *kockelianus* Zone). The subspecies ranges up to the Givetian *ansatus* Zone. In Middle Asia (Tajikistan–Central Asian Orogenic Belt), it was noted in the sample 1845 in the Ispena Formation, which yielded conodonts attributable to the upper part of the *kockelianus* Zone (Bardashev 1992). In south-central Turkey, the new subspecies has been identified in the Bozgüney Ösk section (Anatolide-Tauride Block of Gondwanan provenance), in the interval spanning samples from 12-T-BOZ-1 to 12-T-BOZ-4, corresponding to the *timorensis–ansatus* zone interval of the lower to middle Givetian (Demiray 2017). In the Central Pyrenees, *P. linguiformis sahariacus* has been found in samples Re19 and Re20 in the Renanué section, attributed to the lowermost part of the Middle *varcus* Zone (Liao et al. 2001). The Lower

hermanni Zone has been suggested as the highest range by Aboussalam (2003, tab. 10, p. 80). This age raises some doubts, however, as the illustrated specimen (plate 17, fig. 4 in Aboussalam 2003) is from the Hassi Nebech 2 section, sample 10d, in which it co-occurs with the specimen identified as *Schmidtognathus hermanni* (Aboussalam 2003, pl. 22, figs. 1, 2). The latter, however, can hardly be regarded as a typical representative of *Sch. hermanni* because its platform outline is more typical of *Polygnathus* (compare with Bultynck 1987, pl. 8, fig. 1). Most probably this is a transitional form which may not be a proper zonal indicator.

In the Si Phai section, the new subspecies was found in the samples VD-MD-33 and VD-MD-35 (Fig. 3), whose age was determined as the *ansatus* Zone.

Stratigraphical distribution. *kockelianus–ansatus* zones (late Eifelian–middle Givetian).

Polygnathus linguiformis vietnamicus subsp. nov.
Figure 4o–t

1978 *Polygnathus linguiformis* "epsilon" Morphotype sensu Ziegler and Klapper—Requadt and Weddige: fig. 12i.
1980 *Polygnathus linguiformis linguiformis* Hinde, epsilon morphotype Ziegler and Klapper—Bultynck and Hollard: pl. 7, fig. 7.
1987 *Polygnathus linguiformis klapperi* Clausen, Leuteritz and Ziegler—Bultynck: pl. 9, fig. 19.
1995 *Polygnathus linguiformis* Hinde—Sparling: fig. 7.2
cf. 2004 *Linguipolygnathus klapperi* Clausen, Leuteritz and Ziegler—Aehnelt and Weller: pl. 2, fig. 7

Etymology. The name is derived from the country where the subspecies was first described as the new taxon.

Type material. Holotype no. SMF 100.000, the specimen illustrated in Fig. 4s, t from the Si Phai section, Dong Van area, N Vietnam, Si Phai Formation, sample VD-MD-35, deposited in the Senckenberg Research Institute.

Material. 5 specimens.

Diagnosis. The narrow elongated P_1 element displays a nearly straight or slightly concave inner platform margin forming a straight line with the inner margin of the tongue. The outer platform margin is curved and most expanded in the posterior part of the platform just anterior of the onset of the tongue. Both platform margins are slightly raised in the anterior 1/3 of the platform length; the inner one can be more elevated. A high flange is not developed. Ornamentation is composed of short, distinct ribs regularly distributed in both platform margins. The carina is gently curved parallel to the outer platform margin. Adcarinal troughs are deeper in the anterior platform, shallower towards the posterior. The tongue is pointed, deflected downwards, crossed by transversal ridges. The basal cavity with thick margins is located in the anterior 1/4 of the platform.

Description. The P_1 element is narrow and elongated, arched in lateral view. Anterior platform termination is not straight, tending to join the free blade at an acute angle, the inner margin more anteriorly than the outer one. The anterior part of the tongue is as wide as the platform, gradually narrowing to the pointed tip. In the posterior platform the carina is composed of low nodes, becoming higher and narrower along with the elevation of the platform margins, and grading into denticles of the free blade. The latter is short and composed of ca. 6 denticles, with the two central ones being highest.

Remarks. *Polygnathus linguiformis vietnamicus* is similar to *Polygnathus linguiformis* Hinde predelta morphotype (Uyeno 1998). The essential difference is the lack of a tongue in the latter form. In the predelta morphotype, the carina continues to the tip of the platform. In the form transitional between *P. ling. vietnamicus* and *P. ling.* predelta morphotype (Fig. 4u), the carina is longer and interrupts transverse ridges on the tongue.

Occurrence. In Europe, the new subspecies was found in the Rhenish Massif (Germany) in volcanogenic facies of the Schaufertsbachtal section, in sample 236, ascribed to the Lower–Middle *varcus* Zone (Requadt and Weddige 1978, fig. 14), as well as in the Harz Mountains in the Elbingerode Reef Complex outcrop 11 (Schöth), in sample Schö/3/14c dated to the *hemiansatus* Zone (Aehnelt and Weller 2004). In North America, it was identified in the Plum Brook Shale (north-central Ohio, USA) in sample S8 1 P10 (Sparling 1995, fig. 1). It was dated to the *timorensis* Zone based on the first appearance of *Icriodus brevis* (Sparling 1995, fig. 5.38; 5.39) in sample S8 1 P9e and *Polygnathus eiflius* (Sparling 1995, fig. 2.31; 2.34; 2.35; 2.38) in the interval from sample S8 1 P10v to sample S8 2 P6F (Sparling 1995, fig. 1). In the Moroccan Tafilalt area, representatives of the subspecies have been found in the Bou Tchrafine section, in sample no. 23, ascribed to the *timorensis* Zone (Bultynck and Hollard 1980). In Vietnam, the new subspecies was found in the Si Phai section, in samples VD-MD-28 to VD-MD-35 (Fig. 3).

Stratigraphical distribution. *timorensis–ansatus* zones (lower–middle Givetian).

Polygnathus rhenanus Klapper, Philip and Jackson, 1970

Diagnosis (after Klapper, Philip and Jackson 1970). Representative specimens of *Polygnathus rhenanus* have a

markedly asymmetrical, short platform and a long free blade that is about two-thirds the length of the unit. In large specimens, the basal cavity is at the junction of the free blade and the anterior end of the platform. The platform is smooth, except for the carina and a node that may be present on each side at the geniculation points, which are opposite.

Polygnathus rhenanus rhenanus Klapper, Philip and Jackson, 1970
Figure 5i–k

1970 *Polygnathus rhenanus* sp. nov.—Klapper, Philip and Jackson: pl. 2, figs. 13–15, 19–22 (holotype).
1978 *Polygnathus timorensis* Klapper, Philip and Jackson—Orchard: pl. 108, figs. 17–18, 39, 42–43.
1980*Polygnathus rhenanus* Klapper, Philip and Jackson—Bultynck and Hollard: pl. 6, figs. 15, 16, 17.
1981 *Polygnathus rhenanus marijae* n. subsp.—Huddle: pl. 17, figs. 10–12; pl. 18, figs. 1–2, 3–4, 5–7, 9–11, 12.
1983 *Polygnathus timorensis* Klapper, Philip and Jackson—Wang and Ziegler: pl. 6, fig. 19.
1986 *Polygnathus rhenanus* Klapper, Philip and Jackson—Garcia-Lopez: pl. 11, figs. 3–5, 6–8, 11–12.
1987 *Polygnathus rhenanus* Klapper, Philip and Jackson—Bultynck: pl. 7, figs. 13, 14, 15; pl. 8, fig. 23.
1989 *Polygnathus timorensis* Klapper, Philip and Jackson—Mawson and Talent: pl. 4, figs. 7–8, 9.
1992 *Polygnathus timorensis* Klapper, Philip and Jackson—Ji et al.: pl. 4, figs. 3, 4.
1992 *Polygnathus varcus* Klapper, Philip and Jackson—Ji et al.: pl. 4, figs. 5, 6.
1999 *Polygnathus rhenanus* Klapper, Philip and Jackson—Sparling: figs. 3.26–3.27, 3.28–3.29.
2001 *Polygnathus rhenanus* Klapper, Philip and Jackson—Liao et al.: pl. 3, fig. 24.
2007 *Polygnathus rhenanus* Klapper, Philip and Jackson—Benfrika et al.: figure 9N.
2007 *Polygnathus rhenanus* Klapper, Philip and Jackson—Narkiewicz and Bultynck: figs. 9B, 9E.
2008 *Polygnathus rhenanus* Klapper, Philip and Jackson—Liao and Valenzuela-Rios: figs. 3M–N, 3O–P.
2017a *Polygnathus rhenanus* Klapper, Philip and Jackson—Königshof et al.: figures 4.11–12, 4.13.

Material. 25 specimens.

Diagnosis. In representative specimens of the nominate subspecies, the platform is small, with more or less convex margin outlines and a rounded posterior termination. The outer anterior trough margin is characterized by a more pronounced outward bowing, whereas the inner one is very weakly developed. The platform margins may or may not be ornamented. The geniculation points are generally opposite to each other. The carina is composed of 5–6 nodes. The basal cavity, with thick margins, is located in the anteriormost part of the platform. The straight keel extends from the basal cavity, slightly protruding beyond the posterior end of the platform.

Remarks. *Polygnathus rhenanus rhenanus* can be distinguished from *P. timorensis* by the positions of the geniculation points and the ratio of the platform to the free blade length. In *P. timorensis*, the geniculation points are not opposite to each other, and the platform is half the length of the unit.

Occurrence. *Polygnathus rhenanus rhenanus* is the index subspecies for the *rhenanus* Zone of the middle Givetian. Its stratigraphical range includes the *rhenanus/varcus–ansatus* zones (Bultynck 1987). The highest occurrence of the subspecies has been reported from the upper part of the *semialternans* Zone in the Central Pyrenees (Liao and Valenzuela-Rios 2013; Gouwy et al. 2013), but this finding requires better documentation to be fully confirmed.

Stratigraphical distribution. *rhenanus/varcus–ansatus* zones (middle Givetian).

Polygnathus rhenanus siphai subsp. nov.
Figure 5a–b, d–e, l, cc-dd

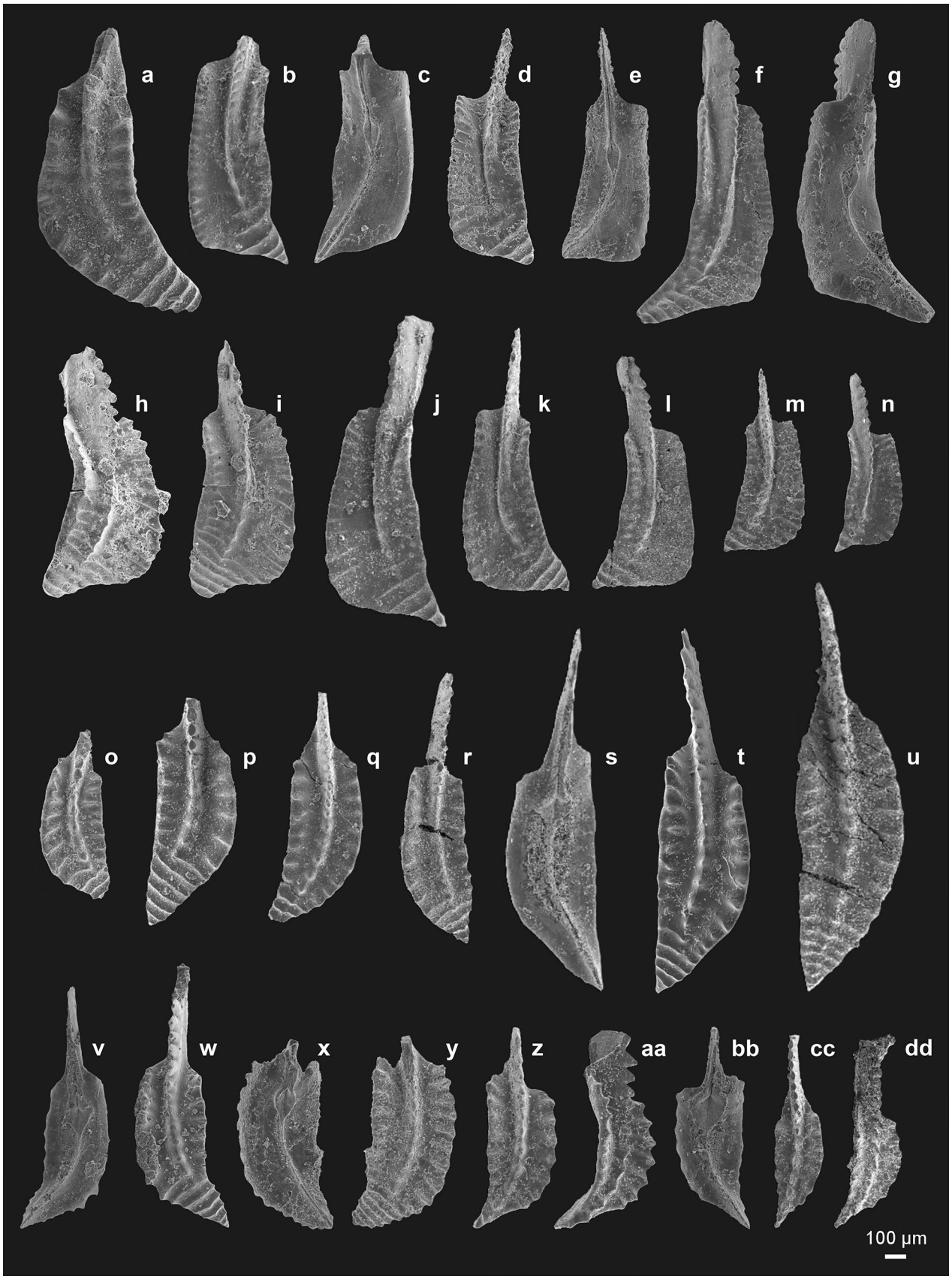
1986 *Polygnathus rhenanus* Klapper, Philip and Jackson—Garcia-Lopez: pl. 11, figs. 9–10.
1994 *Polygnathus rhenanus* Klapper, Philip and Jackson—Bai et al.: pl. 22, fig. 18.
1999 *Polygnathus timorensis* Klapper, Philip and Jackson—Lazreq: pl. 1, fig. 5.
2001 *Polygnathus rhenanus* Klapper, Philip and Jackson—Liao et al.: pl. 4, figs. 1–2, 4–5.
2008 *Polygnathus rhenanus* Klapper, Philip and Jackson—Liao et al.: figure 3O–P.

Etymology. The name is derived from the name of the Formation where the subspecies was first described as the new taxon.

Type material. Holotype no. SMF 100.001, the specimen illustrated in fig. 5a, b from the Si Phai section, Dong Van area, N Vietnam, Si Phai Formation, sample VD-MD-33, deposited in the Senckenberg Research Institute.

Material. 13 specimens.

Diagnosis. Subspecies of *Polygnathus rhenanus* characterized by a very narrow elongated platform, arrow-like, and with a pointed termination. Nodose carina extends to the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◂**Fig. 4** *Polygnathus linguiformis* Hinde 1879; all specimens are from the Si Phai Formation. **a** *Polygnathus linguiformis klapperi* sensu Clausen, Leuteritz and Ziegler, 1979, pl. 1, fig. 8, upper view, sample VD-MD-33. **b–g** *Polygnathus linguiformis linguiformis* Hinde 1879, γ1a morphotype Walliser and Bultynck, 2011, sample VD-MD-35: **b, c** upper and lower views; **d, e** upper and lower views; **f**, **g** upper and lower views. **h**, **i** *Polygnathus linguiformis* aff. *klapperi* Clausen, Leuteritz and Ziegler, 1979, oblique and upper views, sample VD-MD-1, the specimen differing from the holotype in having a shorter tongue and a longer platform. **j–n** *Polygnathus linguiformis saharicus* subsp. nov.: **j**, **k**, **l** upper views, sample VD-MD-33; **m**, **n** upper views of juvenile specimens, sample VD-MD-35. **o–t** *Polygnathus linguiformis vietnamicus* subsp. nov.: **o** upper view, sample VD-MD-28; **p** upper view, sample VD-MD-29; **q**, **r** upper views, sample VD-MD-33; **s**, **t** (holotype, SMF 100.000) lower and upper views, sample VD-MD-35. **u** *Polygnathus linguiformis vietnamicus* subsp. nov.→*Polygnathus linguiformis* Hinde predelta morphotype Uyeno, 1998, upper view, sample VD-MD-33, the platform outline and development of the free blade are similar to those of *P. ling. vietnamicus* subsp. nov. but the specimen differs from typical representatives of the subspecies in having a spindle-like outline of the platform which is widest in the middle part, while the transverse ribs on the tongue are disconnected by carinal nodes. **v**, **w** *Polygnathus linguiformis* subsp. sensu Liao et al. 2001 pl. 2, figs. 21, 22, lower and upper views, sample VD-MD-35. **x**, **y** *Polygnathus linguiformis* subsp. Hinde 1879, lower and upper views, sample VD-MD-33. **z–dd** *Polygnathus linguiformis mucronatus* Wittekindt, 1966: **z**, **aa**, **bb** upper, oblique, and lower views, sample VD-MD-35; **cc**, **dd** upper and oblique views of a juvenile form, sample VD-MD-26. *Scale bars* are 100 µm

platform end. The geniculation points are more or less opposite. The outer anterior trough margin is long and bows distinctly outwards. The inner anterior trough is shorter than the outer one. The anterior ends of the anterior trough margins meet the blade in different positions.

Description. Ornamentation developed as nodes is generally limited to the anterior platform margins, although it may also extend further posteriorwards. The length of the inner anterior trough varies from short—as in the nominal subspecies—to much longer, but the trough is not bowed outward. The almost round basal cavity with thick lips is slightly stretched posteriorwards, and is located in the anteriormost part of the platform. The keel running from the basal cavity towards the posterior end is curved gently inwards and extends distinctly beyond the carina.

Remarks. *Polygnathus rhenanus siphai* differs from *P. rhenanus rhenanus* in the development of the platform, which is narrower and longer with nearly straight margins and pointed termination. The carina in the nominal subspecies is composed of 5–6 nodes of nearly the same height, but in the described form it is considerably longer and composed of 4–6 small, densely distributed nodes in the anterior part of the platform and 4–5 larger nodes in its posterior half. It differs from *Polygnathus timorensis* in having a nearly straight outer platform margin, by the positions of the geniculation points, which are generally opposite to each other, and by a longer inner anterior trough.

Occurrence. The new subspecies has been identified in the Spanish Asturias Province, in the lower part of the Candás Formation, in sample Ca-12 (Garcia-Lopez 1986); in the Spanish Central Pyrenees in the Compte section and in the Aragonian Pyrenees in the Renanué section, in samples 3 and 5 ascribed to the Lower *varcus* Zone (Liao et al. 2001, fig. 2). However, in the cited samples, localized in the lower part of the section, the present authors were not able to find evidence for the quoted age assignement. In southern China, *Polygnathus rhenanus siphai* has been identified in the Guangxi Province in the Baqi section (Bq62) in sample 19.7, with the age estimated as the Middle *varcus* Zone (Bai et al. 1994, fig. 8-1b). In Central Morocco, the subspecies has been identified in the region of d'Azrou in the Jebel Ben Arab section, in sample N_{19b}, ascribed to the Middle *varcus* Zone (Lazreq 1999). The assemblages from the investigated samples VD-MD-33 and VD-MD-35 from the Si Phai section (Fig. 3) are the same age.

Stratigraphical distribution. *ansatus* Zone (middle Givetian).

Polygnathus xylus Stauffer, 1940

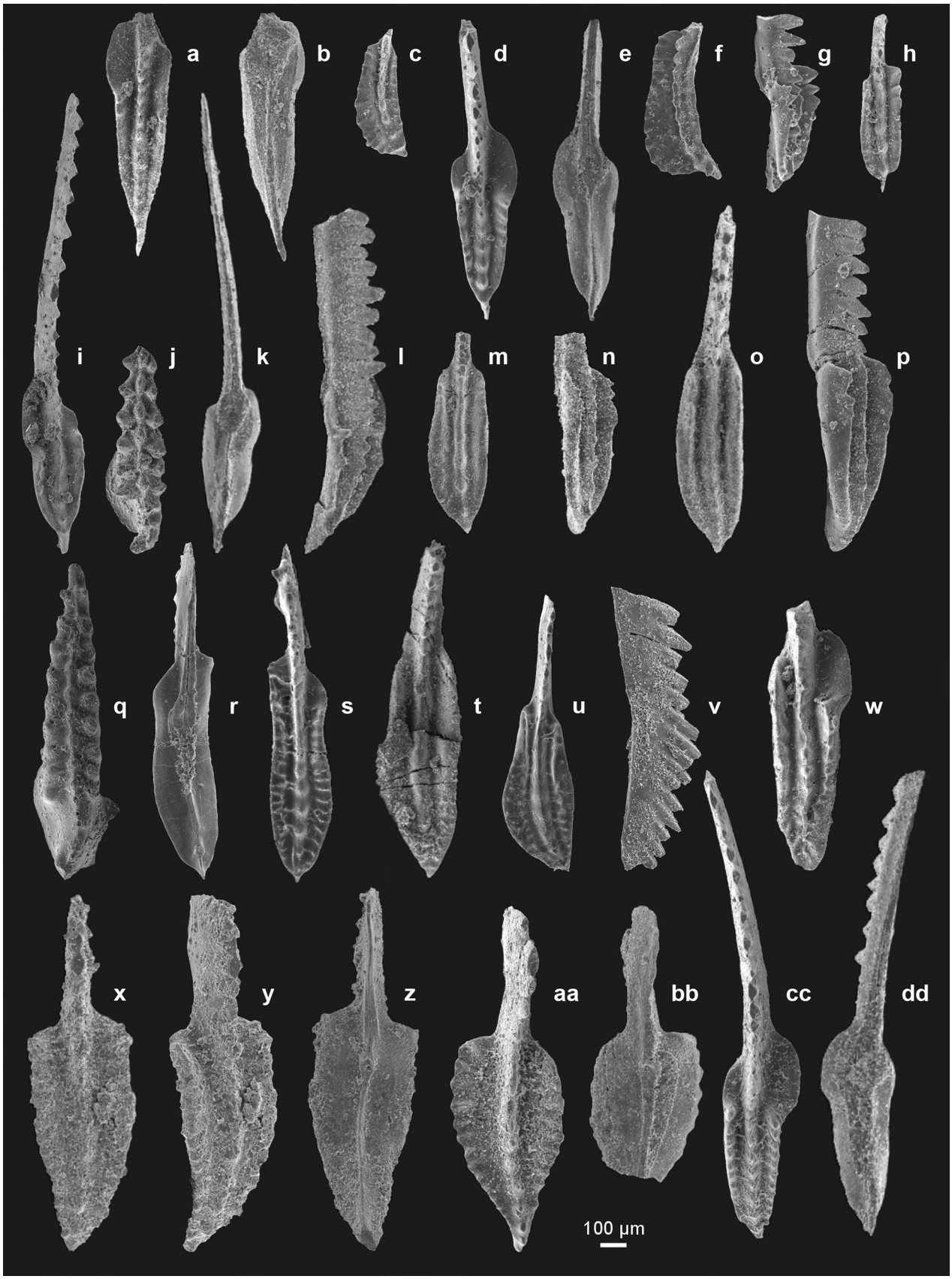
Diagnosis (after Ziegler et al. 1976). Representative specimens of *Polygnathus xylus* have a more or less symmetrical platform and a free blade that is about half the length of the unit. The platform margins are essentially parallel. In large specimens, the basal cavity is about halfway between midlength and the anterior end of the platform. The platform may be smooth, except for the carina, or may have serrations or subdued nodes marginally or weak nodes next to the adcarinal grooves. The geniculation points are opposite.

Polygnathus xylus xylus Stauffer, 1940

Diagnosis (after Ziegler et al. 1976). In representative specimens of the nominate subspecies, the platform margins just posterior of the geniculation point are not distinctly serrated; one serration at the most is weakly developed. The posterior platform is not strongly arched downward.

Polygnathus xylus bacbo subsp. nov.
Figure 5m–p, t

Etymology. The name is derived from the region in northern Vietnam where the subspecies was first found.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◂**Fig. 5a–bb** All specimens are from the Si Phai Formation. **a**, **b**, **d**, **e**, **l**, **cc**, **dd** *Polygnathus rhenanus siphai* subsp. nov., sample VD-MD-33: **a**, **b** (holotype SMF 100.001) upper and lower views; **d**, **e** upper and lower views; **l** oblique view; **cc**, **dd** upper and lower views. **c**, **f** *Polygnathus parawebbi* Chatterton, 1974: **c** upper view, sample VD-MD-10; **f** lateral view, sample VD-MD-35. **g**, **h** *Polygnathus xylus ensensis* Ziegler and Klapper, 1976, lateral and upper views, sample VD-MD-10. **i**, **k** *Polygnathus rhenanus rhenanus* Klapper, Philip and Jackson, 1970, upper and lower views, sample VD-MD-33. **j** *Icriodus brevis* Stauffer, 1940, upper view, sample VD-MD-35. **m–p**, **t** *Polygnathus xylus bacbo* subsp. nov., sample VD-MD-33: **m**, **n** upper and oblique views; **o**, **p** (holotype SMF 100.001) upper and oblique views; **t** upper view. **q** *Icriodus* sp., upper view, sample VD-MD-35. **r**, **s** *Polygnathus timorensis* Klapper, Philip and Jackson, 1970 → *Polygnathus pollocki* Druce, 1976, lower and upper views, sample VD-MD-36, overall platform development, with the outward bowing of the outer anterior trough margin, is typical of *P. timorensis*, whereas the length and development of the free blade and shape of the basal cavity with thick margins gradually converging posteriorly and anteriorly are characteristic of *P. pollocki*. **u** *Polygnathus eiflius* Hinde 1879, upper view, sample VD-MD-36. **v** *Ozarkodina plana* (Bischoff and Ziegler 1957), lateral view, sample VD-MD-33. **w** *Polygnathus timorensis* Klapper, Philip and Jackson, 1970, upper view, sample VD-MD-33. **x–bb** *Polygnathus* aff. *dengleri sagitta* Aboussalam and Becker, 2007: **x**, **y**, **z** upper, oblique, and lower views, sample VD-MD-38, the specimen differs from typical representatives by a posterior platform distinctly arched downwards, and longer free blade which is composed of six denticles of roughly the same height; **aa**, **bb** upper and lower views, VD-MD-37, the specimen differs from typical representatives in that the platform does not taper gradually towards the posterior, and in the development of the carina being low in the posterior part, becoming rapidly elevated from ca. middle of the platform, and grading anteriorly into an even higher free blade. *Scale bars* are 100 µm

Type material. Holotype no. SMF 100.002, the specimen illustrated in Fig. 5o–p from the Si Phai section, Dong Van area, N Vietnam, Si Phai Formation, sample VD-MD-33, deposited in the Senckenberg Research Institute.

Material. 6 specimens.

Diagnosis. The subspecies of *Polygnathus xylus* is characterized by a narrow, elongated platform with near-parallel margins and with an elevated inner margin, particularly in its anterior part. In adult specimens, the tip of the posterior platform is gently bowed down. The outer margin may be gently convex. The platform is generally smooth except for serrated anterior margins, the inner of which has 2–4 denticles and the outer has one or none. The carina is low, forming a uniform ridge in the anterior part, and is dismembered into discrete denticles posteriorly. The basal cavity is small, oval in shape, kite-like in outline with a longer posterior part, and located in the anteriormost part of the platform almost at the junction with the free blade.

Remarks. The representatives of the new subspecies are similar to *P. xylus xylus* in the presence of a narrow platform with smooth, near-parallel margins and steeply downward declined anterior trough margins. They resemble *P. xylus ensensis* in having serrated anterior platform margins, but they differ from it in not displaying a strongly downward-arched platform. The main difference from both taxa is the presence of an elevated inner platform margin.

Occurrence. The specimens from the Si Phai section were identified in the sample VD-MD-33 ascribed to the *ansatus* Zone (Fig. 3).

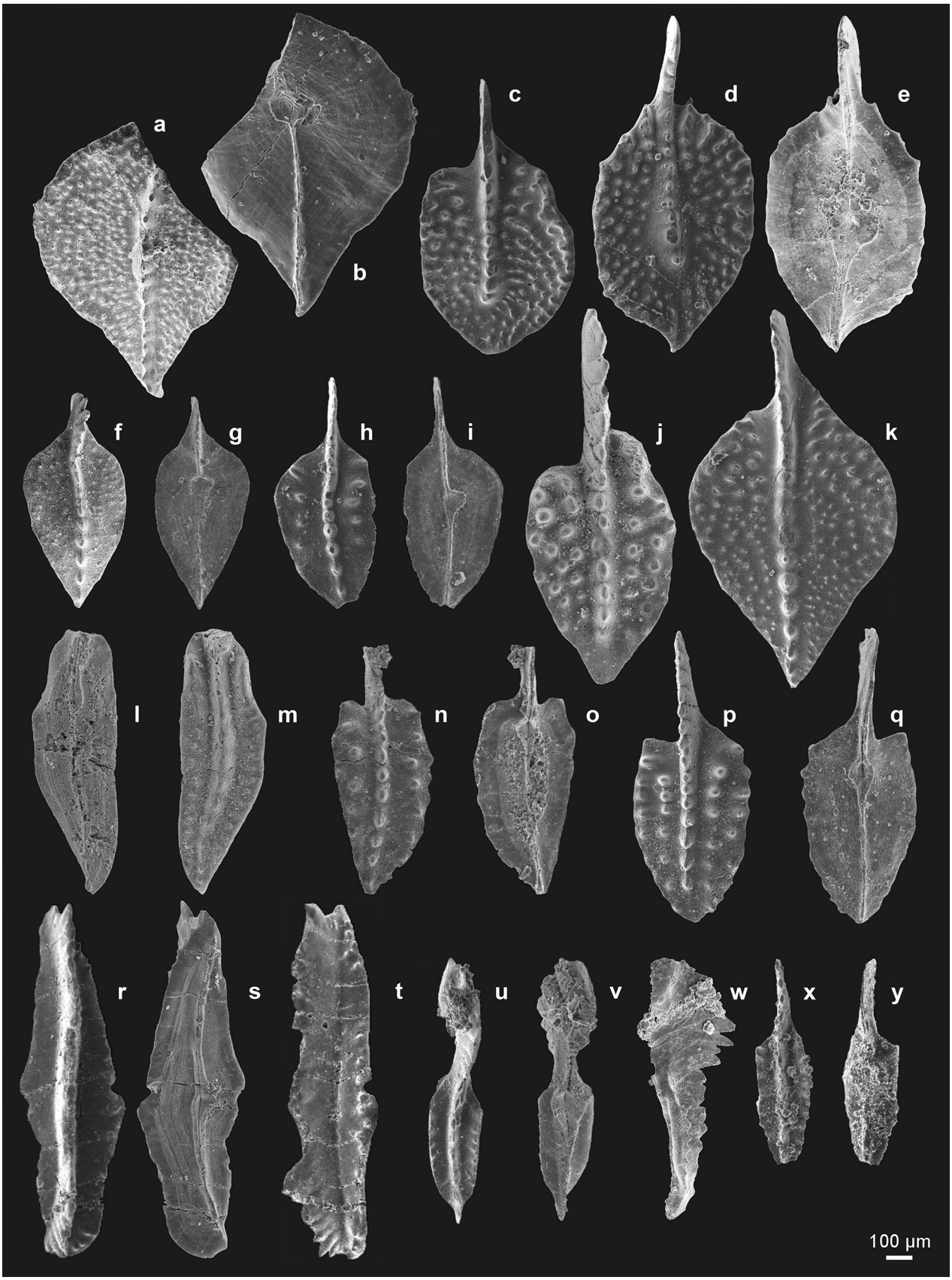
Stratigraphical distribution. *ansatus* Zone (middle Givetian).

Genus and species indet.
Figure 6r–t

Description. The platform is elongated, more or less elliptical in outline, widest in the middle part but at the same time asymmetric, with a narrower inner part. In lateral view it is flat (not arched). The anterior tip of the platform is pointed while the posterior one is rounded. The carina is very high, slightly sinuous, twisted in the posterior part. It is composed of almost completely fused denticles, particularly in the middle part, except for separated denticle tips (the upper part of this sector of the carina is broken). In the posterior 1/3 of the platform, the denticles of the carina are narrower, smaller, more distinct, and inclined posteriorly. In the anterior 1/3 of the platform, the denticles of the carina are narrower, smaller, and inclined anteriorly. The ornamentation of the platform is composed of delicate nodes that are arranged along the platform margins and are particularly visible on the outer side (the inner margin is broken but delicate nodes present in its posterior part suggest that they may occur along the entire margin). The basal cavity is located in approximately the middle of the platform in its widest portion, and is linked with a distinct keel both posteriorly and anteriorly. The cavity is oval, asymmetric, and wider in the inner part.

Remarks. The described form probably belongs to a new genus. It resembles the specimen figured by Aboussalam and Becker (2007, fig. 8L), from the lower *dengleri sagitta* Subzone (=Lower *disparilis*), identified as gen. et sp. indet.

Occurrence. Si Phai section, sample VD-MD-36, ascribed to the lower part of the Lower *disparilis* Zone (Fig. 3).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◂**Fig. 6a–y** All specimens are from the Si Phai Formation. **a**, **b** *Polygnathus cristatus* Hinde 1879→*Klapperina disparilis* (Ziegler and Klapper 1976), upper and lower views, sample VD-MD-36, platform margins slightly elevated whereby its surface becomes gently concave; asymmetric basal cavity located in the middle of the platform. **c–e** *Klapperina disparilis* (Ziegler and Klapper 1976): **c** upper view, sample VD-MD-37; **d**, **e** upper and lower views, sample VD-MD-36. **f**, **g** *Polygnathus cristatus* Hinde 1879→*Klapperina disparata* (Ziegler and Klapper 1982), upper and lower views, sample VD-MD-38, the specimen is characterized by delicate ornamentation, as in *Kl. disparata*, but the basal cavity is larger than in the latter species. **h**, **i** *Polygnathus cristatus* Hinde 1879→*Klapperina disparilis* (Ziegler and Klapper 1976), upper and lower views, sample VD-MD-38, the platform outline and ornamentation is like those of *P. cristatus*, but the asymmetric, nearly L-shaped basal pit is characteristic of *K. disparilis*. **j** *Polygnathus cristatus ectypus* Huddle, 1934, upper view, sample VD-MD-37. **k** ?*Klapperina disparata* (Ziegler and Klapper 1982), upper view, sample VD-MD-36, basal cavity destroyed. **l**, **m** *Polygnathus dubius* Hinde 1879, upper and lower views, sample VD-MD-38. **n–q** *Polygnathus cristatus cristatus* Hinde 1879: **n**, **o** upper and lower views, sample VD-MD-38; **p**, **q** upper and lower views, sample VD-MD-37. **r**, **s**, **t** Genus and species indet., upper, lower, and lateral views, sample VD-MD-36. **u–y** *Schmidtognathus wittekindti* Ziegler, 1966, sample VD-MD-38: **u**, **v**, **w** upper, lower, and lateral views; **x**, **y** upper and lower views of juvenile forms. *Scale bars* are 100 µm

Biofacies and palaeogeographical distribution

The carbonate deposits of the Si Phai Formation are interpreted as pelagic and hemipelagic facies characterized by low sedimentation rates (Königshof et al. 2017a) and are thus generally favorable for conodont occurrence. Nevertheless, most of the studied interval, spanning the upper Eifelian (?) to the middle Givetian, shows a very low conodont frequency (Table 1), which may attest to a rather inhospitable environment for conodont animals and/or may be connected with the shaly and silty lithology of most sediments. A much higher abundance in carbonates, probably related to improved environmental conditions, is noted in two intervals. The first comprises the sample VD-MD-33 and the sample VD-MD-35 located ca. 1 m higher; both of these assemblages are dated to the *ansatus* Zone. The second interval includes the samples from VD-MD-36 to VD-MD-38 ascribed to the lower part of the Lower *disparilis* Zone (Table 1). It should be noted that both intervals are separated by 30-cm-thick limestones comprising three conodont zones: *latifossatus/semialternans*, Lower and Upper *hermanni*. This may indicate either a stratigraphic gap or at least a considerable condensation.

The assemblage from the lower interval is characterized by middle Givetian fauna, including *Polygnathus* (dominant) and *Icriodus* and *Ozarkodina* (less frequent), whereas the upper assemblage is composed of upper Givetian genera: *Klapperina* (dominant), *Polygnathus*, and *Schmidtognathus*. The taxonomic diversity is therefore the same at the genus level, but it is much higher for the older assemblage when analyzed at the species level (Table 1). The biofacies analysis included samples VD-MD-33 and VD-MD-35 from the lower interval as well as the combined samples VD-MD-36 and VD-MD-37 and the sample VD-MD-38 from the upper interval.

The sample VD-MD-33 is characterized by the polygnathid biofacies, with the nominal genus composing 90% of all specimens and the remaining 10% represented by *Ozarkodina plana* (Bischoff and Ziegler 1957). The most frequent species within the genus *Polygnathus* is *P. rhenanus* (37%), followed by *P. linguiformis* (24%) and *P. xylus* (10%). The polygnathid biofacies was found in the sample VD-MD-35 too, with the nominal genus comprising 98% of the entire assemblage, the proportion of *P. linguiformis* rising to 36%, and that of *P. rhenanus* dropping to 30%.

According to previous studies, *P. linguiformis* is ubiquitous in a wide range of facies from neritic to pelagic, although it is most common in deep-water environments (Narkiewicz et al. 2016). In the latter it attains high frequencies, exceeding 100 specimens per sample (see Klapper 1971, tab. 5; Bultynck 1987, fig. 4). It is less abundant in hemipelagic facies (below 100 specimens per sample; Bultynck 1987, fig. 7; 1989), while in neritic facies it is considerably more rare (generally a few specimens per sample). The environmental preferences of *P. rhenanus* are yet to be investigated, but it was noted that it commonly co-occurs with *P. linguiformis*. The increasing proportion of *Polygnathus linguiformis* relative to narrow-platform *P. rhenanus* may be related to a progressive deepening related to the Taghanic transgression, as recorded by the samples VD-MD-33 and VD-MD-35 (Narkiewicz et al. 2016).

Both of the analyzed samples contain diverse assemblages, including 14 species and subspecies in the lower one and 16 taxa of the same rank in the upper one. The species *Polygnathus linguiformis*, *P. xylus*, and *P. rhenanus*, found in both assemblages, are widespread globally, occurring in Euramerica, Gondwana, South China, the Central Asian Orogenic Belt, and the Central Pyrenees. On the other hand, the three newly described subspecies are less widespread. *Polygnathus linguiformis saharicus* and *P. rhenanus siphai* have not been found in Euramerica, and *P. xylus bacbo* is known only from Vietnam. *P. linguiformis vietnamicus* has a wider distribution—both Euramerica (Germany, Ohio in the USA) and Gondwana (Morocco).

The conodont assemblage of the combined samples VD-MD-36 and VD-MD-37 is characterized by the polygnathid-klapperinid biofacies, in which the proportions of both genera are 50% for *Polygnathus* and 46% for *Klapperina*. *Polygnathus* is dominated by the species *P. cristatus*, while *Klapperina* is dominated by *K. disparilis*. The klapperinid biofacies was found in sample VD-MD-38, with *Klapperina* making up 76% of the assemblage, while the

proportion of *Polygnathus* is 19%. This biofacies is dominated by the wide-platform element of *Klapperina disparilis* at various stages of ontogenetic development. An accessory component of the above biofacies is *Schmidtognathus wittekindti*. The three species mentioned above have wide global distributions, having been found in Euramerica, Gondwana, South China, Montagne Noire, the Central Pyrenees, and Tajikistan (Klapper and Johnson 1980; Bultynck and Hollard 1980; Feist and Klapper 1985; Ziegler and Wang 1985; Bardashev 1992; Ji et al. 1992; Bai et al. 1994; Lazreq 1999; Aboussalam 2003; Liao and Valenzuela-Rios 2013).

The upper Givetian conodont biofacies have only been investigated by Lazreq (1999) in central Morocco. The polygnathid biofacies prevailing in the Lower *disparilis* Zone studied by this author were attributed to pelagic environments. The klapperinid biofacies has not been reported in previous studies, although the species has been found worldwide, including in Euramerica, Gondwana, the Central Pyrenees, South China, and other Asian terranes (Klapper and Johnson 1980; Bardashev 1992; Bai et al. 1994; Liao and Valenzuela-Rios 2013). Thus, the domination of *Klapperina* in the assemblages studied here seems to be unique among the late Givetian conodont assemblages studied so far, and may point to special environmental conditions. The fact that it commonly co-occurs with cephalopod fauna (Ziegler and Klapper 1982) suggests deeper marine hemipelagic and pelagic environments. This is consistent with the development of the sedimentary unit 6 in the Si Phai section, as this unit is mainly composed of styliolinid wackstones and packstones suggestive of pelagic deposition (Königshof et al. 2017a; fig. 3). According to the biofacies model of Narkiewicz et al. (2016, fig. 9), the klapperinid biofacies could occupy the far offshore areas of the external shelf, even beyond the polygnathid biofacies. During the early Frasnian, these environments could have been taken over by wide-platform representatives of the mesotaxid biofacies within the offshore pelagic environment (Ziegler and Sandberg 1990).

The studied Vietnamese conodont assemblages show high taxonomic similarity to those described from the Chinese Guangxi Province located about 4 km to the east of the studied section (Königshof et al. 2017a, fig. 2). This suggests that the Dong Van region in NE Vietnam and the Guangxi area were both parts of the same Middle Devonian basin. This is further corroborated by the similarity of the palaeothermal patterns of both regions. The thermal maturity of the Devonian in the Guangxi area neighboring the Dong Van region shows conodont CAI values of 4–5 (Bai et al. 1994), the same as in the Si Phai section. This may be due to a continuity of the Pingxiang Fault zone and the associated higher thermal maturity area from the Chinese territory westwards into the Dong Van region. Facies analysis, conodont assemblages, and thermal maturity (CAI data) suggest a palaeogeographic affinity of the studied Middle Devonian deposits with the South China Terrane.

Conclusions

In the first detailed study of the Middle Devonian conodonts from Vietnam (Si Phai section), a relatively rich assemblage was found, including 27 taxa of species or subspecies rank and 11 taxa described in an open nomenclature. Among the dominant *Polygnathus* forms, four new taxa (subspecies) have been described: *Polygnathus linguiformis saharicus*, *Polygnathus linguiformis vietnamicus*, *Polygnathus rhenanus siphai*, and *Polygnathus xylus bacbo.*

The conodont biofacies analyzed for the two conodont-rich intervals in the *ansatus* and Lower *disparilis* zones point to offshore pelagic to hemipelagic environments, with the pelagic environment probably related to the deepening event associated with the Taghanic transgression (see also Königshof et al. 2017a).

The unique klapperinid biofacies found in the upper interval may have been connected with specific environmental conditions of a deep outermost shelf or ramp; this appears to be confirmed by microfacies analysis (Königshof et al. 2017a).

The Bắc Bộ Basin was probably closely related to the Chinese Guangxi Basin (South China Terrane), as suggested by a similarity in conodont assemblages, similar patterns in the conodont CAI, other faunal associations published in various papers, as well as a provenance analysis of detrital zircons.

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