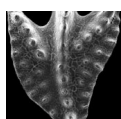


Conodont biodiversity of the Frasnian-Famennian boundary interval (Upper Devonian) in the Southern Urals

REZEDA C. TAGARIEVA



In the sections of the West Uralian Folded Zone (western slope of the South Urals) the boundary between the Frasnian and Famennian (F/F) runs at the bottom of the Barma Horizon. It is established within a lithologically homogeneous brachiopod coquina by simultaneous appearance of the conodont *Palmatolepis triangularis* Sann. and brachiopod *Parapugnax markovskii* (Yud.). The brachiopod shell stone of the F/F boundary interval subdivided into the Upper *rhenana*, *linguiformis*, Lower–Middle *triangularis* zones are thoroughly characterized by means of conodonts. In the upper *linguiformis* Zone at the top of the Frasnian, all the sections show a replacement of the palmatolepid biofacies with its abundant taxa of the genus *Palmatolepis* by the extremely poor, practically monotaxon icriodid biofacies. This is probably due to changes in the global sea levels and the Mass Extinction Event (Upper Kellwasser Event) at the F/F boundary. • Key words: South Urals, boundary F/F interval, brachiopod coquina, conodonts, brachiopods, biofacies.

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Rezeda C. Tagarieva, Russian Academy of Sciences, Ufa Research Centre, Institute of Geology, Karl Marx Street 16/2, Ufa 450000, Russia; stpal@ufaras.ru

The Upper Devonian of the West Uralian Folded Zone (western slope of the South Urals) is subdivided into the Frasnian and Famennian. The Frasnian is represented by the Sargai, Domanik, Mendym and Askyn horizons (Antsygin *et al.* 1993). The Famennian includes the Barma beds and also the Makarovo, Murzakaev, Kushelga and Lytva horizons. In many sections (Gabyuk, Mendym, Zigan and others) there are gaps at the F/F boundary (Abramova 1999, Abramova & Artyushkova 2004, Veimarn *et al.* 2004). The duration of the gaps ranges from one zone to several conodont zones. An individual peculiarity of a number of sections (Bol'shaya Barma, Akkyr, Ryauzyak, Kuk-Karauk and Kuktash) is the development of thin (up to 2.1 m) brachiopod shell limestones within the boundary F/F interval characterized by a continuous conodont succession (see Fig. 1). In these shell rocks the F/F boundary lithologically is unrecognized and determined only by the replacement of conodont and brachiopod assemblages. Faunistically the lower part of the coquinas belongs to the Askyn Horizon of the Frasnian and has a small thickness in all the sections from 0.15 m to 0.35 m. The thicker upper part of the shell limestones (0.45–1.78 m) belongs to the Barma beds of the Famennian.

Investigation history of the F/F boundary on the western slope of the South Urals

The Barma beds were first described by D.V. Nalivkin as the brachiopod limestones with *Rhynchonella* (*Pugnax*) *triaequalis* Goss. at the base of the Famennian Stage (Nalivkin 1926; Fig. 2). They were named after the Bol'shaya Barma River on the western slope of the South Urals (Nalivkin 1931). In 1934–1937 the detailed investigations on Devonian deposits of the Middle and South Urals were carried out by Markovsky (1948). He concluded that the Barma beds should be attributed to the uppermost Askyn Horizon of the Frasnian and represent a brachiopod facies of the upper part of the beds with *Hypothyridina cuboides* Sow. (see Fig. 2). Domrachev (1952) emphasized the necessity of separating the Barma beds as an individual stratum straton within the top of the Frasnian Stage. He considered the Barma beds to be a typical horizon of regional significance for the Urals. This viewpoint was reflected in subsequent stratigraphic schemes of the Urals (Khodalevich 1968, Breyvel *et al.* 1980; see Fig. 2).

The very first data on conodonts from the Upper Devonian deposits of the western slope of the South Urals were gained in the late 1980s (Abramova 1999). In all the

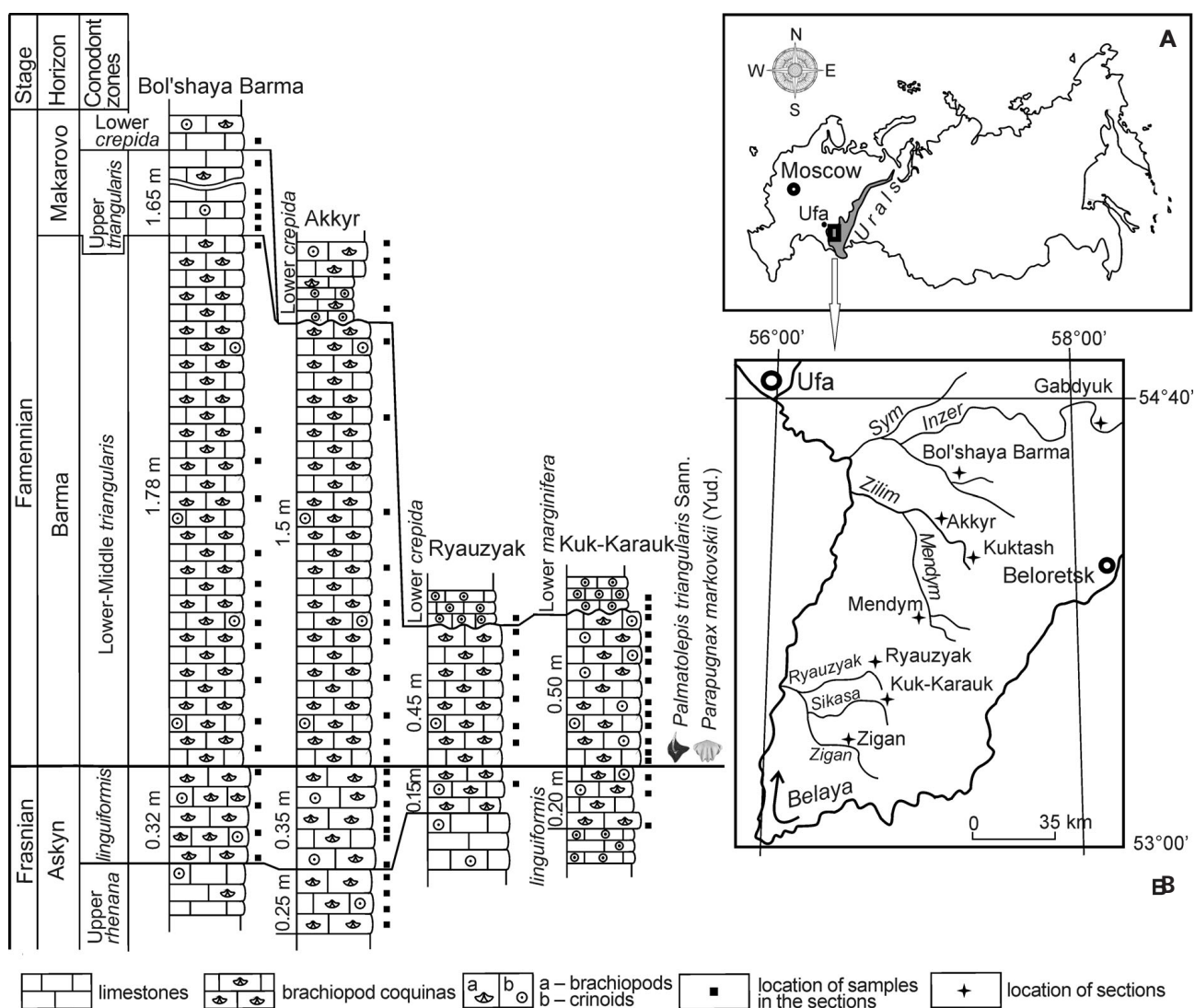


Figure 1. Correlation of sections of the Frasnian-Famennian boundary deposits in the West Uralian Folded Zone (western slope of South Urals).
 • A – sketch map with the location of the studied area in Russia; B – location of the sections.

sections where the F/F interval consists of brachiopod shell limestones in the form of continuous sequences, A.N. Abramova revealed the simultaneous occurrence emergence of the conodont *Palmatolepis triangularis* Sann. and brachiopod *Parapugnax markovskii* (Yud.) (= *Pugnoides triaequalis* Goss.), the guide fossils for the Barma beds (Abramova 1999, Abramova & Artyushkova 2004). Therefore, the F/F boundary was established at the bottom of the Barma beds in the stratigraphic scheme accepted by the 4th Ural Stratigraphic Conference (Antsygin *et al.* 1993; see Fig. 2).

The A.N. Abramova's brachiopod collection from the F/F boundary interval from sections of Bol'shaya Barma and Akkyr was reviewed Mizens (2007, 2009). At a time the brachiopod shells from these sections were studied for C-isotope analysis (Izokh & Mizens 2009). The simulta-

neous appearance of *Palmatolepis triangularis* Sann. and *Parapugnax markovskii* (Yud.) corresponded with the positive excursions $\delta^{13}\text{C}$ curve were fixed at the base of the Barma Beds in the Bol'shaya Barma section. Whereas the first occurrence of *Parapugnax markovskii* (Yud.) and higher $\delta^{13}\text{C}$ values in the Akkyr section were marked below the F/F boundary (according to A.N. Abramova's subdivision), *i.e.*, prior to the appearance of *Palmatolepis triangularis* Sann. (Fig. 3). On the basis of these data A.G. Mizens concluded that the lower part of the Barma beds (about 0.10 m) belongs to the Askyn Horizon of the Frasnian.

In order to solve this contradiction in interpreting the stratigraphic framework of the Barma beds and accordingly the location of the F/F boundary, during 2009 and 2010 additional investigations have been conducted on the

System	Series	Stage	Standard conodont zonation	D.V. Nalivkin (1926, 1931)	B.P. Markovsky (1948)	Khodalevich (1968), Breyvel et al. (1980)	Antsygin et al. (1993)	Abramova (1992) Zhamoyda (2008)
					Beds	Horizon	Horizon	Horizon
Devonian	Upper	Famennian	<i>praesulcata</i>		Ziganian	Kushelga	Lytva	Lytva
			<i>expansa</i>				Abiyuskanian beds	
			<i>postera</i>				Kushelga	Kushelga
			<i>trachytera</i>		Murzakai or beds with <i>Leiorhynchus ursus</i> Nal.	Murzakai	Murzakai	Murzakai
			<i>marginifera</i>		Makarovo or beds with <i>Leiorhynchus polonicus</i> Gür. (= <i>Zilimia polonica</i>)	Makarovo	Makarovo	Makarovo
			<i>rhomboidea</i>					
			<i>crepida</i>					
			<i>triangularis</i>		Beds with <i>Pugnoides triaequalis</i> Goss.	Barma	Barma beds	Barma
		Frasnian	<i>linguiformis</i>	Beds with <i>Hypothyridina cuboides</i> Sow.	Beds with <i>Hypothyridina cuboides</i> Sow.	Askyn	Askyn	Askyn
			<i>rhenana</i>		Mendym	Mendym	Mendym	Mendym
			<i>jamieae</i>		Domanik	Domanik	Domanik	Domanik
			<i>hassi</i>					
			<i>punctata</i>					
			<i>transitans</i>		"Sub-Domanik" or Sargai beds with <i>Hypothyridina calva</i> Mark.	Sargai	Sargai	Sargai
			<i>falsiovalis</i>			Kyn	Kyn	Kyn
	Mid	Giv.						

Figure 2. Investigation history of the F/F boundary on the western slope of the South Urals.

controversial interval with centimetre by centimetre sampling for conodonts. The A.N. Abramova original field materials, and the conodont collection studied by V.N. Baryshev in the 1980's were re-examined. It was found out that the interval 0.25 m thick in which sample 7123 was collected (see Fig. 3) corresponds in fact to the uppermost part of the *linguiformis* Zone (0.17 m) whereas the upper part of the interval 0.08 m thick is already of Famennian age (Tagarieva 2011). It is precisely in this interval that the first *Parapugnax markovskii* (Yud.) make their appearance.

Sharing the opinions of previous authors, it sounds reasonable to rank the Barma beds as a biostratigraphic horizon. This is actually a faunistically recognizable independent stratum characterizing a definite stratigraphic interval within the scope of the conodont Lower–Middle *triangularis* zones (Abramova 1992, Baryshev & Abramova 1996, Abramova & Artyushkova 2004, Artyushkova *et al.* 2011b).

Material and methods

Stone material from the Frasnian/Famennian boundary interval was collected during field works of 2009–2011 from four sections (Bol'shaya Barma, Akkyr, Ryauzyak and Kuk-Karauk). Investigations of the sections were performed

in the most detailed way with centimetre-by-centimetre simultaneous sampling for conodonts and brachiopods. A total of more than 60 samples were collected. The weight of each sample did not exceed 1.5 kg. Brachiopods were separated first before the laboratory treatment of the samples. The rest of the rock (0.3 kg on the average) was used for separating conodonts. To do this a 3–5 percent solution of formic acid was used. All the samples under investigation, despite their small weight, yielded conodont remains. The collection includes about 4133 platform elements belonging to 57 species of seven genera. The collections stored in the Laboratory of Paleozoic Stratigraphy, Institute of Geology, Ufa Research Centre, Russian Academy of Sciences. Conodont photographs were made by means of scanning electron microscopy in the A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences (Novosibirsk) and in the A.A. Borisyak Paleontological Institute of the Russian Academy of Sciences (Moscow).

Brief description of lithology and conodont distribution of the F/F boundary interval in the sections

In the sections that have been studied on the western slope of the South Urals Upper Frasnian and Lower Famennian

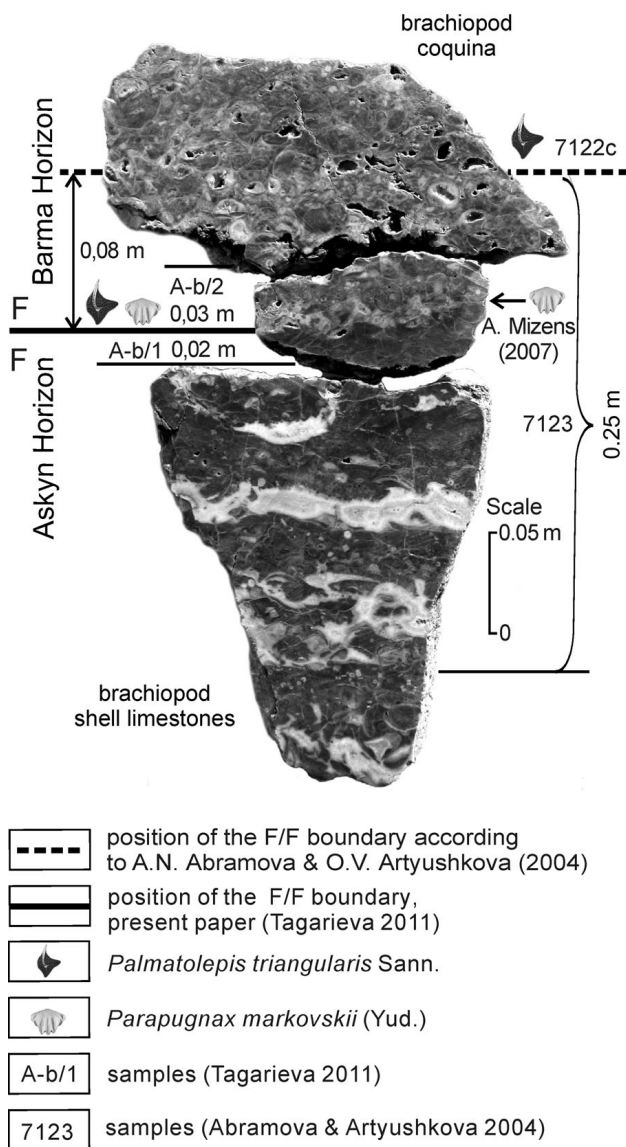


Figure 3. Polished slab of a brachiopod shell limestones from the F/F boundary interval, the Akkyr section.

deposits are characterized by relatively deep shelf facies (Abramova & Artyushkova 2004). A detailed investigation on the Frasnian deposits of the upper Askyn Horizon, and on the Famennian Barma and Makarovo horizons has been carried out.

The Askyn Horizon is usually represented by light-grey and white massive and thick-layered organogenic limestones with abundant brachiopods that form coquinas at some places. The overlying shell limestones of the Barma Horizon of the Famennian occur with a gradational transition. They consist of light-grey limestones overfilled with brachiopods. Above the Barma Horizon the fossil record succession interrupts in most of the sections. For this reason the lower part of the Makarovo deposits is absent from many sections. The Makarovo rocks are light-grey and

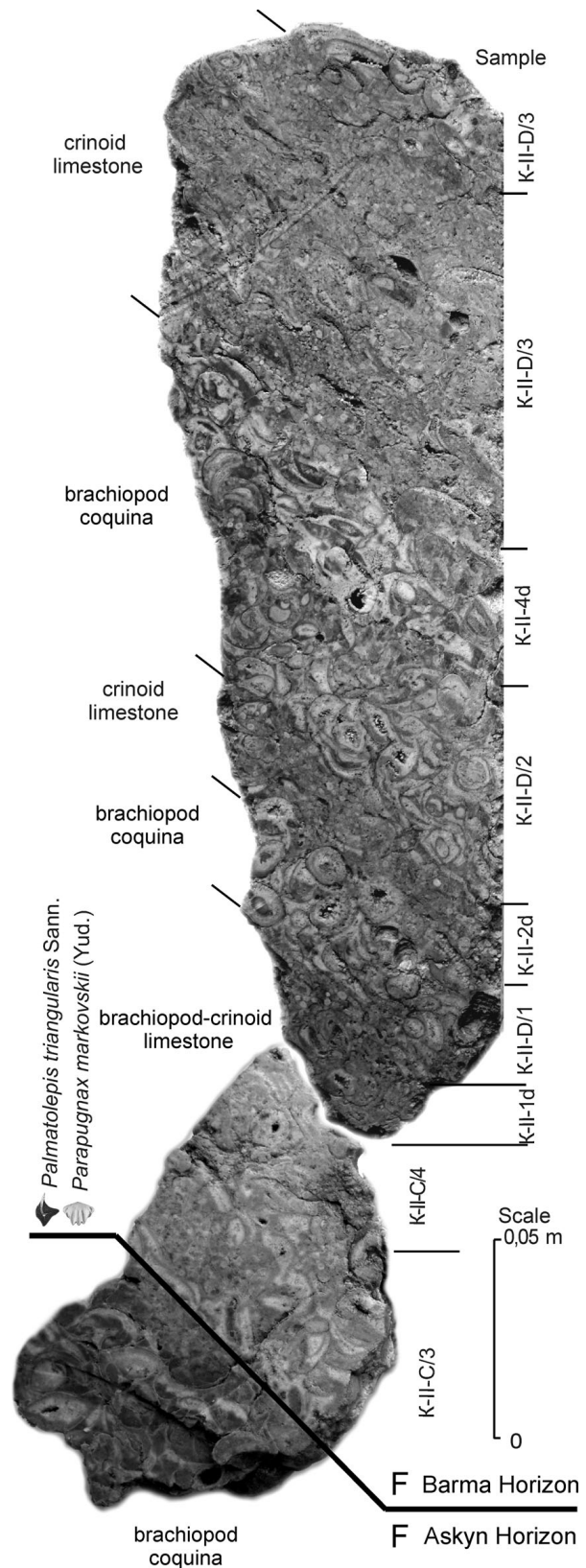


Figure 4. Polished slab of a brachiopod shell stones from the F/F boundary interval, the Kuk-Karauk section. Alternation of beds rich in crinoid detritus and brachiopod varieties in Barma limestones.

Table 1. Numerical distribution of conodont taxa in samples from the Bol'shaya Barma section. For the position of samples in the section see Fig. 1. The samples of the Barma brachiopod coquina yield a conodont assemblage that contains, together with Famennian conodonts, Frasnian species of the genus *Palmatolepis*, which are found in Askyn Horizon (inside the oval). The following abbreviations for conodont genera and species are used throughout the tables and the text paper: *Ad.* – *Ancyrodella*; *Anc.* – *Ancyrognathus*; *B.* – *Belodella*; *Ic.* – *Icriodus*; *Pa.* – *Palmatolepis*; *Pol.* – *Polygnathus*; *a* – *alternatus*; *d* – *delicatula*; *i* – *iowaensis*; *q* – *quadratinodosalobata*; *p* – *perlobata*.

Stage	Frasnian				Famennian																						
Horizon	Askyn				Barma														Makarovo					Lower <i>crepida</i>			
Conodont zone	<i>linguiformis</i>				Lower-Middle <i>triangularis</i>														Upper <i>triangularis</i>								
Meters (m)	0.32				1.78														1.65								
Weight (kg)																											
Sample №																											
Taxon	B-1/5	B-1/6	B-1/7	B-1/8	02357-1	02357-2	02357a	B-1/b	B-1/c	B-1/d	B-2a	B-3	B-4	B-5	B-6	02358	8225	8226	8227	8229	8333	8232	8233				
<i>Pa. amplificata</i> Klapp., Kuzm. & Ovn.	2	1	1																								
<i>Pa. kireevae</i> Ovn.	2																										
<i>Pa. linguiformis</i> Müll.	1	1	1	2			(1)																				
<i>Pa. ljaschenkoae</i> Ovn.	1	1	3	1																							
<i>Pa. nasuta</i> Müll.	1		4	6																							
<i>Pa. rhenana</i> Bisch.	1			1	(aff)		(aff)		(1)	(aff)																	
<i>Pa. subrecta</i> Mill. & Young.	4	5	7	4	(1)																						
<i>Pol. krestovnikovi</i> Ovn.	3	2	10	4																							
<i>Pol. siratchoicus</i> Ovn. & Kuzm.	1	1																									
<i>Pol. uchtensis</i> Ovn. & Kuzm.	1	2																									
<i>Pa. ederi</i> Zieg. & Sand.				1 1																							
<i>Pa. gigas extensa</i> Zieg. & Sand.				2 2				(1)	(1)			(aff)															
<i>Pa. hassi</i> Müll. & Müll.				1 2	(1)																						
<i>Pol. brevilaminus</i> Br. & M.	2	9	9	6	2	10	2	1	3	6	4	2	1	3	4	1	2	4	1	1	1	20	5				
<i>Pa. praetrigularis</i> Zieg. & Sand.					3	2	4	1	1																		
<i>Pa. triangularis</i> Sann.					4	17	1	2	2	6	10	5	11	7	6	5	4	5	3	2	6	42	14				
<i>Pa. d. delicatula</i> Br. & M.					1		1		1	2					3		3				2	1	1				
<i>Ic. alternatus alternatus</i> Br. & M.					2	11				1	2					4		3	8	1	1	10	11				
<i>Ic. alternatus helmsi</i> Sand.					1	7				1	2	3										4					
<i>Pa. clarki</i> Zieg.									1	6	6				4	2	3	2	4	1		1	8	14			
<i>Pa. q. praeterita</i> Schül.										1	4	2	7	4	2		5	1	3			3	1				
<i>Ic. i. iowaensis</i> Youn. & Pet.													1		1	2	8	4				4					
<i>Pol. izhmensis</i> Kuzm.													1	1	1	2											
<i>Pol. subinornatus</i> Strel.														3	2	1	4					2	10				
<i>Pa. subperlobata</i> Br. & M.														1		2					2	2	3				
<i>Pol. praecursor</i> Mat.														1	1			3	2	2							
<i>Pa. spathula</i> Schül.																		1	2				2				
<i>Pa. tenuipunctata</i> Sann.																		1			2		10				
<i>Pa. p. perlobata</i> Ul. & Bas.																		1		1		1	1				
<i>Pa. minuta loba</i> Helms																							1				
<i>Pa. q. sandbergi</i> Ji & Zieg.																							3				

pinkish-grey, thin and medium-layered organogenic limestones with brachiopods, crinoids, rugose corals and other faunas (Abramova 1999, Artyushkova *et al.* 2011a). Brachiopod shell stones of the F/F boundary interval are subdivided into the four conodont Upper *rhenana*, *linguiformis* (Frasnian, Askyn Horizon) and Lower-Middle *triangularis* (Famennian, Barma Horizon) zones (Abramova 1999, Abramova & Artyushkova 2004). The division is performed in terms of the standard conodont zonation (Ziegler & Sandberg 1990). The description of typical (Bol'shaya Barma and Akkyr) and peculiar (Ryauzyak and Kuk-Karauk) sections, including a short description of the conodont faunas is given below.

The Bol'shaya Barma section. – The section on the Bol'shaya Barma River (right tributary of the Askyn River) serves as a stratotype of the Barma Horizon. It is located on the right bank of the river of the same name 1.3 km upstream from its mouth (see Fig. 1A, B). The brachiopod shell limestone thickness in the F/F interval is 2.1 m. The lower part of these shell stones 0.32 m thick belongs to the Askyn Horizon of the Frasnian while the upper part 1.78 m thick corresponds to the Barma Horizon of the Famennian.

The Frasnian portion of the shell stones consists of light-grey compact limestones with interbeds rich in brachiopods where shells are unsorted by size and distributed

Table 2. Numerical distribution of conodont taxa in samples from the Akkyr section. For the position of samples in the section see Fig. 1.

Stage	Frasnian												Famennian													
Horizon	Askyn												Barma												Makarovo	
Conodont zone	Upper <i>rhenana</i>				<i>linguiformis</i>								Lower-Middle <i>triangularis</i>												Lower <i>crepida</i>	
Meters (m)	0.25				0.35								1.50													
Weight (kg)	0.3	0.4	0.2	0.2	0.7	0.2	0.6	0.2	0.7	1.9	0.3	0.3	1.6	1.5	1.0	1.0	0.6	0.8	0.7	0.5	1.5	0.5	0.5	1.2	0.7	0.6
Taxon \ Sample №	A-12a/1	A-12a/2	A-12a/3	A-12a/4	A-12a/5	A-12a/6	A-12a/7	A-a/1	A-a/2	A-a/3	A-b/1	A-b/2	A-14a	A-15a	A-16a	A-17a	A-17b	A-18a	A-18b	A-18c	A-18d	A-18i	A-17a	A-19a	A-19b	A-20A
<i>Ad. ioides</i> Zieg.	3			4																						
<i>Ad. nodosa</i> Ul. & Bas.	1	4	6	11	1																					
<i>Belodella</i> sp.	5	2		1																						
<i>Pa. kireevae</i> Ovn.	1		1																							
<i>Pa. ljaschenkoae</i> Ovn.	1	1	2	5																						
<i>Pa. nasuta</i> Müll.	23	24	23	107	106		8		2	15	11															
<i>Pa. rhenana</i> Bisch.	3	1	2	12	34	1	1	1																		
<i>Pa. subrecta</i> Mill. & Young.	5	10		20	67				1																	
<i>Pol. siratchoicus</i> Ovn. & Kuzm.	2	3	3	10	20																					
<i>Pa. orlovi</i> Khrus. & Kuzm.		1					2		1																	
<i>Pa. hassi</i> Müll. & Müll.			1	3	3		2	3		2	5															
<i>Pa. jamieae</i> Zieg. & Sand.				7	88																					
<i>Pa. juntianensis</i> Han				1	11																					
<i>Pa. mucronata</i> Klapp., Kuzm. & Ovn.				1	1	1																				
<i>Pa. amplificata</i> Klapp., Kuzm. & Ovn					20						2															
<i>Pa. brevis</i> Zieg. & Sand.					9																					
<i>Pa. gigas extensa</i> Zieg. & Sand.					3		2		1	1	1															
<i>Pa. gigas gigas</i> Mill. & Young.					5					1																
<i>Pa. linguiformis</i> Müll.					5																					
<i>Pa. aff. nicolli</i> Klapp.					3																					
<i>Palmatolepis</i> sp.					2																					
<i>Pol. macilentus</i> Ovn. & Kuzm.					3																					
<i>Pol. uchtensis</i> Ovn. & Kuzm.					3																					
<i>Pol. krestovnikovi</i> Ovn.						4	7	5	6	5	1															
<i>Ad. curvata</i> (Br. & M.)						2																				
<i>Pol. webbi</i> Stauf.						1																				
<i>Ic. alternatus alternatus</i> Br. & M.					3	10	18	3	8	9	18	4	74	22	7	5	7	3	2	5	54	45	12	3	10	7
<i>Ic. alternatus helmsi</i> Sand.						2	2				5	1	6								8	10				
<i>Ic. iowaensis iowaensis</i> Youn. & Pet.									1	3	11	7	10	2				1			3	1	1			
<i>Pol. planarius</i> Klapp. & Lane									1	2	1															
<i>Ancyrognathus</i> sp.									1	3	1															
<i>Pol. brevilaminus</i> Br. & M.										3	6	8	5	1			4	1	2		7	4		2		2
<i>Pa. praetriangularis</i> Zieg. & Sand.												2	2													
<i>Pa. triangularis</i> Sann.												2	7	2	1		1	1	1	3	15	3				2
<i>Pa. clarki</i> Zieg.																2	2	2	1	1						
<i>Pa. d. delicatula</i> Br. & M.																	1	1						2	2	
<i>Pa. q. praeterita</i> Schül.																2	2	1		2	10	5	2			2
<i>Pelekysgnathus</i> sp.																		2								
<i>Pol. praecursor</i> Mat.																1	2	2	1		2	1		2		20
<i>Pol. subinornatus</i> Strel.																1		2							2	2
<i>Pa. subperlobata</i> Br. & M.																			1			2	1	3	4	
<i>Pa. p. perlobata</i> Ul. & Bas.																								2	4	
<i>Pa. aff. circularis</i> Szulc.																									2	
<i>Pa. q. sandbergi</i> Ji & Zieg.																									1	
<i>Pa. spathula</i> Schül.																									1	

unevenly in the surrounding rock. The space among brachiopods is filled with fine detritus composed mainly of crinoid segments. The established conodont assemblage is characteristic of the *linguiformis* Zone the nominal species *Palmatolepis linguiformis* Müll. appears at the base of the brachiopod shell stones. The number of specimens for

samples is only 1 or 2. The conodont assemblage includes not many taxa and consists of 2 genera and 14 species (Table 1). The conodonts *Palmatolepis nasuta* Müll., *Pa. subrecta* Mill. & Young., *Polygnathus brevilaminus* Br. & M. and *Polygnathus krestovnikovi* Ovn. quantitatively surpass the other species.

Table 3. Numerical distribution of conodont taxa in samples from the Ryauzyak section. For the position of samples in the section see Fig. 1.

Stage	Frasnian		Famennian							
Horizon	Askyn		Barma						Makarovo	
Conodont zone	<i>linguiformis</i>		Lower-Middle <i>triangularis</i>						Lower <i>crepida</i>	
Meters (m)	0.15		0.45							
Weight (kg)	1.0	0.4	0.3	0.2	0.3	0.2	0.2	0.2	0.6	
Taxon	Sample №	P-b	P-2	P-c	P-3	P-4	P-e	P-5	P-5a	P-6
<i>Ad. curvata</i> (Br. & M.)	3									
<i>Ad. gigas</i> Young.	5									
<i>Ad. nodosa</i> Ul. & Bas.	3									
<i>Belodella</i> sp.	29									
<i>Pa. amplificata</i> Klapp., Kuzm. & Ovn.	18									
<i>Pa. ederi</i> Zieg. & Sand.	1									
<i>Pa. gigas extensa</i> Zieg. & Sand.	39									
<i>Pa. hassi</i> Müll. & Müll.	12									
<i>Pa. juntianensis</i> Han	6									
<i>Pa. kireevae</i> Ovn.	3	1								
<i>Pa. linguiformis</i> Müll.	7									
<i>Pa. ljaschenkoae</i> Ovn.	2									
<i>Pa. nasuta</i> Müll.	70	4								
<i>Pa. rhenana</i> Bisch.	15									
<i>Pa. subrecta</i> Mill. & Young.	2									
<i>Pol. krestovnikovi</i> Ovn.	26	2								
<i>Pol. macilentus</i> Ovn. & Kuzm.	18									
<i>Pol. siratchoicus</i> Ovn. & Kuzm.	15	1								
<i>Pol. uchtensis</i> Ovn. & Kuzm.	6	1								
<i>Ic. alternatus alternatus</i> Br. & M.	15	25	36	63	4	7	17	16		2
<i>Pol. brevilaminus</i> Br. & M.	5		3	12		2		5		1
<i>Ic. alternatus helmsi</i> Sand.		2	2	3				1		
<i>Pa. praetriaangularis</i> Zieg. & Sand.			1	2						
<i>Pa. triangularis</i> Sann.			3	15	1	1	3	3		2
<i>Ic. i. iowaensis</i> Youn. & Pet.						1	3			
<i>Pol. izhmensis</i> Kuzm.						1				
<i>Pa. clarki</i> Zieg.							2	3		8
<i>Pa. q. praeterita</i> Schül.							1			13
<i>Pa. subperlobata</i> Br. & M.							1	1		8
<i>Pol. subinornatus</i> Strel.							3	2		9
<i>Pa. circularis</i> Szulc.										11
<i>Pa. q. sandbergi</i> Ji & Zieg.										21
<i>Pa. spathula</i> Schül.										2

The Barma brachiopod shell limestone encompasses the interval of the joint conodont Lower–Middle *triangularis* zones. It differs from the underlying Frasnian shell limestone by a more even and close “packing” of brachiopods. The very first rare specimens of the conodont *Palmatolepis triangularis* Sann. and brachiopod *Parapugnax markovskii* (Yud.) have been found in a single sample and their appearance determines the base of the Barma Horizon. The nominal species is together with *Icriodus alternatus alternatus* Br. & M., *Ic. alternatus helmsi* Sand., *Ic. iowaensis iowaensis* Young. & Pet., *Pa. delicatula delicatula* Br. & M., *Pa. praetriaangularis* Zieg. & Sand. (see Table 1). *Polygnathus brevilaminus* Br. & M. pass through the Famennian. Scarce specimens of the species *Palmatolepis clarki* Zieg., *Pa. quadratinodosalobata praeterita* Schül., *Pa. subperlobata* Br. & M., *Polygnathus*

izhmensis Kuzm., *Pol. praecursor* Mat., *Pol. subinornatus* Strel. appear in the 0.42 m above base of the Barma shell limestone (see Table 1). It should be noted that the Barma conodont assemblage contains, together with Famennian species, solitary (1 or 2 specimens) *Palmatolepis gigas extensa* Zieg. & Sand., *Pa. rhenana* Bisch., *Pa. hassi* Müll. & Müll., *Pa. subrecta* Mill. & Young., *Pa. linguiformis* Müll., *Pa. aff. rhenana* Bisch. characteristic of the uppermost Askyn Horizon of the Frasnian (see Table 1).

As compared to the other sections, the Famennian portion of the brachiopod coquina (Barma Horizon) has the following peculiarities in the Bol’shaya Barma section. The Barma Horizon’s a maximum thickness is 1.78 m in this section. The taxa of the genus *Icriodus* are found only at the base of the Famennian, and their number is

Table 4. Numerical distribution of conodont taxa in samples from the Kuk-Karauk section. For the position of samples in the section see Fig. 1.

Stage	Frasnian			Famennian													
Horizon	Askyn			Barma												Makarovo	
Conodont zone	<i>linguiformis</i>			Lower–Middle <i>triangularis</i>												Lower <i>marginifera</i>	
Meters (m)	0.20			0.50													
Weight (kg)	0.4	0.2	0.3	0.4	0.2	0.2	0.1	1.0	0.3	1.2	0.1	0.1	0.3	0.1		0.3	0.4
Taxon \ Sample №	K-II-b	K-II-C/1	K-II-C/2	K-II-C/3	K-II-C/4	K-II-D/1	K-II-2d	K-II-D/2	K-II-4d	K-II-D/3	K-II-D/4	K-II-E/1	K-II-E/2	K-II-E/3		K-II-F/1	K-II-F/2
<i>Pa. amplificata</i> Klapp., Kuzm. & Ovn.	2		1														
<i>Pa. nasuta</i> Müll.	4	8	1														
<i>Pol. krestovnikovi</i> Ovn.	1	2	2														
<i>Pol. uchtensis</i> Ovn. & Kuzm.	1																
<i>Ad. ioides</i> Zieg.		1															
<i>Ad. nodosa</i> Ul. & Bas.		1															
<i>Pa. brevis</i> Zieg. & Sand.		1															
<i>Pa. gigas extensa</i> Zieg. & Sand.		3	1														
<i>Pa. hassi</i> Müll. & Müll.		1															
<i>Pa. jamieae</i> Zieg. & Sand.		4															
<i>Pa. linguiformis</i> Müll.		4															
<i>Pa. ljaschenkoae</i> Ovn.		1															
<i>Pa. juntianensis</i> Han		1															
<i>Pa. rhenana</i> Bisch.		1															
<i>Pa. subrecta</i> Mill. & Young.		1															
<i>Pol. macilentus</i> Ovn. & Kuzm.		1	1														
<i>Ad. curvata</i> (Br. & M.)			1														
<i>Anc. asymmetricus</i> (Ul. & Bas.)			1														
<i>lc. alternatus alternatus</i> Br. & M.	4	2	4		7	2	2	4	24	6	31	1	1	14	1		
<i>Pa. triangularis</i> Sann.				1				2	5	1	7	1	2	3			
<i>lc. i. iowaensis</i> Youn. & Pet.							1	2		7							
<i>lc. alternatus helmsi</i> Sand.								4									
<i>Pa. clarki</i> Zieg.								1			1						
<i>Pa. q. praeterita</i> Schül.								1		1	1						
<i>Pol. subinornatus</i> Strel.								8		15		2					
<i>Pol. brevilaminus</i> Br. & M.									1								
<i>Pa. glabra acuta</i> Helms																12	
<i>Pa. glabra glabra</i> Ul. & Bas.																10	
<i>Pa. glabra lepta</i> Zieg. & Hud.																10	
<i>Pa. glabra prima</i> Zieg. & Hud.																22	2
<i>Pa. m. marginifera</i> Helms																8	
<i>Pa. minuta minuta</i> Br. & M.																15	6
<i>Pa. p. schindewolfi</i> Müll.																7	2
<i>Pa. stoppeli</i> Sand. & Zieg.																4	
<i>Pol. glaber glaber</i> Ul. & Bas.																9	

considerably less than those of the genus *Palmatolepis* (see Table 1). The Barma shell stones in the conodont assemblage contain together with *Palmatolepis triangularis* Sann. 6 Frasnian conodont species of the genus *Palmatolepis*, which are found in Askyn Horizon (see Table 1). The signs of reworked shells brachiopods are absent in the Bol'shaya Barma section (Mizens 2007). Some Frasnian conodont and brachiopod taxa may have survived the F/F extinction (Schülke 1995, Racki *et al.* 2002, Abramova & Artyushkova 2004).

The Barma shell stones are gradationally overlaid by light-grey thick-layered crinoid-brachiopod limestones of the Makarovo Horizon, with which they have a continuous

sequence. The base of the Makarovo Horizon is characterized by a conodont assemblage of the Upper *triangularis* Zone (see Table 1).

The Akkyr section. – One of the best exposures of the F/F brachiopod shell limestones is located on the right bank of the Zilim River at the mouth of the Bol'shaya Kunderlya Rivulet (see Fig. 1A, B). A.N. Abramova (1999) called it the Akkyr section. The shell stones are 2.10 m thick. The lower 0.6 m interval has been assigned to the Askyn Horizon of the Frasnian. The upper 1.5 m interval has been identified as the Barma Horizon of the Famennian.

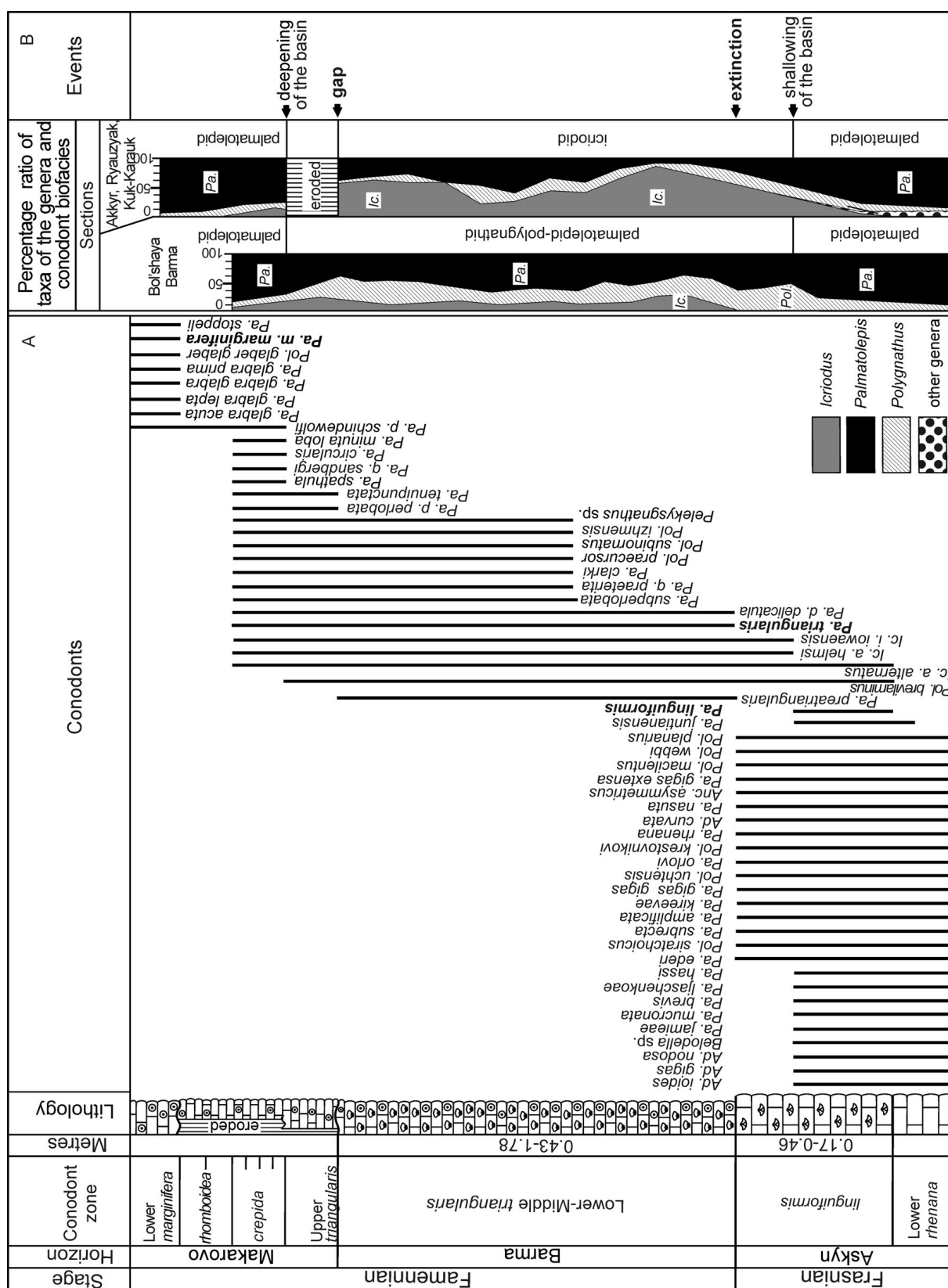


Figure 5. Summary column of the F/F boundary deposits in the West Uralian Folded Zone with conodont distribution (A) and interpretation of paleogeologic, and palaeologic settings (B).

The structure of the Frasnian portion of these brachiopod shell limestones looks like an alternation between thin interbeds (1–2 cm) of light-grey crinoid and brachiopod varieties (see Fig. 3). The lower 0.25 m interval is characterized by conodonts of the Upper *rhenana* Zone. Taxonomically, the conodont assemblage is represented by 4 genera and 14 species (see Table 2). Representatives of the genus *Palmatolepis* dominate the other taxa. Among prevailing species are *Palmatolepis nasuta* Müll. and *Pa. subrecta* Mill. & Young.

In this section the thickness of the *linguiformis* Zone reaches 0.35 m. The conodont assemblage is represented by 5 genera and 27 species (see Table 2). Species of the genus *Icriodus* make their appearance just in this interval, the number getting noticeably greater by the end of the *linguiformis* Zone. Near the F/F boundary the conodont assemblage becomes taxonomically much poorer.

In the Famennian portion the shell limestone (Barma Horizon) are characterized by denser clusters of brachiopods. There is no expressed stratification in the rock (see Fig. 3). Coquina is loose at the base. The matrix that binds brachiopod shells together consists of crinoid segments for the most part. Weak iron staining is visible.

At the base of the Barma Horizon the conodont assemblage contains rare individual specimens of *Palmatolepis triangularis* Sann. and *Pa. praetriaangularis* Zieg. & Sand. Along with them, one can find a great number of pass through the Famennian taxa of the genus *Icriodus* and to a smaller extent *Polygnathus brevilaminus* Br. & M. (see Table 2). The diversity of brachiopods from the Barma coquinas in the Akkyr section is somewhat less than that in the Bol'shaya Barma section. However, the Akkyr section contains pentamerids which are absent in the stratotype (Mizens 2007).

The upper 1.12 m interval of the Barma Horizon is characterized by the occurrence of *Palmatolepis clarki* Zieg., *Pa. delicatula delicatula* Br. & M., *Pa. quadratinodosalobata praeterita* Schül., *Pa. subperlobata* Br. & M., *Polygnathus praecursor* Mat., *Pol. subinornatus* Strel. and *Pelekysgnathus* sp. (see Table 2).

Above the Barma coquinas the conodont succession displays a slight gap corresponding to the Upper *triangularis* Zone. Conodonts characteristic of the Lower *crepida* Zone are accumulated in the overlying thin-lay-

ered crinoid-brachiopod limestones of the Makarovo Horizon (see Table 2).

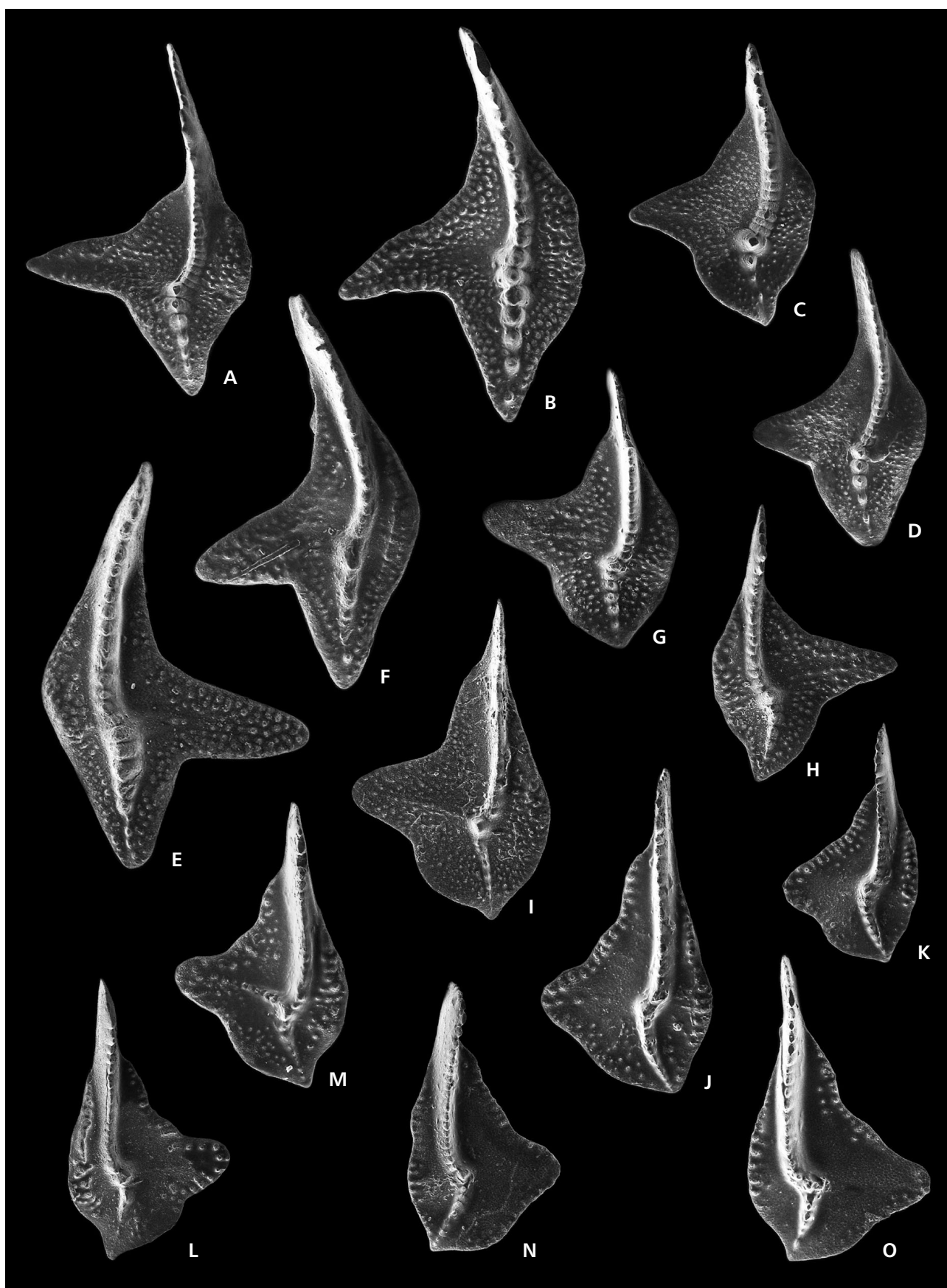
The Ryauzyak section. – The Ryauzyak section is one of the few complete Upper Devonian sections. It is situated on the right bank of the Ryauzyak River, 5 km upstream from the village of Sargaev (see Fig. 1). In this section the brachiopod shell limestone of the F/F interval is of the smallest thickness, as compared to the other sections, and is 0.60 m thick. The coquina is dark-grey; brachiopod shells are in close contact with each other, but for the most part they are recrystallized. The matrix is composed of small crinoid segments.

In this section the Frasnian portion of the brachiopod shell stone does not visually differ from the Famennian one, and the F/F boundary is determined only by the alternation of the conodont and brachiopod faunas.

The Frasnian includes the lower 0.15 m interval of the coquina corresponding to the *linguiformis* Zone. The zonal conodont association is characterized by a rich diversity represented 5 genera and 22 species (Table 3). The most abundant taxa is *Palmatolepis nasuta* Müll., the number of *Belodella* sp., *Icriodus alternatus alternatus* Br. & M., *Palmatolepis amplificata* Klapp., Kuzm. & Ovn., *Pa. gigas extensa* Zieg. & Sand., *Pa. rhenana* Bisch., *Pol. krestovnikovi* Ovn., *Pol. macilentus* Ovn. & Kuzm., *Pol. siratchoicus* Ovn. & Kuzm. is 3 to 5 times less. The rest of the taxa are characterized by scarce specimens. The peculiar feature of the conodont assemblage in this section is the abundant presence of juvenile forms in the samples.

In this section the Barma Horizon has a small thickness of 0.45 m. Similar to the rest of the sections, its base is determined by simultaneous occurrence of the conodont *Palmatolepis triangularis* Sann. and brachiopod *Parapugnax markovskii* (Yud.). The conodont assemblage from the lower part of the Barma Horizon 0.35 m thick is extremely poor and involves solitary specimens of *Palmatolepis triangularis* Sann., *Pa. praetriaangularis* Zieg. & Sand., *Polygnathus brevilaminus* Br. & M., *Icriodus alternatus alternatus* Br. & M., *Ic. alternatus helmsi* Sand., *Ic. iowaensis iowaensis* Young. & Pet. At the top of the Barma shell limestone the conodont biodiversity is complemented by the species *Palmatolepis clarki* Zieg., *Pa. quadratinodosalobata praeterita* Schül., *Pa. subperlobata* Br. & M., *Pol. subinornatus* Strel. (see Table 3).

Figure 6. Conodonts from the Bol'shaya Barma, Akkyr and Kuk-Karauk sections, Upper Devonian, Frasnian, Askyn Horizon (all figures × 40). • A, B, E, F – *Palmatolepis rhenana* Bischoff; A, B, F – Akkyr section; A – Upper *rhenana* Zone, sample A-12a/4; B, F – *linguiformis* Zone, B – sample A-12a/5; E – sample A-12a/6; E – Kuk-Karauk section, *linguiformis* Zone, sample K-II-C/1. • C, D, G, H – *Palmatolepis nasuta* Müller; C, D, H – Akkyr section; C, D – Upper *rhenana* Zone; C – sample A-12a/1; D – sample A-12a/4; H – *linguiformis* Zone, sample A-12a/5; G – Kuk-Karauk section, *linguiformis* Zone, sample K-II-C/1. • I – *Palmatolepis hassi* Müller & Müller, Bol'shaya Barma section, *linguiformis* Zone, sample B-1/8. • J, K, O – *Palmatolepis subrecta* Miller & Youngquist, *linguiformis* Zone; J, K – Akkyr section, sample A-12a/5; O – Kuk-Karauk section, sample K-II-C/1. • L, M – *Palmatolepis amplificata* Klapper, Kuz'min & Ovnatanova, Akkyr section, *linguiformis* Zone, sample A-12a/5. • N – *Palmatolepis ljaschenkoae* Ovnatanova, Akkyr section, *linguiformis* Zone, sample A-12a/5.



A short-time stratigraphic gap is observed above the shell stones of the Barma Horizon, and the overlying Makarovo Horizon begins with the Lower *crepida* Zone. The duration of the gap, as well as in the Akkyr section, corresponds to the interval of the conodont Upper *triangularis* Zone. The Makarovo deposits are represented by layered brownish-grey crinoid limestones, sometimes with iron staining. For the most part the conodont assemblage is characterized by the taxa of the genus *Palmatolepis* represented by abundant specimens perfectly preserved (see Table 3). The number of the representatives of the genus *Icriodus* becomes sharply reduced.

The Kuk-Karauk section. – The Kuk-Karauk section is the most southern one in the West Uralian Folded Zone where the boundary F/F interval is represented by brachiopod shell limestone. It is located on the Sikaza River opposite the mouth of the Kuk-Karauk Rivulet (see Fig. 1A, B). This brachiopod shell stone is 0.7 m thick and characterized by a heterogeneous structure. Polished slab demonstrate repeated 2–3 cm interbedding of light-grey coquina with rather dense shell “packing” and loose crinoid limestone (Fig. 4). The lower part of brachiopod shell stones 0.20 m thick belongs to the *linguiformis* Zone. The assemblage includes 5 conodont genera and 20 species (Table 4). The conodont *Palmatolepis nasuta* Müll. is the most abundant taxon, corresponding to half of the whole conodont fauna. The smaller part is represented by *Icriodus alternatus alternatus* Br. & M., *Polygnathus siratchoicus* Ovn. & Kuzm. and others (see Table 4).

The thickness of the Famennian portion of the shell limestone is 0.50 m; it encompasses the interval of the conodont Lower–Middle *triangularis* zones. The first solitary specimens of *Palmatolepis triangularis* Sann. are found just at the bottom of the Barma shell stones together with brachiopod *Parapugnax markovskii* (Yud.). The conodont assemblage of the Barma Horizon is extremely poor. The lower part of the horizon 0.15 m thick contains only the zonal index species *Palmatolepis triangularis* Sann. and *Icriodus alternatus alternatus* Br. & M. Similar to the rest of the sections, the conodont biodiversity tends to increase in the upper part of the Barma coquina (see Table 4).

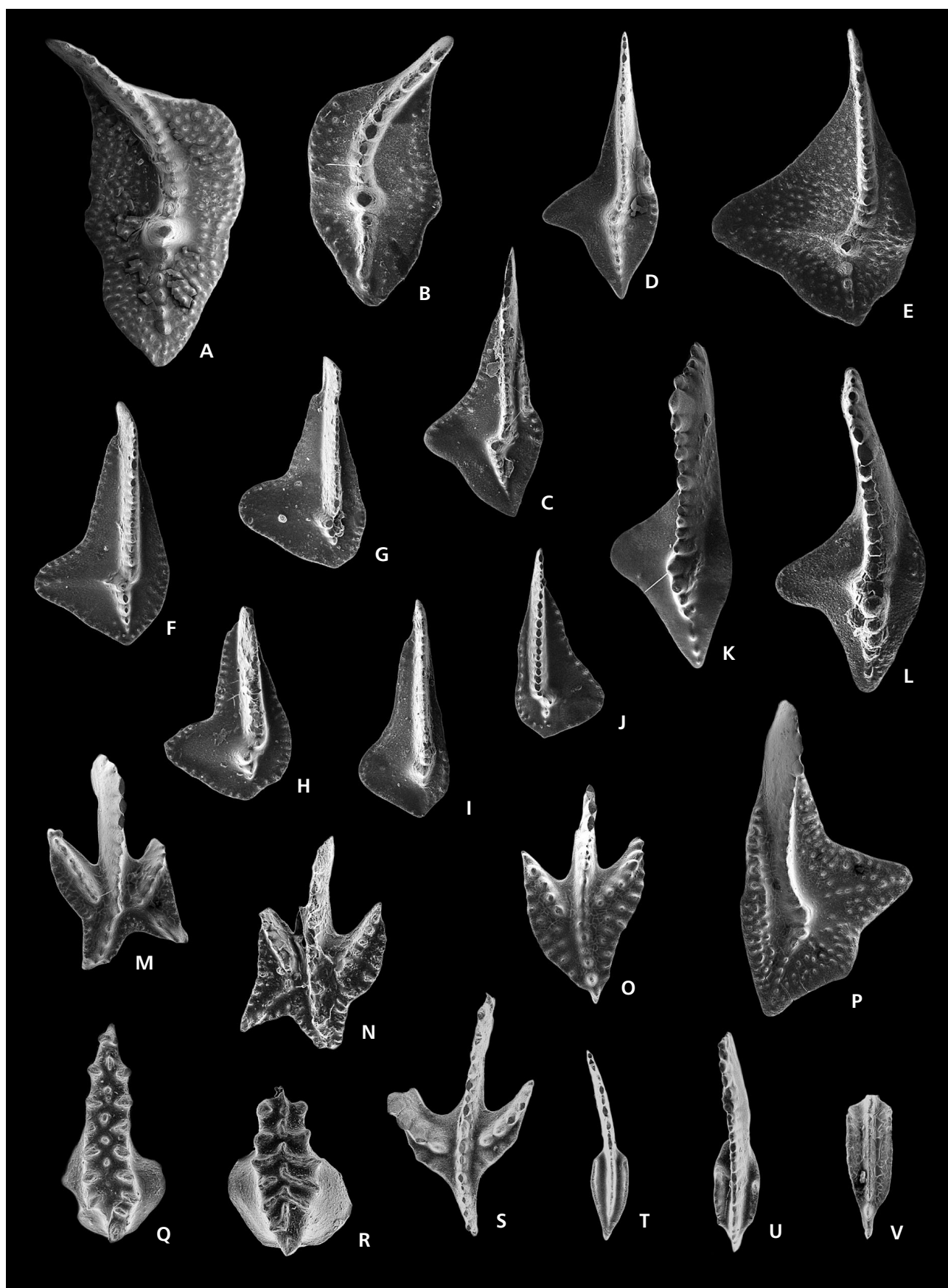
The shell stone of the Barma Horizon are overlaid by light-grey and yellow, grained, layered crinoid-coral limestones of the Makarovo Horizon with a stratigraphic gap that equals the interval of three conodont Upper *triangularis*–Upper *rhomboidea* zones. In the crinoid limestones immediately above the shell stones there are conodonts characteristic of the Lower *marginifera* Zone (see Table 4).

Conodont biodiversity and biofacies

The conodont biodiversity found in the brachiopod shell stone of the boundary F/F interval is characterized by a rich taxonomic composition. Taxa of the genera *Palmatolepis*, *Polygnathus* and *Icriodus* form the basis for conodont assemblages in all the samples. These genera are considered to be the basic indicators of paleobasinal depths (Seddon & Sweet 1971, Sandberg 1976, Sandberg & Dreesen 1984, Dreesen *et al.* 1986, Sandberg *et al.* 1988, Ziegler & Sandberg 1990). Other Upper Devonian genera occur in a markedly smaller number. In the sections under investigation an analysis has been performed for the conodont taxonomic and quantitative diversity in the boundary Frasnian/Famennian interval. The number of unbroken conodonts of the taxa encountered in each of the samples has been calculated.

In the Akkyr, Ryauzyak and Kuk-Karauk sections at the base of the brachiopod shell limestone of the Askyn Horizon of the Frasnian Stage the conodont assemblage is very rich in its diversity and includes 6 genera and 30 species (Fig. 5). The clear dominance belongs to palmatolepids that are represented by 16 taxa and correspond to the comprise 78 percent of the whole fauna (see Fig. 5B, Tables 2–4). Among characteristic species are *Palmatolepis amplificata* Klapp., Kuzm. & Ovn., *Pa. gigas extensa* Zieg. & Sand., *Pa. hassi* Müll. & Müll., *Pa. jamieae* Zieg. & Sand., *Pa. juntianensis* Han, *Pa. nasuta* Müll., *Pa. rhenana* Bisch. and *Pa. subrecta* Mill. & Young. (Figs 6, 7). The abundance of *Palmatolepis nasuta* Müll. is noted almost in each sample whereas the taxa of the genus *Polygnathus* are half as many. Representatives of the genera *Ancyrodella*, *Ancyrognathus*, *Belodella* and *Icriodus* are very rare in the assemblage amounting only to 11 percent (see Tables 2–4).

Figure 7. Upper Devonian, Frasnian, Askyn Horizon conodonts (all figures × 50). • A, B – *Palmatolepis linguiformis* Müller, *linguiformis* Zone; A – Ryauzyak section, sample R-b; B – Akkyr section, sample A-12a/5. • C, D – *Palmatolepis gigas extensa* Ziegler & Sandberg, *linguiformis* Zone; C – Kuk-Karauk section, sample K-II-C/1; D – Ryauzyak section, sample R-b. • E – *Palmatolepis beckeri* Klapper, Akkyr section, Upper *rhenana* Zone, sample A-12a/4. • F–J – *Palmatolepis juntianensis* Han, F, G, I, J – Akkyr section; J – Upper *rhenana* Zone, sample A-12a/4; G, I, J – *linguiformis* Zone, sample A-12a/5; H – Kuk-Karauk section, *linguiformis* Zone, sample K-II-C/1. • K, L – *Palmatolepis* aff. *nicolli* Klapper, Akkyr section, *linguiformis* Zone, sample A-12a/5. • M, N – *Ancyrodella curvata* (Branson & Mehl), *linguiformis* Zone; M – Ryauzyak section, sample R-b; N – Akkyr section, sample A-12a/6. • O – *Ancyrodella gigas* Youngquist, *linguiformis* Zone, R-b. • P – *Palmatolepis* sp., Akkyr section, *linguiformis* Zone, sample A-12a/5. • Q – *Icriodus alternatus alternatus* Branson & Mehl, Akkyr section, *linguiformis* Zone, sample A-12a/5. • R – *Icriodus iowaensis iowaensis* Youngquist & Peterson, Akkyr section, Upper *rhenana* Zone, sample A-a/3. • S – *Ancyrodella ioides* Ziegler, Akkyr section, Upper *rhenana* Zone, sample A-12a/1. • T – *Polygnathus macilentus* Ovnatanova & Kuzmin, Akkyr section, *linguiformis* Zone, sample A-12a/5. • U, V – *Polygnathus brevilaminus* Branson & Mehl, Akkyr section, *linguiformis* Zone; U – sample A-12a/5; V – sample A-a/3.



This conodont assemblage characterizes the palmatolepid (pelagic) biofacies (see Fig. 5B; Sandberg 1976, Ziegler & Dreesen 1984, Sandberg *et al.* 1988, Zielger & Sandberg 1990).

In the upper part of the Askyn coquina (the *linguiformis* Zone), these sections show a considerable reduction in the conodont diversity (see Tables 2–4). The number of taxa of the genus *Palmatolepis* gets halved, and a sudden reduction of their quantity to 23 percent is observed (see Fig. 5A, B). The quantity of the *Icriodus* taxa increases abruptly (52 pc), though they are taxonomically represented by three species only: *Icriodus alternatus alternatus* Br. & M., *Ic. alternatus helmsi* Sand. and *Ic. iowaensis iowaensis* Young. & Pet. Thus, at the end of the Frasnian time, near the F/F boundary the palmatolepid (pelagic) biofacies gives way to the icriodid (shallow water) one (see Figs 5A, B, 6, 7, Tables 2–4).

Among the sections under investigation the Bol'shaya Barma section has its own peculiarities. Here, the *Icriodus* taxa are absent in the Frasnian brachiopod shell stone (the *linguiformis* Zone), and the assemblage contains representatives of the genera *Palmatolepis* and *Polygnathus*. They are almost in the equal ratio (53 and 45 pc) and form the palmatolepid-polygnathid (relatively deep water) biofacies (see Fig. 5B, Table 1).

Along with the conodonts all the sections under investigation contain fish remains, such as Bradiodontidae gen. indet., Acanthodei gen. indet., Crossopterigii gen. indet., Elasmobranchii gen. indet., *Haplacanthus* sp., *Phoebodus* sp., *Cladodus* sp., *Onychodus* sp., *Cobelodus* sp. (Abramova 1999, Artyushkova *et al.* 2011a).

In the uppermost Askyn Horizon, close to the F/F boundary, Frasnian species of the genera *Palmatolepis* die out, and the genera *Ancyrodella* and *Belodella* become totally extinct. *Icriodus alternatus alternatus* Br. & M., *Ic. alternatus helmsi* Sand., *Ic. iowaensis iowaensis* Young. & Pet. and *Polygnathus brevilaminus* Br. & M. pass through the Famennian (see Fig. 5A, Tables 2–4). An identical situation is observed in the brachiopod assemblages. Thus, the genera

Devonoproductus, *Hypothyridina*, *Calvinaria*, *Septalaria*, *Koltubania*, *Atryparia*, *Theodossia*, *Squmulariina*, *Tecnocyrtina* and representatives of the orders Pentamerida and Atrypida become extinct (Rzhonsnitskaya *et al.* 1998; Abramova 1999; Mizens 2007, 2009).

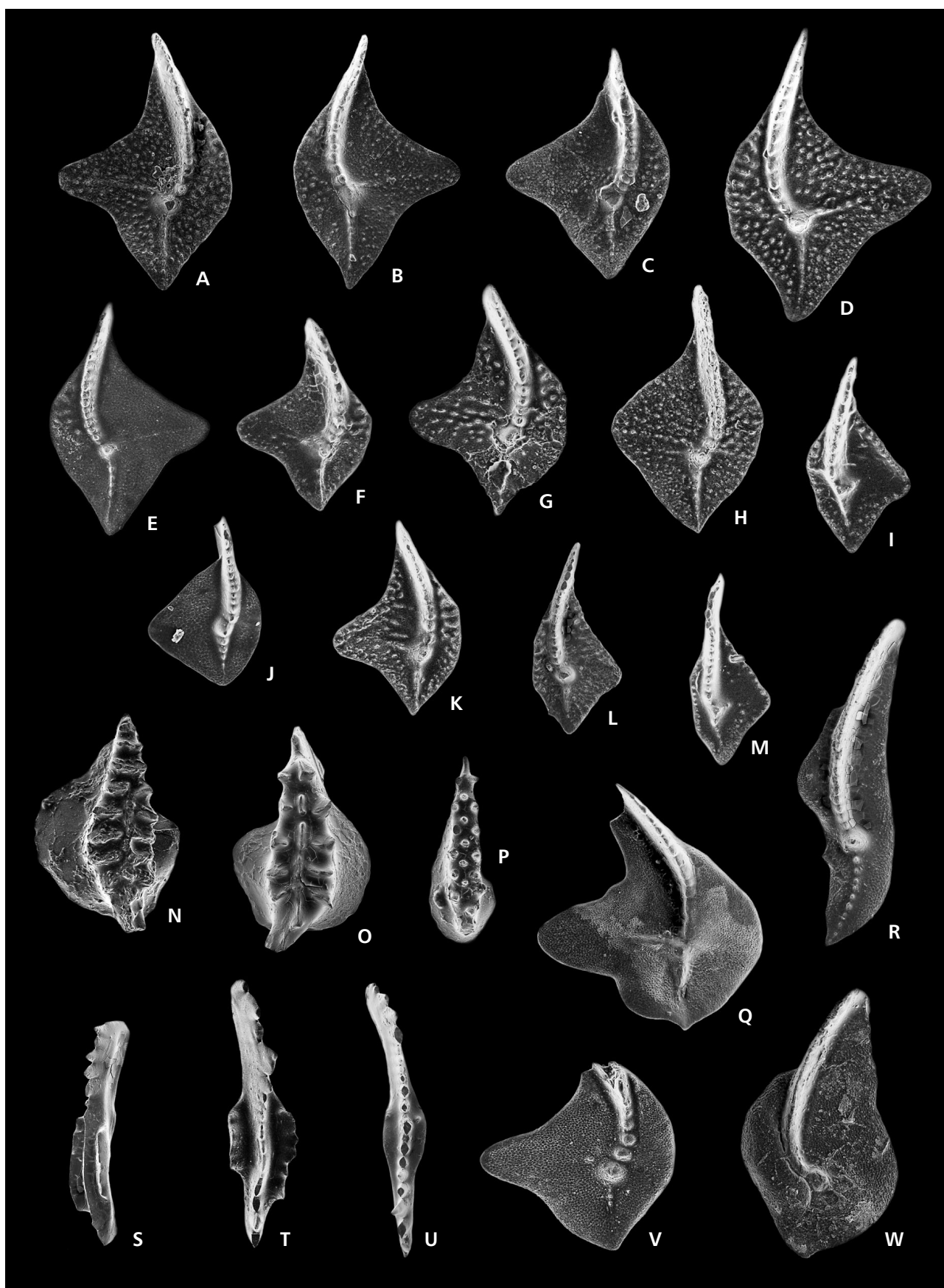
Abrupt changes that occurred in the taxonomic structure of the conodont assemblages at the end of the Frasnian time affected the conodont biodiversity of the early Famennian age. At the base of the Barma Horizon the conodont association is extremely poor and uniform. The genus *Palmatolepis* is represented by solitary specimens of *Palmatolepis triangularis* Sann., *Pa. delicatula delicatula* Br. & M. and *Pa. praetriangularis* Zieg. & Sand. (see Figs 5A, B, 8, Tables 2–4).

In the Akkyr, Ryauzyak and Kuk-Karauk sections the dominance of species of the genus *Icriodus* can be observed *Icriodus alternatus alternatus* Br. & M. and to a smaller extent *Ic. alternatus helmsi* Sand., *Ic. iowaensis iowaensis* Young. & Pet., the number of which reaches a total of 80 percent. The conodont association of the lower part of the Famennian can be assigned to the icriodid (shallow water) biofacies (see Fig. 5A, B, Tables 2–4).

In the Bol'shaya Barma section the taxa of the genera *Palmatolepis* and *Polygnathus* continue to prevail beginning with the base of the Barma Horizon, however, the assemblage is complemented with rare specimens of *Icriodus* that make their first appearance in this section (see Table 1). Beginning with the Famennian age, the conodont association in this section is characterized palmatolepid-polygnathid (relatively deep water) biofacies (see Fig. 5B).

The enrichment of the assemblages with new species, such as *Palmatolepis clarki* Zieg., *Pa. quadratinodosalobata praeterita* Schül., *Pa. subperlobata* Br. & M., *Polygnathus izhmensis* Kuzm., *Pol. praecursor* Mat., *Pol. subinornatus* Strel. (see Fig. 8) is observed far above the Frasnian/Famennian boundary, the span corresponds to 0.42 m in the Bol'shaya Barma section, 0.38 m in the Akkyr section, 0.33 m in the Ryauzyak section and 0.15 m in the Kuk-Karauk section (see Tables 1–4).

Figure 8. Upper Devonian, Famennian conodonts (A–M × 60, N–W × 50). • A–E, H – *Palmatolepis triangularis* Sannemann, Barma Horizon, Lower–Middle *triangularis* zones; A, B – Ryauzyak section, sample R-3; C, D, H – Akkyr section; C, H – sample A-b/2; D – sample A-18d. • E – Bol'shaya Barma section, sample 02357-1. • F, G, K – *Palmatolepis quadratinodosalobata praeterita* Schülke, Barma Horizon, Lower–Middle *triangularis* zones; F–K – Akkyr section; sample A-18d; G – Bol'shaya Barma section, sample 02358. • I, L, M – *Palmatolepis clarki* Ziegler; I, M – Akkyr section, Barma Horizon, Lower–Middle *triangularis* zones, sample A-18a; L – Ryauzyak section, Makarovo Horizon, Lower *crepida* Zone, sample R-6. • J – *Palmatolepis delicatula delicatula* Branson & Mehl, Akkyr section, Makarovo Horizon, Lower *crepida* Zone, A-19b. • N–O – *Icriodus iowaensis iowaensis* Youngquist & Peterson, Barma Horizon, Lower–Middle *triangularis* zones; N – Akkyr section, sample A-14a; O – Ryauzyak section, sample R-e. • P – *Icriodus alternatus alternatus* Branson & Mehl, Akkyr section, Barma Horizon, Lower–Middle *triangularis* zones, sample A-14a. • Q – *Palmatolepis circularis* Szulcowski, Ryauzyak section, Makarovo Horizon, Lower *crepida* Zone, sample R-6. • R – *Palmatolepis glabra lepta* Ziegler & Huddle, Kuk-Karauk section, Makarovo Horizon, Lower *marginifera* Zone, sample K-II-F. • S, T – *Polygnathus brevilaminus* Branson & Mehl, Barma Horizon, Lower–Middle *triangularis* zones, S – Ryauzyak section, sample R-3; T – Bol'shaya Barma section, sample 02357-1. • U – *Polygnathus izhmensis* Kuzmin, Ryauzyak section, Barma Horizon, Lower–Middle *triangularis* zones, sample R-e. • V – *Palmatolepis wolskae* Ovnatanova, Akkyr section, Makarovo Horizon, Lower *crepida* Zone, A-19b. • W – *Palmatolepis stoppeli* Sandberg & Ziegler, Kuk-Karauk section, Makarovo Horizon, Lower *marginifera* Zone, sample K-II-F.



Above the Barma coquina a complete conodont succession has been established only in the Bol'shaya Barma section. The beginning of the Makarovo Horizon base is noted for the appearance of species *Palmatolepis perlobata perlobata* Ul. & Bas., *Pa. spathula* Schül. and *Pa. tenuipunctata* Sann. characteristic of the Upper *triangularis* Zone (Barskov *et al.* 1987, Ziegler & Sandberg 1990, Schülke 1995; see Table 1). The ratio among the taxa of the genera *Palmatolepis*, *Polygnathus* and *Icriodus* does not change, and the palmatolepid-polygnathid (relatively deep water) biofacies is still preserved in this interval (see Fig. 5B). The appearance of the species *Pa. quadratinodosalobata sandbergi* Ji & Ziegl. and *Pa. wolskiae* Ovn. in the Bol'shaya Barma section characterizes the Lower *crepida* Zone (Barskov *et al.* 1987, Ziegler & Sandberg 1990, Schülke 1995; see Table 1). In the conodont assemblage an abrupt increase in the number of elements belonging to the genus *Palmatolepis*, up to the 75 percent of the whole conodont fauna, can be noticed. The palmatolepid-polygnathid (relatively deep water) biofacies of the Upper *triangularis* Zone gives way to the palmatolepid (pelagic) biofacies in the Lower *crepida* Zone (see Fig. 5B).

In the Akkyr and Ryauzyak sections the stratigraphic sequence does not yield any conodont indicative of the Upper *triangularis* Zone; here, the Makarovo Horizon begins with the Lower *crepida* Zone (see Tables 2, 3). The conodont association of the Lower *crepida* Zone, as in the Bol'shaya Barma section, is characterized by an abrupt increase in the number of the *Palmatolepis* taxa (69 pc) and corresponds to the palmatolepid (pelagic) biofacies (see Figs 5A, B, 8).

Only the upper part of the Makarovo Horizon in the scope of the conodont Lower *marginifera* Zone was determined in the Kuk-Karauk section above the Barma coquina. The richest taxonomic composition of conodonts is represented by species of the genus *Palmatolepis* and thus can be attributed the palmatolepid (pelagic) biofacies (see Figs 5A, B, 8, Table 4).

Conclusions

In the sections of the West Uralian Folded Zone (Bol'shaya Barma, Akkyr, Ryauzyak and Kuk-Karauk) the F/F boundary interval is represented by brachiopod shell limestone. According to conodonts, there can be recognized the Frasnian (upper part of the Askyn Horizon) and Famennian (Barma Horizon) portions of the shell stones, in which the detailed zonal conodont-based subdivision and establishment of biofacies have been performed.

At the top of the brachiopod coquina of the Askyn Horizon of the Frasnian (the *linguiformis* Zone) all the sections under investigation display much poorer conodont biodiversity; at the F/F boundary the majority of Frasnian

conodont and brachiopod taxa become totally extinct. At the end of the Frasnian age abundant specimens of the *Palmatolepis* taxa that represent the pelagic (palmatolepid) biofacies are gradually replaced by the *Polygnathus* and *Icriodus* taxa of the shallow-water (icriodid) biofacies. Judging from the changes in the composition of the brachiopod assemblage at the end of the Frasnian age, it can be assumed that the basin was characterized by an active hydrodynamic regime with slight muddiness of ground (Mizens 2009). It is quite possible that observable restructurings in the conodont and brachiopod communities result from regression of the basin at the F/F boundary (Johnson *et al.* 1985; Johnson & Sandberg 1988; Sandberg *et al.* 1988; Veimarn *et al.* 1998, 2004; Racki 1998; House *et al.* 2000; Racki *et al.* 2002; Yudina *et al.* 2002).

Beginning with the Famennian time after extinction of the majority of the Frasnian taxa, the recovery of the conodont faunal community proceeded at a very slow pace. The conodont assemblage of the Barma Horizon (Lower–Middle *triangularis* zones) is taxonomically poor and it can be assigned to shallow-water conodont biofacies. An abrupt increase in the conodont biodiversity is seen only in the Lower *crepida* and especially during to Lower *marginifera* zones corresponding to the deposition of the Makarovo Horizon.

At the F/F boundary in this region there occurs marked tendency to shallowing of the basin with its maximum in the Lower–Upper *triangularis* zones. This is evidenced by stratigraphic gaps determined by means of conodonts above the *linguiformis* Zone (Veimarn *et al.* 1998, 2004; Abramova 1999; Artyushkova *et al.* 2011a). In most sections known on the western slope of the South Urals (Gabdyuk, Mendym, Zigan and others) the range of this gap varies from one zone to several conodont zones (Abramova 1999). In those sections where the F/F boundary is determined within brachiopod shell stones the gap is observed above the Barma Horizon (except the Bol'shaya Barma section) and encompasses the interval corresponding to the conodont Upper *triangularis* Zone in the Akkyr and Ryauzyak sections and to the Upper *triangularis*–Upper *rhomboidea* zones in the Kuk-Karauk section.

The Frasnian/Famennian boundary is marked with dark hypoxic limestone and the Upper Kellwasser Mass Extinction Event (Walliser *et al.* 1986, Klapper *et al.* 1993, Walliser 1996, Alekseev 1998, Veimarn *et al.* 1998). In the sections on the western slope of the South Urals the F/F boundary interval is different and characterized by thin brachiopod shell limestones (Bol'shaya Barma, Akkyr, Ryauzyak, Kuk-Karauk and Kuktash sections) and stratigraphic gaps (Gabdyuk, Mendym, Zigan and others sections). The Frasnian/Famennian boundary revealed mass extinction of the main Frasnian conodont and brachiopod taxa (Rzhonsnitskaya *et al.* 1998; Abramova 1999;

Abramova & Artyushkova 2004; Mizens 2007, 2009; Tagarieva 2010). The bio-event is represents a significant regional event that is correlated with the Upper Kellwasser Mass Extinction Event.

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