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Taxonomic problems of some zonal species of the genus *Palmatolepis* and the correlation of the Frasnian of the East European Platform with conodont zonations

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ABSTRACT:

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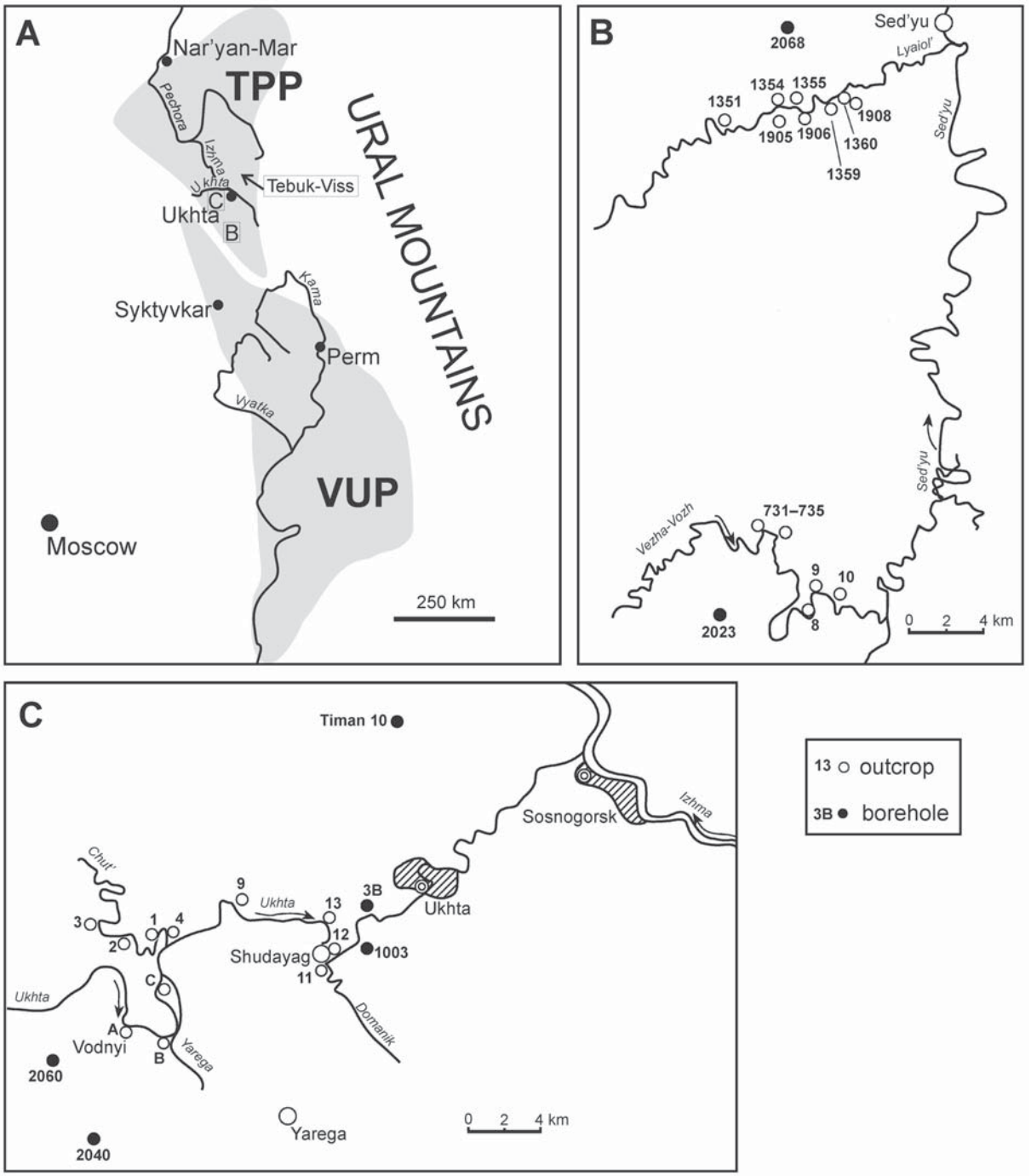
Most of the Frasnian regional stages of the Ukhta region, South Timan, Russia, are composed of basinal deposits, however, the *hassi* and *jamieae* zones of the Standard Conodont Zonation cannot be easily recognised in this region. A revision of the previously elaborated succession of the Timan-Pechora associations revealed that the correlation problems are connected with the taxonomic interpretation of the zonal species *Palmatolepis hassi* and *Palmatolepis jamieae*. Analysis of the conodont collection of Professor W. Ziegler from the Rhenish Slate Mountains, Germany, especially from the interval encompassing the Lower *hassi* to Upper *rhenana* zones, has provided evidence of the lack of validity of the *jamieae* Zone as a separate stratigraphic unit. This statement is based on the composition of the *jamieae* and Lower *rhenana* conodont associations and the absence of *P. jamieae* near the lower boundary of the zone in the stratotype and other sections of the Rhenish Slate Mountains, becoming more common upsection. The correlation between the Timan-Pechora conodont associations III–XI, the Standard Conodont Zonation (Ziegler and Sandberg 1990) and the Frasnian Zonation (Klapper 1989; Klapper and Kirchgasser 2016) is suggested herein. The Domanikian Regional Stage corresponds to the *punctata*–Late *hassi* zones of the Standard Conodont Zonation and to Frasnian Zones 5–10. The boundaries of Frasnian Zones 8–9 need to be further specified in South Timan. The correlation between the Standard Conodont Zonation and the Frasnian Zonation of Klapper is elaborated.

Keywords: Timan; Volga-Ural Region; Rhenish Slate Mountains; Frasnian Stage; Conodonts; Standard Conodont Zonation; Frasnian Zonation of Klapper; *Palmatolepis hassi*; *Palmatolepis jamieae*

INTRODUCTION

Frasnian deposits are widespread in the East European Platform (EEP) and consist of various facies; in a number of regions especially in north-eastern European Russia, they constitute distinct reference levels. The attempt of direct correlation between the conodont associations of various sections of the Timan-Pechora province (TPP) and the conodont associations of the Frasnian part of the Upper Devonian Standard Conodont Zonation (Ziegler and Sandberg 1990) has not been entirely successful and



Text-fig. 1. Location of outcrops and boreholes studied. A – Fragment of a map of Russia showing the position of the Timan-Pechora Province (TPP) and the Volga-Ural Province (VUP). B and C show the two study areas to the south and north of Ukhta, respectively; B – Outcrops and boreholes along the Lyaiol' and Vezha-Vozh rivers; C – Outcrops and boreholes along the Chut', Yarega, Domanik and Ukhta rivers, and in the vicinity of Shudayag settlement. Modified after Menner *et al.* (1992)

has raised a need to elaborate a local conodont succession in the reference sections of the southern TPP (Ovnatanova *et al.* 1999a, b), which is correlated with the regional stratigraphic scheme. The stratotypes of most of the regional stages (RS) corresponding to the Frasnian Stage (Timanian, Sargaevian, Domanikian,

stage	regional stage		formation	unit	local conodont zones	TP conodont associations
	VUP	SOUTH TIMAN				
FRASNIAN	Askynian	Livnian			*P. linguiformis*	TP XI
		Evlanovian	Sed'yu		*P. juntianensis*	TP X
			Lyaiol'	4	*P. gyrata*	TP IX
	Mendymian	Sirachoian		3	*P. elegantula – P. semichatovae*	TP VIII
				2		
		Vetlasyanian		1		TP VIIb
	Domanikian		Domanik	3	*P. mucronata – P. amplificata*	TP VIIa
					A. ancyrognathoideus – P. orbicularis	TP VI
				2		TP V
				1	*P. efimovae – P. punctata*	TP IV
	Sargaevian		Ust'-Yarega	u	*A. alata – M. bogoslovskyi*	TP III
				l		
	Timanian		Timan	u		
G						

Text-fig. 2. Correlation of the Timan-Pechora conodont associations (TP III–TP XI) with regional stages, formations and local conodont zones of South Timan and Volga-Ural province, Russia. G indicates Givetian. Modified after Ovnatanova and Kononova (2008)

Vetlasyanian, Sirachoian, Evlanovian and Livnian) were studied in borehole sections and outcrops of the Ukhta region, north-eastern Russia (Menner *et al*. 1992; Ovnatanova *et al*. 1999a, b; Text-fig. 1). Most of the sections comprise the domanikoid facies and contain rich conodont faunas. The upper part of the Frasnian Stage in the Ukhta region is composed mainly of shallow-water sulphate clayey-carbonate deposits and is poor in conodonts; therefore the succession of associations in this interval was studied in the basinal borehole sections of the Tebuk-Viss region located to the east of the Ukhta region (Text-fig. 1A). The previously elaborated succession of conodont associations (Ovnatanova *et al.* 1999a, b) included eleven Timan-Pechora (TP) conodont associations, from TP 1 (upper part of the Timan Formation and lowermost part of the Ust'-Yarega Formation) and up to TP XI (Livnian RS). Later, this succession contributed to the construction of a local zonal conodont scheme for basinal deposits of the EEP (Ovnatanova and Kononova 2008; Text-fig. 2). The lower part of the succession (Timanian and lowermost Sargaevian RS) is composed of shallow-water facies and thus only polygnathids are found there, while *Mesotaxis* spp. and *Ancyrodella* spp. are absent. A reliable correlation of the associations with the Frasnian conodont zones is possible starting from association TP III (Sargaevian RS, upper unit of the Ust'-Yarega Formation). This succession of conodont associations was also confirmed for the TP III–TP V and TP VIII–TP XI intervals of the Volga-Ural province (VUP; Ovnatanova and Kononova 2008; Text-

fig. 1A). Conodont associations TP VI and TP VII were initially supposed to date the Domanikian RS and the lowermost Lyaiol' Formation (Ovnatanova *et al.* 1999a, b); however, it was difficult to trace these intervals in South Timan and the VUP.

The present paper focuses on the characteristics of the Domanikian RS and its boundary deposits in South Timan (Ukhta region) and also on coeval associations in the VUP (Ovnatanova and Kononova 2008). The Domanikian RS was previously considered to correspond to the interval of the *punctata*, Lower and Upper *hassi* and *jamieae* zones of the Standard Conodont Zonation (Resolution… 2008; Artyushkova *et al.* 2011; Fortunatova *et al.* 2016). Moreover, we analyse the taxonomic peculiarities of *Palmatolepis hassi* and *Palmatolepis jamieae*, the index species of the Lower and Upper *hassi*, and the *jamieae* zones, respectively, and the conodont faunas from the reference sections of the Rhenish Slate Mountains, where the zones of the standard scale were established.

FRASNIAN CONODONT ASSOCIATIONS IN SOUTH TIMAN

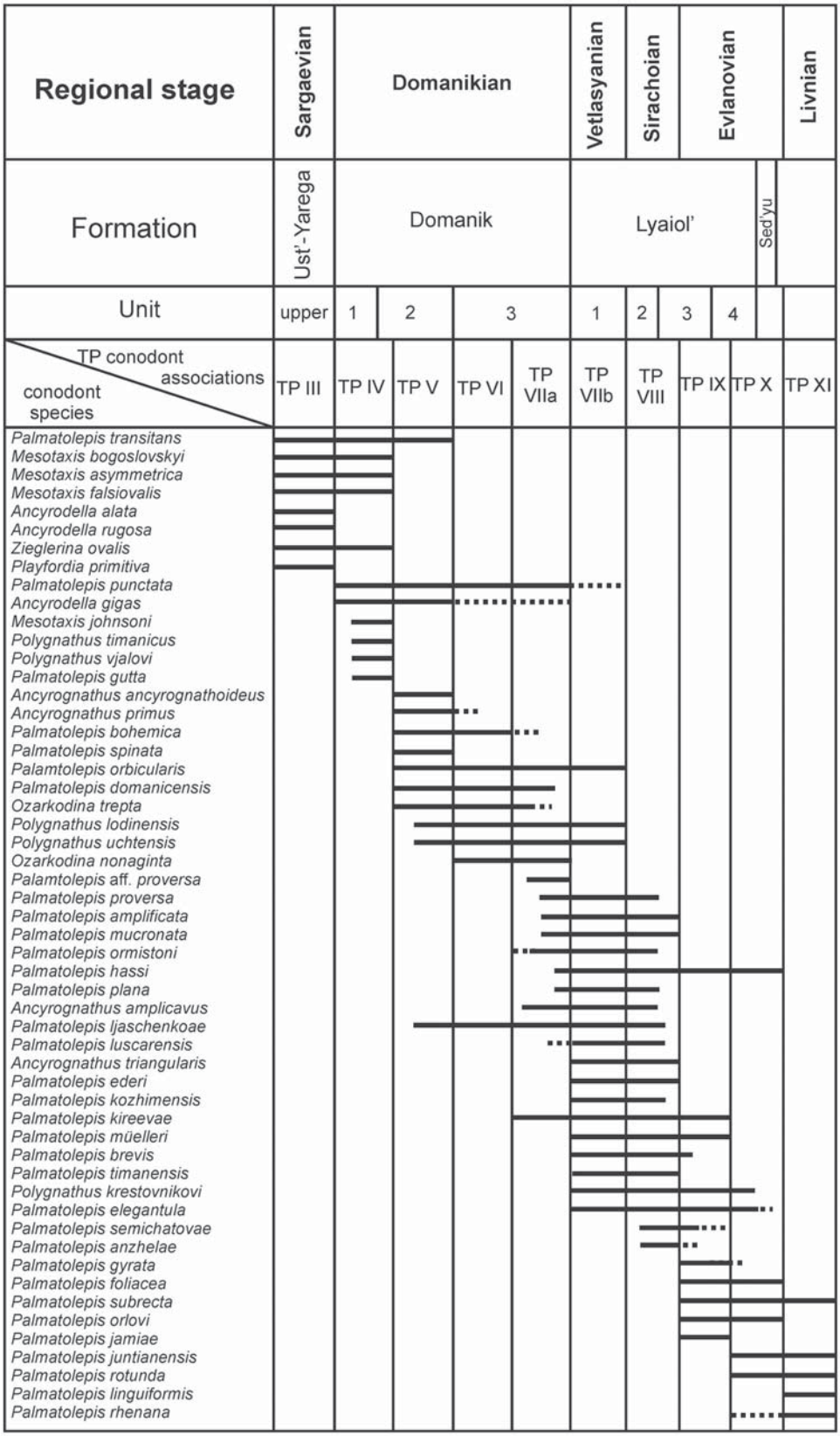
The analysis of the Frasnian succession of conodont associations was initially established (Ovnatanova *et al.* 1999a, b) following the study of samples from borehole sections and outcrops of the Ukhta region in South Timan being stratotypes of most of the regional stages of the Frasnian Stage: Timanian, Sargaevian, Domanikian, Vetlasyanian, Sirachoian, Evlanovian and Livnian. The Timan-Pechora succession consists of conodont associations TP I to TP XI (Text-fig. 2).

The lower Frasnian shallow-water deposits (Timanian and lower Sargaevian RS) of the TPP are characterised mainly by polygnathid biofacies, representatives of *Mesotaxis* spp. and *Ancyrodella* spp. being absent. In the overlying Sargaevian RS strata, conodonts are taxonomically more diverse; at first *Ancyrodella rotundiloba* appears at the top of the lower unit of the Ust'-Yarega Formation, which is probably related with basin deepening. Thus, the lower boundary of the Frasnian Stage may be traced at the level of the lower boundary of the upper Timan Formation (Kuz'min 1995; Ovnatanova *et al.* 1999a, b; Menner *et al.* 2001; Ovnatanova and Kononova 2008; Text-fig. 2). This position of the lower boundary of the Frasnian Stage in the study area is also confirmed by the study of conodonts from the Chernyshev Ridge and Subpolar Urals (Ovnatanova *et al.* 2017).

Fifty-four conodont taxa have been recognised in the Frasnian deposits of South Timan (Text-fig. 3; the alphabetical list of conodont species mentioned in the paper is given in the Appendix). Association TP III from the upper part of the Ust'-Yarega Formation in the Vodnyi settlement-Uhkta area along Yarega River and Ukhta River (outcrops A, B, C) and in boreholes nos. 1003 and 3B (Text-fig. 1C) is characterised by the co-occurrence of *Ancyrodella alata*, *A. rugosa*, *Mesotaxis asymmetrica*, *M. bogoslovskyi*, *M. falsiovalis*, *Palmatolepis transitans*, *Playfordia primitiva* and *Zieglerina ovalis* (Ovnatanova *et al.* 1999b, p. 354). The *Ancyrodella alata–Mesotaxis bogoslovskyi* local zone is defined on the basis of association TP III (Text-fig. 2). In the VUP, association TP III corresponds to the uppermost Sargaevian RS (Text-fig. 2).

Association TP IV was described from unit 1 of the Domanik Formation and the basal clayey bed of unit 2 of the Domanik Formation [outcrop 1 (= 7 of Yudina and Moskalenko 1997) on the left bank of Chut' River; outcrop 2 (= 15b of Bogoslovsky 1969) along Chut' River; outcrop 3 (= 15c of Bogoslovsky 1969); and borehole 3B; Text-fig. 1C)]. It is characterised by the first occurrence (FO) of *Palmatolepis punctata* in the base of the unit and the FO of *Ancyrodella gigas*, *Mesotaxis johnsoni*, *Palmatolepis gutta*, *Polygnathus timanicus* and *P. vjalovi* somewhat higher upsection (Text-fig. 3). Other important species also present in association TP IV include *Mesotaxis asymmetrica*, *M. falsiovalis* and *Palmatolepis transitans.* Representatives of the genus *Mesotaxis* spp. completely disappear higher up in the section and the association becomes to be dominated by the palmatolepids. The *Polygnathus efimovae–Palmatolepis punctata* local zone was established based on association TP IV; it also characterises the lowermost Domanikian RS of the VUP (Text-fig. 2).

Association TP V characterises unit 2 of the Domanik Formation (except its basal clayey bed; Text-fig. 2). It was found in exposures along Chut' River [outcrop 2 (= 15b of Bogoslovsky 1969); outcrop 3 (= 15c of Bogoslovsky 1969)], in the mouth of Chut' River [outcrop 4 (= 28 of Bogoslovsky 1969)], in quarries and exposures along Ukhta River [outcrop 9 (= 39 of Bogoslovsky 1969) on the left bank of Ukhta River; outcrop 13 in the road and water-intake cuts to the north of Shudayag settlement], and in boreholes nos. 3B and 1003 (Text-fig. 1C). It contains: *Ancyrognathus ancyrognathoideus*, *A. primus*, *Ozarkodina trepta*, *Palmatolepis bohemica*, *P. domanicensis*, *P. orbicularis*, *P. spinata*, *Polygnathus lodinensis* and *P. uchtensis.* Deposits with associa-



Text-fig. 3. Stratigraphic distribution of conodonts in the Frasnian deposits of the Ukhta region, South Timan, Russia

tion TP V were defined as the *Ancyrognathus ancyrognathoideus–Palmatolepis orbicularis* local zone (Text-fig. 2). Association TP V presumably also characterises unit 2 of Domanik Formation in the VUP, as it contains *Palmatolepis bohemica*, *P. domanicensis* and *P. spinata* (Ovnatanova and Kononova 2008, table 13; Text-fig. 3).

Association TP VI was studied from a limited number of outcrops, including the uppermost part of outcrop 11 (= 21 of Yudina and Moskalenko 1997) along the Domanik River, 0.5 km from the river mouth (Text-fig. 1C), where *Ozarkodina nonaginta* and *Palmatolepis punctata* were found. This is presumably the lower part of the domanikoid unit 3. *Ozarkodina nonaginta* is also known from the base and upper part of unit 3 of Domanik Formation in boreholes nos. 3B, 2060 and 2068 in the Ukhta region (Klapper *et al.* 1996; Text-fig. 1B and C).

Association TP VIIa characterises the 6–8 m thick carbonate bed near the top of unit 3 of the Domanik Formation. The lowermost part of this bed near the top of the Domanik Formation in outcrop 13 on the left bank of Ukhta river, upstream of Shudayag settlement near the water-intake (Text-fig. 1C), is characterised by the FO of *Ancyrognathus amplicavus*, *Palmatolepis mucronata*, *P. ormistoni* and *P.* aff. *proversa*, which were found together with taxa from association TP VI (Text-fig. 3).

Unit 3 of the Domanik Formation still remains the most poorly studied; in some exposures (outcrop 13 near Shudayag settlement; Text-fig. 1C), the uppermost limestones of the Domanik Formation contain *Palmatolepis hassi*, *P. plana* and *P. proversa*. The unit was tentatively included in the *Palmatolepis mucronata–Palmatolepis amplificata* local zone; this zone was also traced in the uppermost part of the Domanikian RS of the VUP (Text-fig. 2).

We have previously noted (Ovnatanova *et al*. 1999a, b) that many of the species listed above are known also from the overlying Vetlasyanian RS. Initially, association TP VII was supposed to characterise both the 6–8 m thick upper carbonate bed near the top of unit 3 of the Domanik Formation and the Vetlasyanian RS (Ovnatanova *et al.* 1999a, b; Becker *et al*. 2000; House *et al*. 2000), where the TP associations were correlated with regional ammonoid, conodont and miospore zonations and regional stages and formations of the TPP.

The associations of the upper unit of the Domanik Formation and the Vetlasyanian RS are evidently similar in the presence of *Palmatolepis hassi*, *P. plana* and *P. proversa*. However, it was found out later (Ovnatanova and Kononova 2008) that the Vetlasyanian RS (outcrops 1354, 1355, 1905 and 1906 along Lyaiol' River and outcrops 731–735 along Vezha-Vozh River; Text-fig. 1B) contains also *Ancyrognathus triangularis*, *P. ederi*, *P. elegantula* and *P. kozhimensis* (= *P. menneri*). Thus, this association may be considered as a separate unit and is referred to herein as association TP VIIb. In turn, the association occurring in unit 3 of the Domanik Formation is referred to as TP VIIa (Text-fig. 2).

It was previously assumed (Ovnatanova *et al.* 1999b, p. 355) that after the completion of excavation works near Shudayag settlement, the uppermost carbonate unit of the Domanik Formation would be exposed for study making possible the determination of the composition of its conodont fauna. Unfortunately, as far as we know, that did not prove to be the case; possibly this part of the section was never sufficiently exposed. *Palmatolepis ederi*, *P. ljaschenkoae*, *P.* cf. *luscarensis*, *P. proversa* and *P.* aff. *punctata* were identified in outcrop 12 on the right bank of Ukhta River, near the hospital in Shudayag settlement (Text-fig. 1C), which was initially supposed to represent the upper part of the Domanikian RS; however, the presence of *P. ederi* suggests that it represents a higher part of the succession. It cannot be excluded that the succession may expose the boundary between the Domanik and Lyaiol' formations, whereas the uppermost part of the Domanik Formation was possibly not exposed or could not be studied. *Palmatolepis kozhimensis* was found together with *P. orbicularis*, *P. mucronata*, and *P.* aff. *punctata* in the road cut near the hospital in Shudayag settlement (outcrop 12 in Text-fig. 1C). The occurrence of *P. kozhimensis* is restricted to units 1 and 2 of the Lyaiol' Formation in South Timan (Ukhta region) and the Mendymian RS of the VUP (see Text-fig. 3). The association is abundant in unit 1 of the Lyaiol' Formation (Vetlasyanian RS) in outcrop 1905 along Lyaiol' River (Text-fig. 1B), where *Palmatolepis kireevae*, *P. mucronata*, *P. plana* and *P. proversa* are still present and *Ancyrognathus triangularis*, *Palmatolepis ederi* and *P. elegantula* have their FO. The association was also identified in unit 1 of the Lyaiol' Formation (Vetlasyanian RS) in outcrop 1354 along Lyaiol' River (Text-fig. 1B), judging from the presence of *Palmatolepis brevis*, *P. elegantula*, *P. müelleri* and *P. timanensis*. Conodonts extracted from samples collected by V.V. Menner from exposures along Lyaiol' River (outcrop 1906 in Text-fig. 1B) include *P. ederi* together with *P. ljaschenkoae*, *P. kireevae*, *P. mucronata*, *P. orbicularis*, *P. plana*, *P. proversa* and *P. timanensis* in supposed deposits of unit 3 of the Domanik Formation. The polygnathids include *Polygnathus uchtensis* and

P. krestovnikovi. We refer this part of the section to the Vetlasyanian RS and not to the Domanikian RS based on the presence of *Palmatolepis ederi* and *Polygnathus krestovnikovi*. The latter species was widely noted in the Voronezh-Livnian strata of the VUP (Ovnatanova and Kononova 2008, table 20) and also in the Lower *rhenana–Polygnathus linguiformis* Zone of the Rhenish Slate Mountains (Ziegler *et al.* 2000, chart 2, pl. 3, figs 12–14).

Hence, the conodont association of unit 1 of the Lyaiol' Formation (TP VIIb) is now considered as a separate unit within the Vetlasyanian RS and does not include the association from the uppermost part of the Domanik Formation as previously suggested (Ovnatanova *et al.* 1999a, b; Becker *et al.* 2000; House *et al.* 2000).

Association TP VIII was studied in exposures along the Lyaiol' (outcrops 1906, 1906A and 1355) and Vezha-Vozh rivers (outcrops 8 and 9), and in boreholes Timan 10, 2023, 2040 and 2068 (Text-fig. 1B and C); it characterises unit 2 and the lower part of unit 3 of the Lyaiol' Formation (Syrachoian RS) and is defined by the co-occurrence of *Ancyrognathus triangularis*, *Palmatolepis amplificata*, *P. ederi*, *P. elegantula*, *P. mucronata*, *P. plana* and *P. timanensis*; additionally, *Palmatolepis anzhelae* and *P. semichatovae* appear in the middle of unit 2. Deposits characterised by associations TP VIIb and TP VIII were defined as the *Palmatolepis elegantula–Palmatolepis semichatovae* local zone and indicate the Mendymian RS of the VUP (Text-fig. 2).

Association TP IX was studied in exposures along the Lyaiol' (outcrops 1359, 1360, 1908) and Vezha-Vozh rivers (outcrops 8, upper part of 9, and 10), and in boreholes nos. 2023 and 2068 (Text-fig. 1B); it characterises most of unit 3 and the lower clayey-carbonate part of unit 4 of the Lyaiol' Formation (lower Evlanovian RS). It comprises *P. foliacea*, *P. gyrata*, *P. hassi*, *P. jamieae*, *P. orlovi* and *P. subrecta* (= *P. winchelli*), which indicate the *Palmatolepis gyrata* local zone of the lowermost Evlanovian RS (Text-fig. 2).

Association TP X (upper part of the Evlanovian RS) is known from outcrops 1359, 1360 and 1908 along Lyaiol' River, and outcrop 10 along Vezha-Vozh River (Text-fig. 1B); it is characterised by the FO of *P. juntianensis* and *P. rotunda* (= *P. bogartensis*) in the upper part of the Lyaiol' Formation. We also refer to association TP X the clayey strata of the Sed'yu Formation with the upper Evlanovian RS spore association (Ovnatanova *et al.* 1999a, b; Ovnatanova and Kononova 2008) and the uppermost Evlanovian RS up to association TP XI. Association TP X was defined as the *Palmatolepis juntianensis* local zone (Ovnatanova and Kononova 2008). In the VUP, associations TP IX and TP X characterise most of the Askynian RS (Text-fig. 2).

Association TP XI in the Ukhta region is composed mainly of shallow-water sulphate clayey-carbonate deposits. The conodonts and spores in the TP XI association probably correspond to the Livnian RS. The association is known from sections located to the east of South Timan, where the whole Upper Frasnian is composed of basinal facies and association TP XI (Livnian RS) is characterised primarily by the FO of *Palmatolepis linguiformis* and the co-occurrence of *P. juntianensis*, *P. orlovi*, *P. rhenana*, *P. rotunda* and *P. subrecta*. In the VUP, association TP XI characterises the upper part of the Askynian RS (Text-fig. 2).

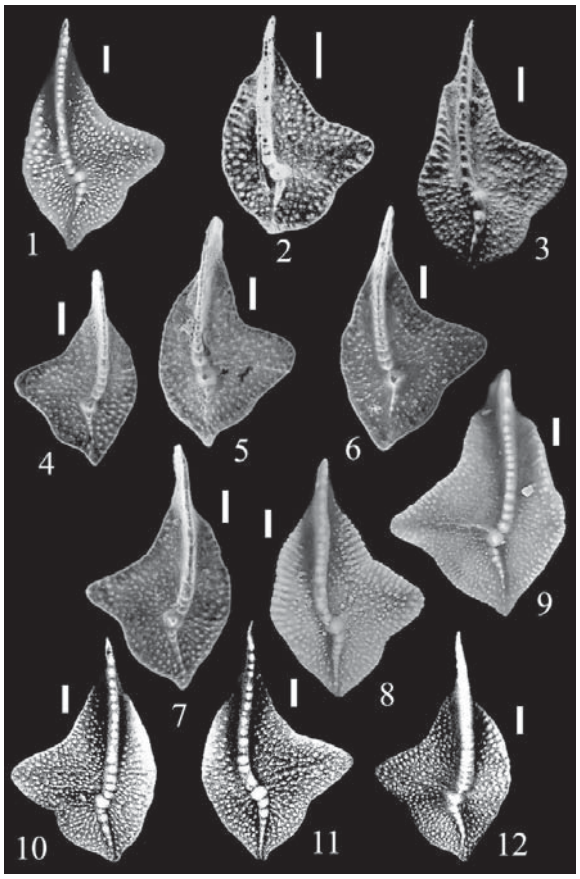
The composition of associations TP X and TP XI in the upper part of the Evlanovian RS and the Livnian RS, and the associations across the Frasnian–Famennian boundary were studied in more detail in the sections of the Tebuk-Viss region of the Izhma-Pechora Depression (Kuz'min *et al.* 1998).

LIMITATIONS IN THE USE OF THE STANDARD CONODONT ZONATION FOR THE EAST EUROPEAN PLATFORM

In the TPP and VUP of the East European Platform, the use of the Standard Conodont Zonation (Ziegler and Sandberg 1990) is restricted to regions with basinal facies, where the *transitans*, *punctata*, Lower and Upper *rhenana*, and *linguiformis* zones are well detected in contrast to the Lower and Upper *hassi*, and *jamieae* zones.

The limitations in the use of the Frasnian part of the Standard Conodont Zonation were previously mentioned by Ovnatanova *et al.* (2005) and Bultynck (2007). The major issues are caused by taxonomic problems, which exclude a reliable correlation of the Lower and Upper *hassi*, and *jamieae* conodont zones, as the stratigraphic ranges of *Palmatolepis hassi* and *P. jamieae* remain uncertain due to a broad concept of these species by different authors, not corresponding to the holotype.

Menner *et al.* (2001) correlated the lower part of the Domanikian RS of the TPP (TP IV) with the *punctata* Zone, and the overlying TP V to TP VI less reliably with the Lower and Upper *hassi* zones. The position of the interval corresponding to the *jamieae* Zone remained uncertain. Ovnatanova and Kononova (2008) interpreted the interval encompassing the up-



Text-fig. 4. Taxonomic concept of *Palmatolepis hassi* Müller and Müller, 1957. All figured elements are re-illustrated from the cited papers. 1 – holotype SUI 9958 (original of Müller and Müller 1957, pl. 140, fig. 4); from bed 7, Amana beds, Highway 220 near Middle Amana, Iowa, USA. 2 – SMF 38671; from Benner Bicken section, Rhenish Slate Mountains, Germany, Lower *rhenana* Zone (original of Ziegler and Sandberg 1990, pl. 2, fig. 4). 3 – SMF 38672; from Steinbruch Schmidt section, Rhenish Slate Mountains, Germany, Lower *rhenana* Zone (original of Ziegler and Sandberg 1990, pl. 2, fig. 5). 4, 5 – from sample 20, interval 2595–2601 m of borehole no. 1, Mar'el', TPP, Russia; Lyaiol' Formation, unit 2, Lower *rhenana* Zone; 4 – PIN 5255/41 (original of Ovnatanova and Kononova 2008, pl. 4, fig. 11); 5 – PIN 5255/42 (original of Ovnatanova and Kononova 2008, pl. 4, fig. 12). 6 – PIN 5255/43; from sample 14, depth 149 m of borehole no. 2023, TPP, Russia; Lyaiol' Formation, upper part of unit 3, Upper *rhenana* Zone (original of Ovnatanova and Kononova 2008, pl. 4, fig. 13). 7 – PIN 5255/44; from sample 19A, depth 46 m of borehole no. 2068, TPP, Russia; Lyaiol' Formation, unit 2, Lower *rhenana* Zone (original of Ovnatanova and Kononova 2008, pl. 4, fig. 14). 8-9 – GSWA location 46757; Virgin Hills Formation, Canning Basin, Western Australia; lower part of Frasnian Zone 13a; 8 – GSWA F48969 (original of Klapper and Foster 1993, fig. 15.5); 9 – GSWA F48970 (original of Klapper and Foster 1993, fig. 15.6). 10-11 – Virgin Hills Formation, Canning Basin, Western Australia; 10 – GSWA F51337 from Horse Spring section 11, Frasnian Zone 11 (original of Klapper 2007, fig. 3.1); 11 – GSWA F51338 from Horse Spring section 11, Frasnian Zone 11 (original of Klapper 2007, fig. 3.2); 12 – GSWA F51339 from Horse Spring section 9, Frasnian Zone 10 (original of Klapper 2007, fig. 3.3). Scale bars equal to 100 μm

per part of the Lower *hassi*, Upper *hassi* and *jamieae* zones as uncorrelated.

Below are considered the taxonomic peculiarities of the Pa-elements of the index species *P. hassi* and *P. jamieae*.

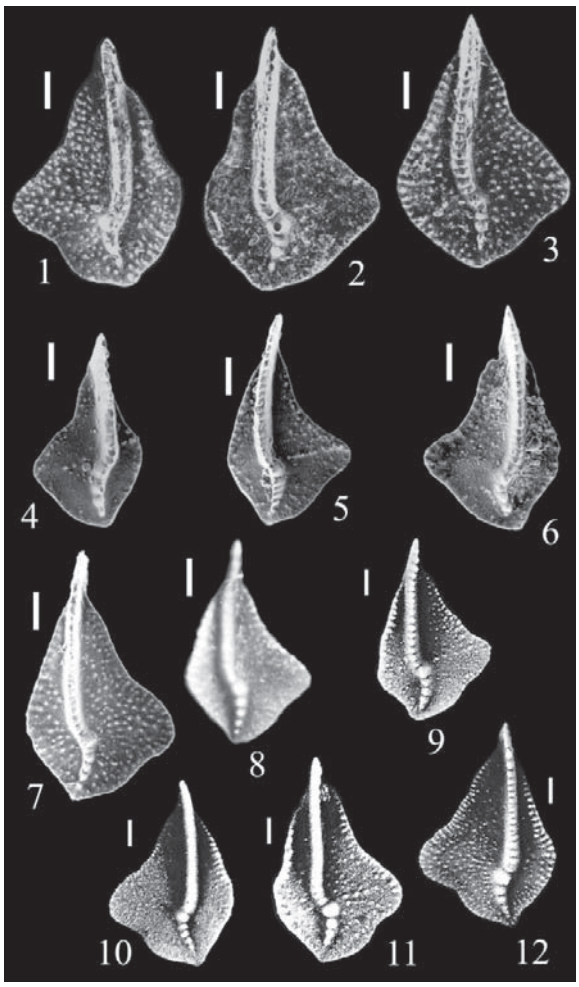
The concept of *Palmatolepis hassi*

Along with the species holotype (Ziegler and Sandberg 1990, pl. 2, fig. 2; Text-fig. 4.1), we also refer to *P. hassi* specimens from the Lower *rhenana* Zone of the quarry sections from the Rhenish Slate Mountains: Benner Bicken (Ziegler and Sandberg 1990, pl. 2, fig. 4; Text-fig. 4.2) and Steinbruch Schmidt (Ziegler and Sandberg 1990, pl. 2, fig. 5; Text-fig. 4.3). The figures of *P. hassi* reported by Ziegler and Sandberg (1990, pl. 2, figs 2–9) testify that they used a broad definition of this species, with all specimens published (Ziegler and Sandberg 1990, pl. 2, figs 3, 6–9) strongly differing from the holotype. The characteristic features of the species include a wide subtriangular platform with a well-pronounced, laterally directed lobe and deep sinuses demarcating the lobe. The platform margin behind the posterior sinus is strongly convex. The early morphs of *P. hassi* were not illustrated by Ziegler and Sandberg (1990) and thus it is impossible to understand whether they belong to *P. hassi* or to another species.

The most prominent representatives of *P. hassi* were published by Klapper and Foster (1993) and Klapper (2007) (Text-fig. 4.8–4.12 herein). According to Klapper (2007), the stratigraphic range of the species was restricted to Frasnian Zones 10–13a. In the TPP, singular specimens of *P. hassi* were found in beds referred to the upper part of the Upper *hassi* Zone (in association TP VIIa), and in larger abundance in associations TP VIIb to TP X (Text-fig. 4.4–4.7).

The concept of *Palmatolepis jamieae*

Ziegler and Sandberg (1990, pl. 6, figs 1–10; pl. 11, fig. 6) used a broad concept of *P. jamieae* that was also reported by Klapper (2007). The holotype of the species (Text-fig. 5.1) and other specimens (Text-fig. 5.2, 5.3) come from the upper part of the Lower *rhenana* Zone of the Steinbruch Schmidt section, Rhenish Slate Mountains (Ziegler and Sandberg 1990, text-fig. 4, bed 23, sample 84-GER-1). The holotype has a distinctly pronounced pear-shaped platform with a relatively short, laterally directed lobe with a well-pronounced posterior sinus. The median ridge (= carina) is straight up to the azygous node and slightly curved in the posterior part of the platform.



Text-fig. 5. Taxonomic concept of *Palmatolepis jamieae* Ziegler and Sandberg, 1990. All figured elements are re-illustrated from the cited papers. 1-3 – from sample 84-GER-1, Steinbruch Schmidt section, Rhenish Slate Mountains, Germany; Lower *rhenana* Zone; 1 – holotype SMF 38708 (original of Ziegler and Sandberg 1990, pl. 6, figs 1–3); 2 – SMF 38714 (original of Ziegler and Sandberg 1990, pl. 6, fig. 9); 3 – SMF 38715 (original of Ziegler and Sandberg 1990, pl. 6, fig. 10). 4-6 – from sample 18, depth 125 m of borehole no. 2023, TPP, Russia; Lyaiol' Formation, unit 4, Upper *rhenana* Zone; 4 – PIN 5255/53 (original of Ovnatanova and Kononova 2008, pl. 10, fig. 16); 5 – PIN 5255/54 (original of Ovnatanova and Kononova 2008, pl. 10, fig. 17); 6 – PIN 5255/55 (original of Ovnatanova and Kononova 2008, pl. 10, fig. 18). 7 – PIN 5255/56; from sample 4, outcrop 1908 along Lyaiol' River, TPP, Russia; Lyaiol' Formation, unit 4, Evlanovian RS (original of Ovnatanova and Kononova 2008, pl. 11, fig. 2). 8 – PIN 5254/21; sample 59, from depth interval 1646–1649 m in Severnyi Kupol borehole no. 71; Tatarstan, VUP, Russia, Evlanovian RS (Ovnatanova and Kononova 2008, pl. 11, fig. 3). 9-12 – from Horse Spring, Canning Basin, Western Australia; Virgin Hills Formation, Frasnian Zone 12; 9 – GSWA F51349, Horse Spring section 43 (original of Klapper 2007, fig. 4.5); 10 – GSWA F51350, Horse Spring section 34 (original of Klapper 2007, fig. 4.6); 11 – GSWA F51350, Horse Spring section 34 (original of Klapper 2007, fig. 4.7); 12 – GSWA F5135; Horse Spring section 45 (original of Klapper 2007, fig. 4.8). Scale bars equal to 100 μm

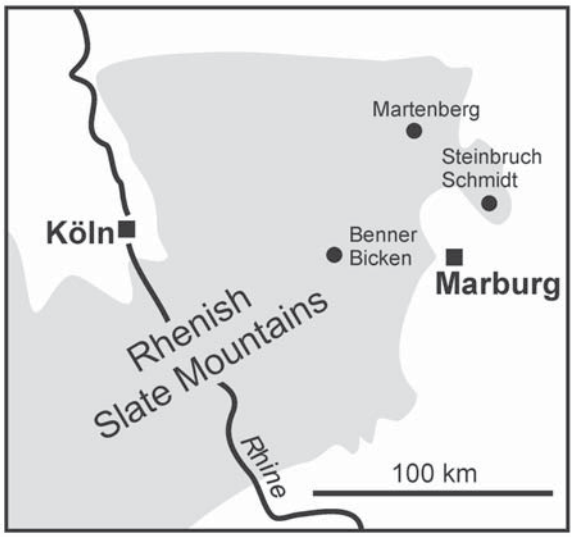
The platform margins are somewhat raised anteriorly and bear small nodes that are especially well-pronounced in mature specimens. Klapper (2007) established two new species, *Palmatolepis feisti* and *P. uyenoi*, and placed into their synonymy several specimens identified as *P. jamieae* in the paper of Ziegler and Sandberg (1990). Specimens of *P. jamieae* from the EEP come from the Askynian RS deposits of the VUP, and units 3 and 4 of the Lyaiol' Formation of South Timan, from strata corresponding to the Upper *rhenana* Zone (Text-fig. 5.4–5.8).

ZONES OF THE STANDARD CONODONT ZONATION IN THE SECTIONS FROM THE RHENISH SLATE MOUNTAINS

Our interest in the analysis and rethinking of the present material is primarily connected with the position of the Lower and Upper *hassi* and *jamieae* zones in the sections of the Rhenish Slate Mountains and the EEP. Recently, the *jamieae* Zone of the EEP has been included into the Domanikian RS of the Southern Urals (Abramova 1999; Artyushkova *et al.* 2011), VUP (Fortunatova *et al*. 2016), and north-eastern European Russia (Savage and Yudina 2001; Tsyganko 2011). In the resolution of the Interdepartmental Stratigraphical Committee, the *punctata*, Lower and Upper *hassi*, and *jamieae* zones were included into the Domanikian RS (Resolution… 2008).

In 1994, we studied the conodont collection from the Frasnian sections of the Rhenish Slate Mountains in the laboratory of Professor W. Ziegler in order to detect and study the polygnathids (Ziegler *et al.* 2000), which usually constitute most of the Frasnian shallow-water conodont associations in the sections of the central part of the EEP (Voronezh Anteclise and Moscow Syneclise). However, some of the peculiarities listed below in the distribution of zonal and characteristic species from the sections of the Rhenish Slate Mountains (Text-fig. 6) have proven worthwhile for the correlation of zonal schemes. Unfortunately, the conodonts were not photographed except for species of *Polygnathus* spp.

The south-western Martenberg VI' (Ma VI') section near Diemelsee-Adorf, Germany is the reference section for the interval of *transitans–jamieae* zones (text-fig. 3 in Ziegler and Sandberg 1990; for location see Text-fig. 6 herein). We have identified conodonts from this section in the interval from the *punctata* Zone to the Upper *rhenana* Zone. *Ancyrodella gigas*, *Ancyrognathus ancyrognathoideus*, *Mesotaxis falsiovalis*, *Palmatolepis punctata*, *P. transitans*,



Text-fig. 6. Location of selected sections in the Rhenish Slate Mountains, Germany. Modified after Ziegler *et al.* (2000)

Polygnathus decorosus, *P. pennatus*, *P. timanicus*, *P. webbi* and *Zieglerina ovalis* were identified in sample 16 in the lower part of the succession. As indicated by Ziegler and Sandberg (1990), this conodont association is typical of the *punctata* Zone. Unfortunately we did not analyse in detail the conodont associations from the overlying deposits assigned to the Lower and Upper *hassi* Zones and only noted that in the beds assigned to the Lower (samples 13–15) and Upper *hassi* zones (samples 10–12) the palmatolepid species include *P. domanicensis*, *P. punctata* and *P. transitans*; in addition, their samples 13–15 contain *Ancyrognathus ancyrognathoideus* and *A. primus*. In beds assigned to the Upper *hassi* Zone, *P. punctata* was found together with *Ancyrognathus tsieni* and *P. proversa*, and probably also *Ancyrognathus iowaensis*, which was possibly previously determined as *A. triangularis* (Ziegler and Sandberg 1990; samples 10 and 12). Single specimens of *P. hassi* and *P. plana* were found only in beds assigned to the uppermost Upper *hassi* Zone (sample 10). The only *Ancyrodella* species is *A. gigas* found in beds assigned to the Lower and Upper *hassi* zones (samples 10–15). Morphs of *A. gigas* were not recorded. Polygnathids are represented by *Polygnathus decorosus*, *P. dubius* and *P. webbi*.

The *jamieae* Zone in the Ma VI' section was initially identified in samples 6–9 (Ziegler and Sandberg 1990). The base of the *jamieae* Zone (sample 9) is characterised by the FO of *Ancyrognathus triangularis*, *Ancyrodella nodosa* and *Palmatolepis ederi*. *Palmatolepis hassi*, *P. plana*, *P. proversa*, and *P. transitans* range upwards from the lower part of the section. The base of the *jamieae* Zone in nearby section Ma VI (sample 11b) is defined by the co-occurrence of *Ancyrognathus triangularis*, *Ancyrodella curvata*, *A. gigas*, *A. nodosa*, *Palmatolepis hassi*, *P. plana* and *P. proversa*. Polygnathids in sample 11b include *Polygnathus decorosus*, *P. dubius*, *P. foliatus*, *P. lodinensis*, *P. politus*, *P. uchtensis* and *P. webbi*. We did not find *P. jamieae* in the collection from section Ma VI', but the specimens of *P. jamieae* from the *jamieae* Zone of section Ma VI (sample 11a) were figured by Ziegler and Sandberg (1990, pl. 6, figs 5–8); in our view, none of the figured specimens represents *P. jamieae*. One of them (Ziegler and Sandberg 1990, pl. 6, fig. 7 only) was later synonymised with *Palmatolepis feisti* (Klapper 2007). *Palmatolepis ederi* was reported from sample 1b of section Ma IV (Ziegler and Sandberg 1990, pl. 10, figs 8–10) and became the base for correlation with the *jamiae* Zone in section Ma VI.

The conodont association of the Lower *rhenana* Zone in section Ma VI' is relatively scarce; samples 3–5 contain *Ancyrodella nodosa*, *Ancyrognathus triangularis*, *Palmatolepis ederi*, *P. hassi*, *P. nasuta* and *P. plana*; *Palmatolepis proversa* was found in beds assigned to the lower part of the zone (sample 5), whereas *P. jamieae* was not encountered. A specimen of *P. jamieae* (Ziegler and Sandberg 1990, pl. 6, fig. 4) from section Ma VI (sample 10c) was later put into the synonymy of *P. feisti* (Klapper 2007). Polygnathids are represented only by *P. lodinensis*.

In conclusion, the conodont associations of the Lower *rhenana* Zone of the Martenberg sections do not differ considerably from the associations of the *jamieae* Zone. The conodont association of the Upper *rhenana* Zone of the Ma VI' section (samples 1 and 2) is characterised by the co-occurrence of *Ancyrodella ioides*, *Palmatolepis foliacea*, *P. hassi*, *P. rhenana* and *P. subrecta* together with *Ancyrodella nodosa* and *Ancyrognathus triangularis*, which also occur in the lower part of the section.

In 1994 we studied conodonts from beds P and Q of section q from north-western Martenberg, Adorf (Ziegler and Sandberg 2000, fig. 2). A sample from the middle of bed Q, 22 cm above the base of a 40 cm thick ledge, yielded *Ancyrodella curvata*, *A. nodosa* and *Ancyrognathus triangularis* together with *Palmatolepis ederi*, *P. hassi P. nasuta* and *P.* sp. B of Klapper and Foster (1986), renamed later as *P. feisti* by Klapper (2007). Other species present in the sample from bed Q include *Palmatolepis kireevae*, *P. ljaschenkoae*, *P. punctata* and *P. transitans*. The identified polygnathids include *Polygnathus lodinensis*,

P. politus, *P. uchtensis* and *P. webbi*. This conodont association, especially the presence of *Ancyrognathus triangularis* and *Palmatolepis ederi*, lead to the attribution of bed Q to the Lower *rhenana* Zone.

The lower part of the 24 cm thick bed P from north-western Martenberg, Adorf (Ziegler and Sandberg 2000, fig. 2) contains *Ancyrodella ioides*, *A. nodosa*, *Ancyrognathus triangularis*, *Palmatolepis brevis*, *P. hassi*, *P. jamieae*, *P. kireevae*, *P. rhenana* and *P. subrecta*. The polygnathids include *Polygnathus lodinensis* and *P. politus*. The presence of *Palmatolepis subrecta* together with single specimens of *Ancyrodella ioides*, *Palmatolepis hassi* and *P. rhenana* indicate the Upper *rhenana* Zone for bed P.

In the following analysis of the Frasnian conodont associations from other sections of the Rhenish Slate Mountains, special attention will be drawn to the interval of the *jamieae* and Lower *rhenana* zones.

We did not find the *jamieae* zonal species in the Benner Bicken section, which is the regional reference section for the Middle and Upper Frasnian deposits of the Dill Syncline, Rhenish Slate Mountains (Ziegler and Sandberg 1990, text-fig. 6). The lower part of the section (samples Bi 58–60) yielded *Ancyrodella gigas*, *Ancyrognathus triangularis*, *A. tsieni*, *Palmatolepis barba*, *P. ederi*, *P. hassi*, *P. luscarensis*, *P. nasuta*, *P. plana* and *P. proversa*. Additionally, *Palmatolepis orbicularis* was also noted in sample Bi 60. The associated polygnathids include *Polygnathus decorosus* and *P. lodinensis*.

Samples Bi 34 to Bi 24 and sample 84-Ger-13 represent the Lower *rhenana* Zone and are characterised by an abundant association including *Ancyrodella gigas*, *A. nodosa*, *Ancyrognathus triangularis*, *A. tsieni*, *Palmatolepis ederi*, *P. nasuta* and *P. proversa*. *Palmatolepis jamieae* was not found in the beds attributed to the lower part of the Lower *rhenana* Zone; its only specimens were found in samples 21–24 attributed to the upper part of the Lower *rhenana* Zone, and in samples 25 and 25a attributed to the Upper *rhenana* Zone. Generally, as in the case of section Ma VI', the discussed conodont association of the Lower *rhenana* Zone does not differ from the conodont association of the *jamieae* Zone.

We have also analysed the collection from the Lower to Upper *rhenana* zones of the Steinbruch Schmidt section in Branau, near Bad Wildungen, Rhenish Slate Mountains (Ziegler and Sandberg 1990, text-fig. 4). The lower part of the section (samples 21–23) is characterised by the presence of *Ancyrodella nodosa*, *Ancyrognathus triangularis*, *Palmatolepis ederi* and *P. hassi*. A specimen of *Palmatolepis semichatovae* was found in sample 21. *Palmatolepis nasuta* was found in sample 23. The polygnathids found in sample 21 are *Polygnathus politus*, *P. krestovnikovi* and *P. lodinensis*. A specimen of *Palmatolepis jamieae* was found in sample 23 from the upper part of the Lower *rhenana* Zone and more specimens came from the higher part of the section, from samples 24/2, 25/4, 26/5, 27/6 and 1/7 representing the Upper *rhenana* Zone. The holotype of *jamieae* comes from a sample attributed to the upper part of the Lower *rhenana* Zone of this section (sample 23). The overlying deposits of the Steinbruch Schmidt section were attributed to the Upper *rhenana* Zone based on the co-occurrence of *Palmatolepis rhenana* (sample 24/2), *P. rotunda* (sample 25/4) and *P. subrecta* (sample 25/4); *P. juntianensis* appears within the Upper *rhenana* Zone (sample 1/7) and is present up to the *linguiformis* Zone (sample 4/11).

Thus, *Palmatolepis jamieae*, used by Ziegler and Sandberg (1990, p. 19) as the marker of the lower boundary of the *jamieae* Zone, appears in stratotype sections distinctly above this boundary. The lowermost finding of the species (represented by the holotype) was made at a level attributed to the upper part of the Lower *rhenana* Zone in the Steinbruch Schmidt section. In the sections of French-Belgian Basin (Bultynck 2007), *P. jamieae* occurs above the last occurrence (LO) of *Palmatolepis semichatovae* and below *P. linguiformis*, i.e., higher than in the Standard Conodont Zonation (Ziegler and Sandberg 1990).

According to Ziegler and Sandberg (1990, p. 19), *Palmatolepis rhenana nasuta* indicates the lower boundary of the Lower *rhenana* Zone; however, as shown above, the only specimens of this species were found both in samples from beds attributed to the *jamieae* and the Lower *rhenana* zones (Ziegler and Sandberg 1990).

These facts, coupled with the similarity of conodont associations found in beds attributed to the *jamieae* and Lower *rhenana* zones in sections from the Rhenish Slate Mountains, testify that the *jamieae* Zone should not be considered as a separate biostratigraphic unit and must be included into the Lower *rhenana* Zone.

Initially, the *jamieae* Zone was defined in section Ma VI' in the interval with samples 6–9 (Ziegler and Sandberg 1990, text-fig. 3). Later, Ziegler and Sandberg (2000, text-fig. 2) referred the same interval of this section to the Lower *rhenana* Zone based on the finding of *Palmatolepis semichatovae* in sample 11b from the base of the earlier established *jamieae* Zone of section Ma VI. *Palmatolepis semichatovae* was also figured by Ziegler and Sandberg (2000, pl. 1, figs 2–3).

CORRELATION OF THE FRASNIAN DEPOSITS OF SOUTH TIMAN WITH THE STANDARD CONODONT ZONATION

A reliable correlation of the Frasnian of South Timan with the Standard Conodont Zonation (Ziegler and Sandberg 1990) is possible from the *transitans* Zone onwards (Text-fig. 7). Deposits with conodont association TP III are correlated with the *transitans* Zone based on the appearance of *Palmatolepis transitans* in the upper part of the Ust'-Yarega Formation. Association TP IV characterises unit 1 and the basal clayey bed of unit 2 of the Domanik Formation (Text-figs 2 and 7); it can be correlated with the *punctata* Zone based on the FO of *Palmatolepis punctata.* Association TP V from unit 2 of the Domanik Formation lacks the zonal species *Palmatolepis hassi* but may be tentatively correlated with the Lower *hassi* Zone based on the appearance of *Ancyrognathus primus* and *Palmatolepis domanicensis.* Association TP VI of the lowermost part of the carbonate unit 3 of the Domanik Formation comprises *Ozarkodina nonaginta* and *Palmatolepis punctata*; deposits yielding conodont association TP VI may be provisionally referred to the Upper *hassi* Zone. The uppermost part of the carbonate unit 3 of the Domanik Formation contains association TP VIIa and may be correlated with the Upper *hassi* Zone based on the presence of *Palmatolepis amplificata*, *P. mucronata* and *P. proversa* together with *P. hassi* and *P. plana*. Association TP VIIb characterises unit 1 of the Lyaiol' Formation (Vetlasyanian RS) and association TP VIII characterises unit 2 and the lowermost part of unit 3 of the Lyaiol' Formation (Sirachoian RS; Text-figs 2 and 7). These associations contain *Ancyrognathus triangularis*, *Palmatolepis ederi*, *P. elegantula*, *P. kozhimensis* and *P. timanensis*; in addition, association TP VIII is also characterised by the FO of *Palmatolepis anzhelae* and *P. semichatovae*. Associations TP VIIb and TP VIII may be correlated with the Lower *rhenana* Zone based on the presence of the listed species. Association TP IX is known from the upper part of unit 3 and the lowermost part of unit 4 of the Lyaiol' Formation (lower part of the Evlanovian RS; Text-figs 2 and 7) and is characterised by the FO of *Palmatolepis foliacea*, *P. gyrata* and *P. subrecta*. The presence of *P. foliacea* and *P. subrecta* allows for the correlation of these deposits with the lower part of the Upper *rhenana* Zone. The FO of *Palmatolepis juntianensis* and *P. rotunda* (= *P. bogardensis*) in the uppermost part of unit 4 of the Lyaiol' Formation, as well as in the bed overlying the clay sequences of the Sed'yu Formation (with the Upper Evlanovian spore assemblage) allows us to assign these beds to association TP X (Ovnatanova *et al.* 1999a, b; Ovnatanova and Kononova 2008). Association TP X is referred to the upper part of the Upper *rhenana* Zone based on

<table>
<tr><th colspan="2">regional stage</th><th>formation</th><th>unit</th><th rowspan="2">TP conodont associations</th><th rowspan="2">Standard Conodont Zonation</th><th rowspan="2">Frasnian Zonation</th></tr>
<tr><th>VUP</th><th colspan="3">SOUTH TIMAN</th></tr>
<tr><td rowspan="5">Askynian</td><td>Livnian</td><td></td><td rowspan="2"></td><td>TP XI</td><td>linguiformis</td><td>13b</td></tr>
<tr><td rowspan="3">Evlanovian</td><td>Sed'yu</td><td rowspan="3">TP X</td><td rowspan="3">Upper rhenana</td><td rowspan="3">13a</td></tr>
<tr><td rowspan="4">Lyaiol'</td><td>4</td></tr>
<tr><td rowspan="2">TP IX</td><td rowspan="2">12</td></tr>
<tr><td rowspan="3">Mendymian</td><td rowspan="2">Sirachoian</td><td>3</td></tr>
<tr><td>2</td><td>TP VIII</td><td rowspan="2">Lower rhenana</td><td rowspan="2">11</td></tr>
<tr><td>Vetlasyanian</td><td>1</td><td>TP VIIb</td></tr>
<tr><td colspan="2" rowspan="4">Domanikian</td><td rowspan="4">Domanik</td><td rowspan="2">3</td><td rowspan="2">TP VIIa</td><td rowspan="3">Upper hassi</td><td>10</td></tr>
<tr><td>9</td></tr>
<tr><td rowspan="2">TP VI</td><td>8</td></tr>
<tr><td>2</td><td>TP V</td><td>Lower hassi</td><td>7</td></tr>
<tr><td colspan="2">Sargaevian (upper part)</td><td>Ust'-Yarega</td><td>1</td><td>TP IV</td><td>punctata</td><td>6</td></tr>
<tr><td colspan="2">Sargaevian (upper part)</td><td>Ust'-Yarega</td><td>u</td><td>TP III</td><td>transitans</td><td>5</td></tr>
</table>

Text-fig. 7. Correlation of the South Timan and VUP regional stages and formations, and Timan-Pechora conodont associations (TP III–TP XI) with the Standard Conodont Zonation of Ziegler and Sandberg (1990), and the Frasnian Zonation of Klapper (1989) and Klapper and Kirchgasser (2016)

the presence of *Palmatolepis juntianensis* and *P. rotunda*. Association TP XI corresponds to the Livnian RS judging from the association of conodonts and spores (Text-figs 2 and 7). Its composition is known from the sections to the east of the Ukhta region (Kuz'min *et al.* 1998), which are composed mainly of the basinal domanikoid deposits with *Palmatolepis linguiformis*, *P. rhenana* and *P. subrecta*. These deposits are attributed to the *linguiformis* Zone based on the presence of *P. linguiformis*.

CORRELATION OF THE FRASNIAN DEPOSITS OF SOUTH TIMAN WITH THE FRASNIAN ZONATION OF KLAPPER

The well-known Frasnian Zonation of Klapper (1989) was initially based on the study of twelve sections in Montagne Noire in southern France. It is based on the morphological analysis of Pa-elements, multielement taxonomy, visual differences of the species of *Palmatolepis* and other genera, and on graphic correlation.

The bases of zones in the Frasnian Zonation of Klapper are defined by the FO of species of *Palmatolepis* and other genera, such as *Ancyrodella*, *Ancyrognathus* and *Ozarkodina* according to the Frasnian composite standard elaborated by means of graphic correlation (Klapper 1997). The wide replication of the zonation first elaborated in Montagne Noire was demonstrated valid for numerous sections of the world including European Russia, North America and Western Australia (Klapper *et al.* 1995, 1996; Becker *et al.* 2000; Gouwy and Bultynck 2000; House *et al.* 2000). As this zonation is applicable worldwide, the term was later changed for the Frasnian Zonation (Klapper and Kirchgasser 2016). The scheme includes sixteen zones, from 1 to 16c.

Correlation between the TP conodont associations and the Frasnian Zonation of Klapper (Text-fig. 7) is possible from Frasnian Zone 4 onwards, because the index taxa of Frasnian Zones 1–3 are representatives of *Ancyrodella* spp., which are almost absent in the shallow-water sections of the EEP. Earlier, the correlation between the TP conodont associations and the Frasnian Zonation was proposed by Ovnatanova *et al.* (1999a, b), Becker *et al.* (2000), House *et al.* (2000), and Ovnatanova and Kononova (2008, p. 1055).

Association TP III characterises deposits of the upper part of the Ust'-Yarega Formation and is correlated with Frasnian Zone 4 based on the appearance of *Mesotaxis bogoslovskyi* and *Palmatolepis transitans*. Association TP IV characterises unit 1 and the lowermost unit 2 of the Domanik Formation (basal clayey layer) and is correlated with Frasnian Zone 5 based on the FO of *Palmatolepis punctata* co-occurring with *Ancyrodella gigas*, *Mesotaxis johnsoni*, *Polygnathus timanicus* and *P. vjalovi*. Association TP V (unit 2 of the Domanik Formation excluding the basal clayey layer) may be correlated with Frasnian Zone 6 based on the appearance of *Ancyrognathus primus*, *Ozarkodina trepta*, *Palmatolepis bohemica*, *P. domanicensis* and *P. spinata*. Association TP VI is known from samples coming from the uppermost part of outcrop 11 (= 21 of Yudina and Moskalenko 1997) along the Domanik River, 0.5 km from the river mouth (Text-fig. 1C), where *Ozarkodina nonaginta* and *Palmatolepis punctata* were found. These exposures apparently represent the lowermost part of domanikoid unit 3. *Ozarkodina nonaginta* is also known from the upper part of unit 3 of the Domanik Formation in borehole no. 2068 (Klapper *et al.* 1996; Text-fig. 1B). The lowermost part of unit 3 of the Domanik Formation with association TP VI is referred to Frasnian Zone 7. Association TP VIIa is known from the upper carbonate bed near the top of the Domanik Formation in outcrop 13 on the left bank of Ukhta River, upstream of Shudayag settlement, near the water-intake (Text-fig. 1C), and contains *Ancyrognathus amplicavus*, *Ozarkodina nonaginta*, *Palmatolepis amplificata*, *P. mucronata*, *P. orbicularis* and *P.* aff. *proversa*. The zonal species of the Frasnian Zonation of Klapper is absent and thus the zone cannot be determined.

The conodont association from the overlying part of this upper carbonate bed of the Domanik Formation (outcrop 13; Text-fig. 1C) including *Palmatolepis hassi*, *P. plana* and *P. proversa* was found at the very top of the bed. These species indicate Frasnian Zones 9 and 10 in the upper carbonate Domanik unit. The presence of Frasnian Zone 8 remains uncertain. It is tentatively placed in Text-fig. 7 between Frasnian zones 7 and 9. The position of Zone 10 is determined by the findings of *Palmatolepis hassi* and *P. plana* at the top of the carbonate Domanik unit. The zonal boundaries in the interval encompassing deposits attributable to Frasnian Zones 7–10 cannot be determined definitely due to the scarcity of material but the interval of the Domanikian RS (with TP associations IV to VIIa) definitely corresponds to the interval encompassing Frasnian Zones 5 to 10 (Text-fig. 7).

Association TP VIIb (Vetlasyanian RS, unit 1 of the Lyaiol' Formation; Text-figs 2 and 7) is characterised by the FO of *Ancyrognathus triangularis*, *Palmatolepis ederi*, *P. elegantula*, *P. kozhimen-*

sis, *P. müelleri*, *P. timanensis* and *Polygnathus krestovnikovi*. All of these species range upwards to association TP VIII (Sirachoian RS, unit 2 and lower part of unit 3 of the Lyaiol' Formation; Text-figs 2, 3 and 7); in addition, *Palmatolepis semichatovae* appears in unit 2 of the Lyaiol' Formation. Associations TP VIIb and TP VIII may be correlated with Frasnian Zone 11. Association TP IX characterises the upper part of unit 3 and the lower part of unit 4 of the Lyaiol' Formation (lower part of the Evlanovian RS) and may be correlated with Frasnian Zone 12 based on the FO of *Palmatolepis foliacea*, *P. gyrata* and *P. subrecta*. Association TP X is characterised by the FO of *Palmatolepis rotunda* (= *P. bogartensis*) and *P. juntianensis* in the uppermost part of unit 4 of the Lyaiol' Formation (upper Evlanovian RS). This association corresponds to Frasnian Zone 13a based on the FO of the zonal species *Palmatolepis bogartensis* (Klapper and Kirschgasser 2016). The overlying association TP XI was found in sections of the Tebuk-Viss region located to the east of the Ukhta region (Kuz'min *et al.* 1998; Text-fig. 1A). Borehole samples of basinal facies representing the Livnian RS include *Ancyrodella ioides*, *Palmatolepis boogardi*, *P. linguiformis* and *P. rhenana*. Association TP XI may be correlated with Frasnian Zone 13b based on the FO of the zonal species *Palmatolepis linguiformis* (Klapper and Kirschgasser 2016).

CORRELATION OF THE STANDARD CONODONT ZONATION WITH THE FRASNIAN ZONATION OF KLAPPER

The Montagne Noire zonation (former name of the Frasnian Zonation of Klapper 1989) was first correlated with the Standard Conodont Zonation after the study of the reference section in northern Martenberg, Rhenish Slate Mountains by Klapper and Becker (1999), who sampled it for conodonts in order to identify zones distinguished in the Montagne Noire. The zones identified in the northern Martenberg section (Klapper and Becker 1999) were correlated with the zones of the Standard Conodont Zonation in the south-western Martenberg section, which is the key section for the interval encompassing the *transitans* to Lower *rhenana* zones (Ziegler and Sandberg 1990). In addition, Klapper and Becker (1999) studied also samples from the Upper *rhenana* and *linguiformis* zones of the Martenberg and Steinbruch Schmidt sections.

The correlation of the two existing Frasnian zonations is justified on the basis of the studied conodont associations from sections of the Rhenish Slate Mountains, the sequence of entries of zonal and characteristic species in sections of the Montagne Noire (Klapper 1989, 1990; Klapper and Kirchgasser 2016), and correlation of TP conodont associations with the Frasnian conodont associations of the Standard Conodont Zonation and the Frasnian Zonation of Klapper (Text-fig. 7).

The correspondence of the *transitans* Zone and Frasnian Zone 4 is considered justified as the FO of *Palmatolepis transitans* defines the base of both zones. *Palmatolepis transitans* enters at the base of conodont association TP III. The correspondence of the *punctata* Zone and Frasnian Zone 5 is similarly proved correct, as the FO of *Palmatolepis punctata* defines also the base of conodont association TP IV. Although the zonal species *Palmatolepis hassi* is absent in the Standard Conodont Zonation, the correspondence of the Lower *hassi* Zone with Frasnian Zone 6 is confirmed by the co-occurrence of *Ancyrognathus primus* and *Palmatolepis domanicensis*; these two species also appear in association TP V in unit 2 of the Domanik Formation together with *Palmatolepis bohemica* and *P. spinata*. Association TP VI was found in a few localities in the lowermost part of unit 3 of the Domanik Formation and comprises *Ozarkodina nonaginta* and *Palmatolepis punctata*. It is correlated with Frasnian Zone 7 based on the presence of the zonal species *Ozarkodina nonaginta* and tentatively referred to the Upper *hassi* Zone. The Upper *hassi* Zone in section Ma VI' in the Rhenish Slate Mountains (samples 10–12 in text-fig. 3 of Ziegler and Sandberg 1990) is characterised by *Palmatolepis punctata* in association with *Ancyrognathus iowaensis*, *A. tsieni* and *Palmatolepis proversa*. Presumably it corresponds to Frasnian Zones 8 and 9. The uppermost part of the Upper *hassi* Zone is correlated with Frasnian Zone 10 based on the FO of *Palmatolepis hassi* and *P. plana* in sample 10 from section Ma VI' (Ziegler and Sandberg 1990, text-fig. 3).

We identify the lower part of the Lower *rhenana* Zone in South Timan by the FO of *Ancyrognathus triangularis*, *Palmatolepis ederi*, *P. elegantula*, *P. semichatovae* and *P. timanensis* in association with *Palmatolepis amplificata*, *P. hassi*, *P. mucronata* and *P. plana*. The Lower *rhenana* Zone is correlated with Frasnian Zone 11 by the FO of *Ancyrognathus triangularis* and *Palmatolepis semichatovae*. This correlation is also confirmed by the composition of association TP VIIb in unit 1 of the Lyaiol' Formation (Vetlasyanian RS) and association TP VIII of unit 2 and lowermost part of unit 3 of the Lyaiol' Formation (Sirachoian RS).

The Upper *rhenana* Zone is identified by the FO of *Palmatolepis foliacea* and *P. subrecta* and may be correlated with Frasnian Zone 12. This correlation is confirmed by the FO of *Palmatolepis foliacea*, *P. gyrata* and *P. subrecta* in association TP IX, which characterises most of unit 3 and the clayey-carbonate lower part of unit 4 of the Lyaiol' Formation (lower Evlanovian RS). Association TP X (upper Evlanovian RS) may be probably attributed to the upper part of the Upper *rhenana* Zone by the FO of *Palmatolepis juntianensis* and *P. rotunda* and the presence of *Palmatolepis hassi*, *P. jamieae*, *P. orlovi*, *P. subrecta* and other species. Frasnian Zone 13a is indicated by the presence of *Palmatolepis juntianensis* and may be correlated with the upper part of the Upper *rhenana* Zone (upper part of the Evlanovian RS). The uppermost conodont association TP XI corresponds to the Livnian RS (*linguiformis* Zone) and is known from sections composed of basinal facies in the TPP; in the VUP, it characterises the upper part of the Askynian RS (Ovnatanova and Kononova 2008). Association TP XI can be correlated with the base of Frasnian Zone 13b based on the FO of *Palmatolepis linguiformis*.

CONCLUSIONS

A correlation of the Standard Conodont Zonation (Ziegler and Sandberg 1990) and the Frasnian Zonation of Klapper (1989; Klapper and Kirchgasser 2016) is proposed based on the analysis of conodont associations from South Timan, their correlation with the Standard Conodont Zonation and the Frasnian Zonation, and the analysis of collections of Willi Ziegler from sections in the Rhenish Slate Mountains, Germany, especially from the interval encompassing the *jamieae* to Lower *rhenana* zones. The non-validity of the *jamieae* Zone as a separate stratigraphic unit is proved. The composition and stratigraphic position of association TP VIIb (Vetlasyanian RS, unit 1 of the Lyaiol' Formation) is clarified and the correlation of the Frasnian deposits of the East European Platform with the existing zonal schemes is revised (Text-fig. 7). We prove that the Domanik Formation encompasses the *punctata* to *hassi* zones, and zones 5–10 of the Frasnian Zonation. Due to extremely limited material, the position of the upper boundary of the *Ancyrognathus ancyrognathoideus–Palmatolepis orbicularis* local zone remains unresolved (Text-fig. 2). It cannot be excluded that in the future this zone may turn out to be limited only to unit 2 of the Domanik Formation.

The overlying deposits of the Domanik Formation are characterised by the FO of *Ozarkodina nonaginta* at the base of unit 3, along with a few representatives of *Ancyrognathus amplicavus*, *Palmatolepis* aff. *proversa*, *P. proversa* and *P. hassi*, subsequently appearing in unit 3 of the Domanik Formation, as well as *Palmatolepis amplificata* and *P. mucronata*, which suggest correspondence with zones 7–10 of the Frasnian Zonation. However, the boundaries of zones 7–9 in South Timan need to be clarified in the future.

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APPENDIX

Alphabetical list of conodont species mentioned in the paper.

Ancyrodella alata Glenister and Klapper, 1966
Ancyrodella curvata (Branson and Mehl, 1934)
Ancyrodella gigas Youngquist, 1947
Ancyrodella ioides Ziegler, 1958
Ancyrodella nodosa Ulrich and Bassler, 1926
Ancyrodella rotundiloba (Bryant, 1921)
Ancyrodella rugosa Branson and Mehl, 1934
Ancyrognathus amplicavus Klapper, Kuz'min and Ovnatanova, 1996
Ancyrognathus ancyrognathoideus Ziegler, 1958
Ancyrognathus iowaensis Youngquist, 1947
Ancyrognathus primus Ji, 1986
Ancyrognathus triangularis Youngquist, 1946
Ancyrognathus tsieni Mouravieff, 1982
Mesotaxis asymmetrica (Bischoff and Ziegler, 1957)
Mesotaxis bogoslovskyi Ovnatanova and Kuz'min, 1991
Mesotaxis falsiovalis Sandberg, Ziegler and Bultynck, 1989
Mesotaxis johnsoni Klapper, Kuz'min and Ovnatanova, 1996
Ozarkodina nonaginta Klapper, Kuz'min and Ovnatanova, 1996
Ozarkodina trepta Ziegler, 1958
Palmatolepis amplificata Klapper, Kuz'min and Ovnatanova, 1996
Palmatolepis anzhelae Khrustcheva and Kuz'min, 1996
Palmatolepis barba Ziegler and Sandberg, 1990
Palmatolepis bogartensis (Stauffer, 1938)
Palmatolepis bohemica Klapper and Foster, 1993
Palmatolepis boogardi Klapper and Foster, 1993
Palmatolepis brevis Ziegler and Sandberg, 1990
Palmatolepis domanicensis Ovnatanova, 1970
Palmatolepis ederi Ziegler and Sandberg, 1990
Palmatolepis elegantula Wang and Ziegler, 1987
Palmatolepis feisti Klapper, 2007
Palmatolepis foliacea Youngquist, 1945
Palmatolepis gutta Kuz'min, 1998
Palmatolepis gyrata Kuz'min and Melnikova, 1991
Palmatolepis hassi Müller and Müller, 1957
Palmatolepis jamiae Ziegler and Sandberg, 1990
Palmatolepis juntianensis Han, 1987
Palmatolepis kireevae Ovnatanova, 1976
Palmatolepis kozhimensis Savage and Yudina, 2001 (= *Palmatolepis menneri* Ovnatanova and Kononova, 2008)
Palmatolepis linguiformis Müller, 1956
Palmatolepis ljaschenkoae Ovnatanova, 1976
Palmatolepis luscarensis Klapper and Foster, 1993
Palmatolepis menneri Ovnatanova and Kononova, 2008
Palmatolepis mucronata Klapper, Kuz'min and Ovnatanova, 1996
Palmatolepis müelleri Klapper and Foster, 1993
Palmatolepis nasuta Müller, 1956
Palmatolepis orbicularis Ovnatanova and Kuz'min, 1991
Palmatolepis orlovi Khrustcheva and Kuz'min, 1996
Palmatolepis ormistoni Klapper, Kuz'min and Ovnatanova, 1996
Palmatolepis plana Ziegler and Sandberg, 1990
Palmatolepis proversa Ziegler, 1958
Palmatolepis punctata (Hinde, 1879)
Palmatolepis rhenana Bischoff, 1956
Palmatolepis rotunda Ziegler and Sandberg, 1990
Palmatolepis semichatovae Ovnatanova, 1976
Palmatolepis spinata Ovnatanova and Kuz'min, 1991
Palmatolepis subrecta Miller and Youngquist, 1947
Palmatolepis timanensis Klapper, Kuz'min and Ovnatanova, 1996
Palmatolepis transitans Müller, 1956
Palmatolepis uyenoi Klapper, 2007
Palmatolepis winchelli (Stauffer, 1938)
Playfordia primitiva (Bischoff and Ziegler, 1957)
Polygnathus decorosus Stauffer, 1938,
Polygnathus dubius Hinde, 1879
Polygnathus foliatus Bryant, 1921
Polygnathus krestovnikovi Ovnatanova, 1986
Polygnathus lodinensis Pölsler, 1969
Polygnathus pennatus Hinde, 1879
Polygnathus politus Ovnatanova, 1969
Polygnathus timanicus Ovnatanova, 1969
Polygnathus uchtensis Ovnatanova and Kuz'min, 1991
Polygnathus vjalovi Zvereva, 1986
Polygnathus webbi Stauffer, 1938
Zieglerina ovalis (Ziegler and Klapper, 1964)