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Conodont association of the Bashkirian-Moscovian boundary interval of the Donets Basin, Ukraine

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ABSTRACT

Ten sections spanning the Bashkirian-Moscovian boundary interval were studied in the Donets Basin. Six of them contain most representative conodont and foraminifer associations. In this paper we focused on three the most complete sections that include stratigraphically important conodont species, which belong to the *Declinognathodus, Idiognathoides, Idiognathodus, Neognathodus,* "*Streptognathodus*", *Mesogondolella* and *Diplognathodus* genera. The majority of those species are widely distributed, which makes the correlation to other areas reliable. Two biotic events in conodont evolution were discovered in these sections. Two conodont lineages established here are considered as potential markers for the definition of the lower boundary of the Global Moscovian Stage: *D. marginodosus – D. donetzianus* and *Id. sulcatus sulcatus – Id. postsulcatus*. The conodonts *D. donetzianus* and *Id. postsulcatus*, both proposed before as potential markers for the definition of the GSSP at the Bashkirian-Moscovian boundary, are described and compared to those from the other areas. The entry of *D. donetzianus* is updated and confirmed to the top of the limestone K_1 in both sections, the Zolota Valley and the Malo-Mykolaivka

RESUMEN

En este trabajo se estudian diez secciones que abarcan el intervalo del límite Bashkiriense-Moscoviense en la Cuenca de Donets. Seis de estas secciones contienen las asociaciones más representativas de conodontos y foraminíferos. En este artículo nos centramos en tres de las secciones más completas y que incluyen especies de conodontos estratigráficamente importantes pertenecientes a los géneros *Declinognathodus*, *Idiognathoides*, *Idiognathodus*, *Neognathodus*, «*Streptognathodus*», *Mesogondolella* y *Diplognathodus*. La mayoría de las especies están ampliamente distribuidas, lo que hace que la correlación con otras áreas sea fiable. En estas secciones se descubrieron dos eventos bióticos en la evolución de los conodontos. Dos linajes de conodontos establecidos aquí se consideran marcadores potenciales para la definición del límite inferior de la Etapa Global Moscoviense: *D. marginodosus* - *D. donetzianus* y *Id. sulcatus sulcatus* - *Id. postsulcatus*. Los conodontos *D. donetzianus* y *Id. postsulcatus*, ambos propuestos anteriormente como posibles marcadores para la definición del GSSP en el límite entre Bashkiriense y Moscoviense, se describen y comparan con los de las otras áreas. La entrada de *D. donetzianus* se

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sections. The other proposals for the definition of the lower Moscovian boundary by conodonts are discussed. Three conodont zones characterize the Bashkirian-Moscovian boundary interval. These are, in ascending order: the *Id. tuberculatus – Id. fossatus* Zone and *D. marginodosus* Zone from the upper Bashkirian, and *D. donetzianus* Zone from the lower Moscovian. They were recently described and shortly given in this paper.

Keywords: Conodonts, Bashkirian-Moscovian, zonation, lineage, evolution event.

actualiza y confirma en la parte superior de la caliza K_1 en ambas secciones: las secciones del Valle de Zolota y de Malo-Mykolaivka. Se discuten las otras propuestas para la definición del límite inferior Moscoviense con conodontos. Tres zonas de conodontos caracterizan el intervalo límite entre Bashkiriense y Moscoviense. Estos son, en orden ascendente: la Zona *Id. tuberculatus - Id. fossatus* y la *D. marginodosus* para el Bashkiriense superior, y la Zona *D. donetzianus* para el Moscoviense inferior. Han sido descritos recientemente y en este trabajo sólo se reseñan brevemente.

Palabras clave: Conodontos, Bashkiriense-Moscoviense, zonación, linaje, evento de evolución.

1. INTRODUCTION

The position of the boundary between the Global Bashkirian and Moscovian stages (Lower-Middle Pennsylvanian boundary) or GSSP for the lower boundary of the Moscovian Stage is not still established and remains one of the main tasks of the International Subcommission on the Carboniferous Stratigraphy (Alekseev & Task Group, 2017).

The Bashkirian Stage is the lowest series of the Pennsylvanian Subsystem. It was first established as "the Bashkirian beds" by Semikhatova (1934) at the Askyn section, South Urals. These beds were characterized by a specific group of brachiopods called "coarse ribbed *Choristites*". Later, these beds were rank as a stage (Semikhatova, 1941).

The Moscovian Stage was established by S.N. Nikitin in 1890 in the Moscow Syneclise, Russia, as equivalent to the middle series of the Carboniferous (Nikitin, 1890). Nikitin thought that the Moscovian Stage of the Moscow Syneclise corresponds to the Middle Carboniferous of the Urals. For a long time, the title "Moscovian" has been related to the entire Middle Carboniferous. When the Bashkirian Stage was established, the Middle Carboniferous was not called "the Moscovian" any longer.

The stratotype of the Moscovian Stage is located in the Moscow Syneclise, and the Bashkirian stratotype in Urals. There is quite a distance between the two type areas. Moreover, the basal beds of the Moscovian Stage in its type area are represented by terrestrial deposits and thus do not contain marine fossils. Furthermore, an unconformity eliminates marine Bashkirian deposits and fossils in the Moscow Syneclise, including foraminifers that were used traditionally for definition of the Bashkirian-Moscovian boundary position and for intrastage correlations. As a result, the lower boundary of the Moscovian Stage is difficult to correlate with the other areas, especially with the Bashkirian stratotype. The latter is completely carbonate section but its fauna in the Bashkirian-Moscovian transition is rather specific, and the correlation is not easy.

The Carboniferous of the Donets Basin, Ukraine, is one of the best successions to attempt to solve the problem of the Bashkirian-Moscovian boundary correlation. The Carboniferous of the Donets Basin is a thick terrigenous strata of interbedded argillites, siltstones and sandstones with thin limestone interlayers and coal seams. In spite of rather small percentage of carbonates, an essential advantage of the Donbas Carboniferous succession is the presence of a great variety of marine and continental fossils, which provide reliable correlations not only to the regions of development of the marine rocks but also to continental subdivisions of Western Europe. The data obtained from the marine and continental fossils all prove that the Donets Basin Carboniferous is more complete than those in the other areas.

Conodonts are considered as the most reliable fossils for the definition of the stage boundaries and correlations. They occur in all types of marine rocks, widely distributed and are not as susceptible to provincialism as other groups. These features together with high rates of evolution ensure their successful use for Carboniferous biostratigraphy, and the Bashkirian-Moscovian boundary position in particular. For the purpose of regional and international correlation by conodonts, 6 most complete sections spanning the Bashkirian-Moscovian interval at the Donets Basin, Ukraine were selected in this study (Figs 1-2). The details of the conodont assemblages of 4 sections are updated in this paper (Figs 3-5; Tables 1-3). The potential markers and position of Bashkirian-Moscovian boundary are also discussed based on the conodont data presented herein.

2. BASHKIRIAN-MOSCOVIAN BOUNDARY

The boundary between the Global Bashkirian and Moscovian stages in their type areas and elsewhere was originally established by foraminifers. According to Unified

Figure 1. Locality map showing the studied sections.

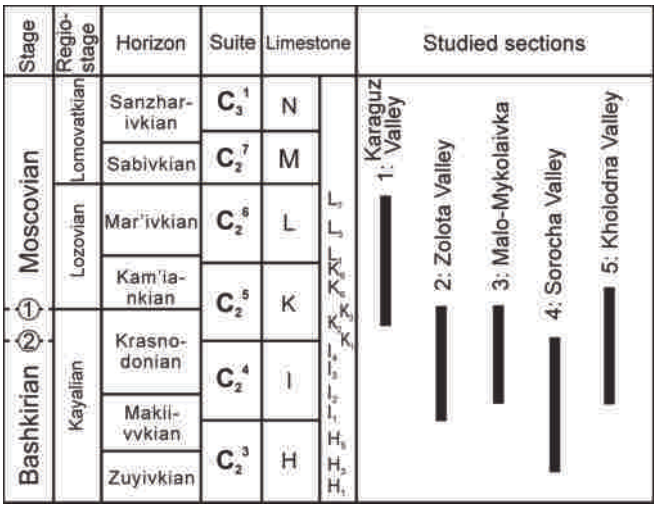


Figure 2. Stratigraphic range of studied sections. Encircled number 1 indicates traditional Bashkirian-Moscovian boundary level in Ukraine. Encircled number 2 shows the current Bashkirian-Moscovian boundary recognized by the FAD of *Declinognathodus donetzianus*.

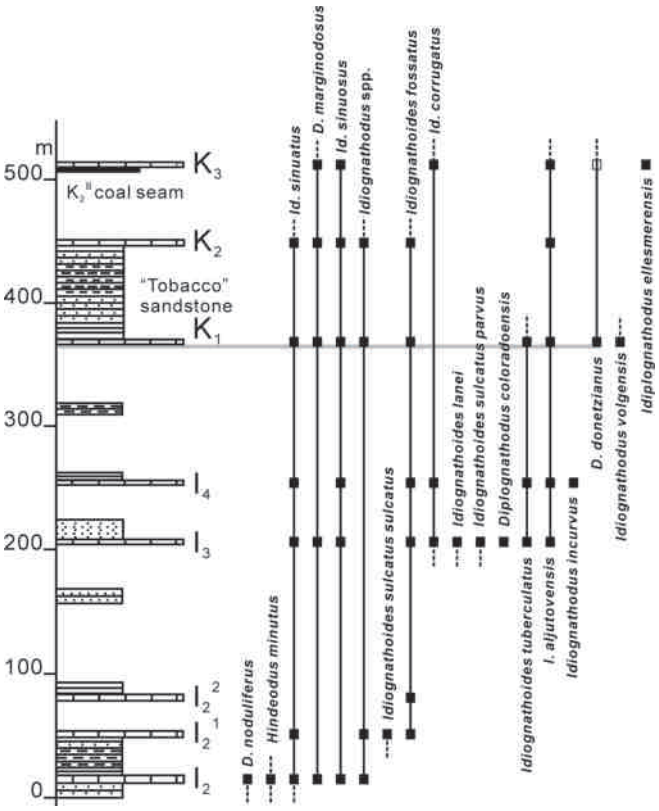


Figure 3. Range chart of important species across the Bashkirian-Moscovian boundary at the Malo-Mykolaivka section (updated from Nemyrovska *et al.*, 2010, fig. 2).

Scheme of the East-European Platform 1988 (Resolutions, 1990), the lower boundary of the Moscovian Stage is defined by the foraminifer *Aljutovella aljutovica* (Rauzer-Chernousova, 1938), whose first appearance datum (FAD) was found in the Aljutovo Formation at the base of the Vereian Substage in the Moscow Syneclise. The position of the Bashkirian-Moscovian boundary in the Donets Basin was defined mostly by correlation with foraminifers of the Moscow Syneclise and has not undergone radical changes for many years.

First, Kireeva (1951) included the whole C_2^5 (K) Suite (formation) of the Donets Basin in the Moscovian Stage. Later, the lower boundary of the Moscovian was raised to limestone K_3 within the same Suite (Aisenverg *et al.*, 1975). Nowadays it is reasonable to lower the Bashkirian/Moscovian boundary in the Donets Basin again down to the base of the C_2^5 (K) Suite by the conodont correlation. Mostly because the conodont *Declinognathodus donetzianus* Nemirovskaya, 1990, which is considered to be a leading marker for the Bashkirian/Moscovian boundary, was found at the base of the Moscovian in its type area, and in the Donets Basin its FAD was recorded within the limestone K_1 at the base of the C_2^5 (K) Suite or the base of the Lozovian Regional Stage of the Moscovian Stage (Nemyrovska, 2017). The exact position of the lower boundary of the Global Moscovian is still a subject of investigation by the International Task Group of the Carboniferous Subcommission.

The study of the Bashkirian-Moscovian boundary beds continues in the most complete sections around the world, including the Cantabrian Mountains, Spain; Urals, Russia; South China; and the Donets Basin, Ukraine. After the index species is officially selected, the investigations will be directed to establish the boundary stratotype. The Moscovian beds in the type area unconformably overlie the Mississippian carbonates. Only in the deep Aza Paleovalley they overlie comformably the uppermost Bashkirian continental and lagoonal sediments. Moreover, the basal Moscovian beds in the type area do not contain

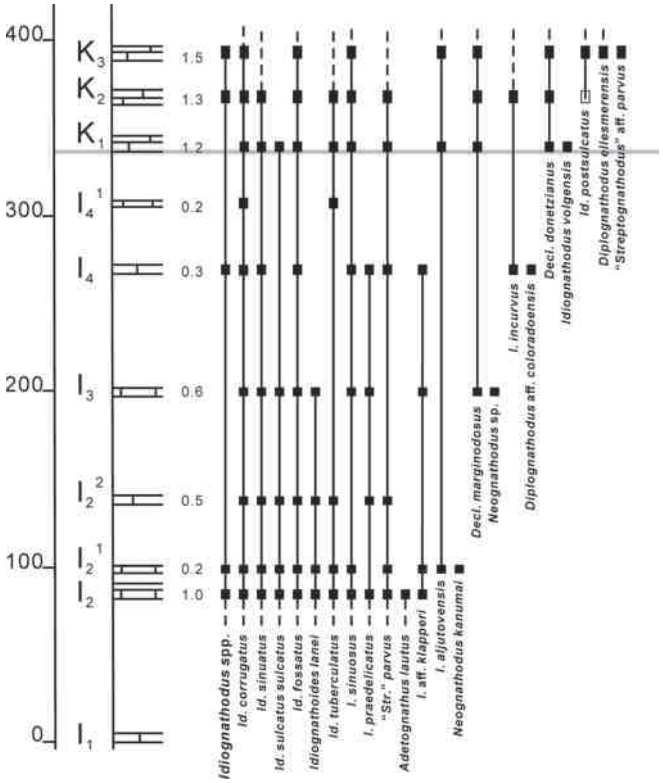


Figure 4. Range chart of important species across the Bashkirian-Moscovian boundary at the Zolota Valley Section (updated from Nemyrovska, 1999, fig. 21).

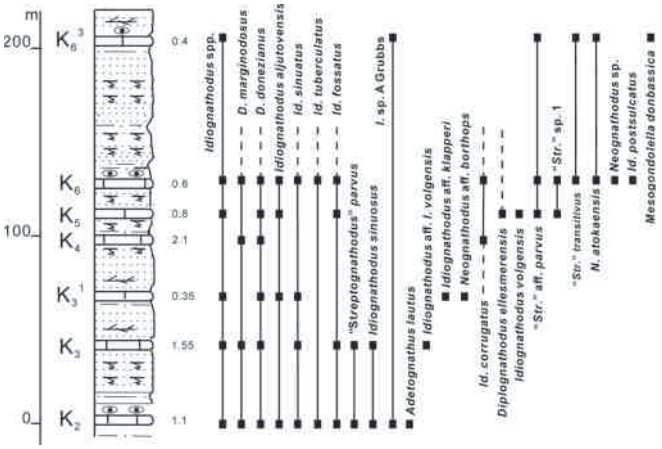


Figure 5. Range chart of important species across the Bashkirian-Moscovian boundary at the Karaguz Valley Section (updated from Nemyrovska, 1999, fig. 23).

marine fossils. As a result, the stratotype of the Bashkirian-Moscovian boundary will be chosen in another region. The most perspective sections for establishing the GSSP at the lower boundary of the Moscovian nowadays are South Urals and South China. The Donets Basin will remain a key section of the Bashkirian-Moscovian boundary.

Since the Task Group to establish a GSSP close to existing Bashkirian-Moscovian boundary was organized, the members of the group were asked to submit the formal proposals for boundary-defining datums. Conodonts and fusulinid foraminifers were selected by the SCCS boundary Task Group as the main fossils for the definition of the boundary GSSP. It is known that the fusulinids are more provincial than the conodonts, which reduces their correlative potential.

The first proposals submitted by 2004 included the identifications of two independent conodont events and four events within fusulinoidean lineages.

The first conodont proposal submitted by Tamara I. Nemyrovska (Groves & Task Group, 2003) considered two biotic events as potential boundary markers: 1) the evolutionary origin of *Declinognathodus donetzianus* from *D. marginodosus* (Grayson, 1984) (Fig. 6); and 2) evolutionary origin of *Idiognathoides postsulcatus* Nemyrovska, 1999 from *Id. sulcatus sulcatus* Higgins & Bouckaert, 1968. They were taxonomically characterized; their stratigraphic and geographic occurrences were well documented (Groves & Task Group, 2004; Nemirovskaya, 1990; Nemyrovska, 1999, 2017).

Both phylogenetic lines are represented by the late species of the genera *Declinognathodus* and *Idiognathoides*. Both proposals were justified by the results of conodont investigations from the Bashkirian-Moscovian boundary beds of the Donets Basin and correlation to other regions. *Declinognathodus donetzianus* is easy to identify but is somewhat limited in its paleogeographic distribution. *Idiognathoides postsulcatus* is more widely distributed but is less easy to identify and maybe non-isochronic from region to region. Besides the Donets Basin, the lineage *Declinognathodus marginodosus – D. donetzianus* (or greater part of it) is known from the Bashkirian-Moscovian boundary transition of the Urals and Volga region of Russia (Kulagina *et al*., 2009; Sungatullina, 2014). *Declinognathodus donetzianus* was recorded at the base of the Moscovian Stage in its type area (Alekseev & Goreva *in* Makhlina *et al*., 2001; Alekseev & Goreva, 2013; Kabanov & Alekseev, 2011). It was previously referred to other species from the Atokan of Alaska, North America (Savage & Barkely, 1985, figs 10.1-10.4), the basal beds of the Bolsovian in Western Europe (van den Boogaard & Bless, 1985, fig. 8.10) and Amazons Basin, South America (Lemos, 1992, pl. 3, fig. 1). One specimen of *D. donetzianus* has been recently found in the lower Atokan of the Appalachian Basin in the eastern U.S.A. (Work *et al*., 2012, fig. 8.1). In South China, only the lineage *Id. sulcatus sulcatus – Id. postsulcatus* was detected (Qi *et al*., 2016; Hu *et al*., 2017). In Spain, both lineages were reported but only a single non-illustrated specimen of *D. donetzianus* was reported (Blanco-Ferrera *et al*., 2009).

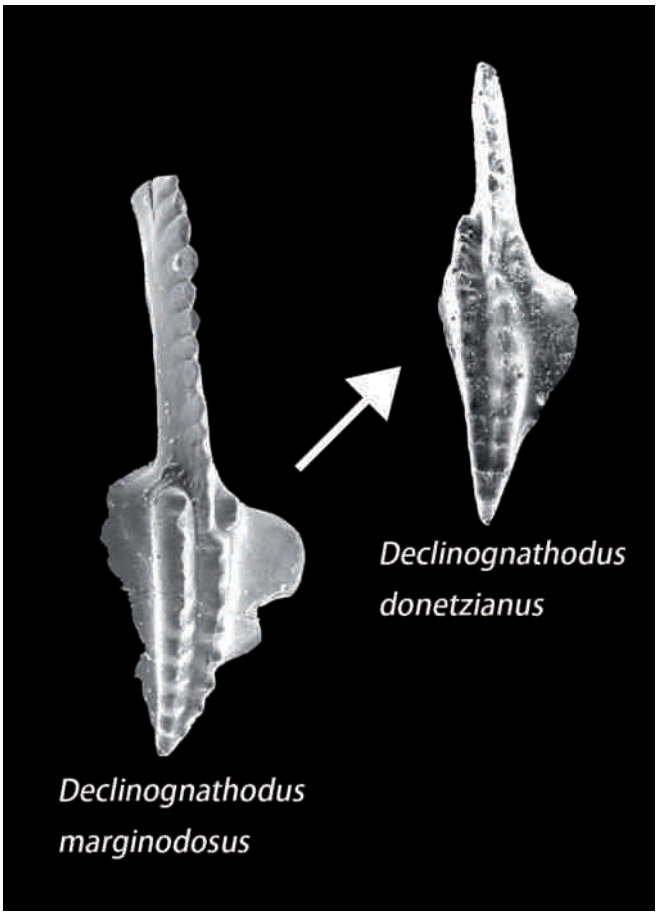


Figure 6. Evolutionary trend from *Declinognathodus marginodosus* to *D. donetzianus* in the Bashkirian-Moscovian transition (from Nemyrovska *et al*., 2010, fig. 3).

Later Lance L. Lambert proposed late morphotype of *Neognathodus nataliae* Alekseev & Gerelzezeg *in* Makhlina *et al*., 2001 as boundary-defining potential marker (Groves and Task Group, 2006). The first occurrence of this species is known from the upper part of the Vereian Substage of the Moscow Syneclise, at the level much higher than the base of the Moscovian Stage in its type area (Goreva & Alekseev *in* Makhlina *et al*., 2001). There is uncertainty with the taxonomic concept of late and early morphotypes. The species has also limited palaeogeographical distribution, it is known only in the Moscow Syneclise and North America so far. At this, *N. nataliae* was not properly documented yet in North America.

Another alternative-conodont *Diplognathodus ellesmerensis* Bender, 1980 was proposed as a marker for the definition of the Bashkirian-Moscovian boundary on the basis of detail investigation of one of the most complete carbonate succession in Asia, the Naqing section in South China (Qi *et al*., 2007). Abundant and diverse conodont association in this section contains different species of *Diplognathodus*, among them *Di. ellesmerensis* is common. This potential species-marker of the boundary was proposed in the hypothetical lineage *Di*. aff. *orphanus* Merrill, 1972 – *Di*. *ellesmerensis* (Wang & Qi, 2003; Qi *et al*., 2013, 2016). Although *Di*. *ellesmerensis* is widespread, its relation to its potential ancestor *Di*. aff. *orphanus* is not clear yet.

Two other alternative conodont taxa, i.e., "*Streptognathodus*" *expansus* Igo & Koike, 1964 and *Mesogondolella*, also have been proposed as markers for the definition of the Bashkirian-Moscovian boundary (Qi *et al*., 2007). However, the different ranges (FAD in particular), uncertain origination and stratigraphic distance from the traditional lower Moscovian boundary limit their utility to be as boundary markers.

Recently, Goreva and Alekseev proposed to move the lower boundary of the Moscovian one substage higher, from the base of the Vereian (lowermost Moscovian) to the base of the Kashirian (Alekseev & Goreva, 2013), by using the FAD of *Neognathodus bothrops* Merrill, 1972, which probably derived from *N. atokaensis* Grayson, 1984. *Neognathodus bothrops* is known from North America, Moscow Basin, Urals, Ukraine (rare) and several specimens in South China. In the Donets Basin, two specimens of *N*. aff. *N. bothrops* were found in the lower Moscovian beds of the Karaguz and Pashenna Valley sections. Real *N. bothrops* was not found. The entry of *N. atokaensis* was recorded at the base of the second Moscovian conodont zone, limestone K_6 (Table 3). If *N. bothrops* would be accepted as a boundary marker the movement of the lower Moscovian boundary will require the redefinition of the scopes of the Bashkirian and Moscovian stages. The proposal had negligible support (Groves & Task Group, 2006).

Among the foraminifers, the representatives of *Profusulinella* were selected as potential markers of the Bashkirian/Moscovian boundary. The proposed fusulinoidean lineages include 1) evolutionary changes within the *Profusulinella* phylogeny; 2) the evolutionary appearance of *Aljutovella* (from *Profusulinella*); 3) the evolutionary appearance of *Neostaffella* (from *Pseudostaffella*); and 4) the evolutionary appearance of *Eofusulina* (from *Verella*) (Groves & Task Group, 2003). Kulagina (2009) proposed to use FAD of *Depratina prisca* (Deprat, 1912) within the lineage *Sraffllaeformes – Depratina* to define the base of the Moscovian. The alternative species could be *Aljutovella aljutovica* (Rauzer-Chernousova, 1938) and *Skelnevatella skelnevatica* (Putrya & Leontovich, 1948) (Kulagina, 2009). Except conodont *Declinognathodus donetzianus* and *Diplognathodus ellesmerensis*, none of other proposed events possesses optimal global correlation so far due to their relatively restricted geographic distribution (Alekseev & Task Group, 2013).

3. REGIONAL STRATIGRAPHY OF THE BASHKIRIAN-MOSCOVIAN BOUNDARY BEDS

The studied stratigraphic interval includes the Krasnodonian Horizon of the Kayalian Regiostage of the Bashkirian Stage (the C_2^4 (I) Suite = formation) and the Kamiankian Horizon of the Lozovian Regiostage of the lower Moscovian (the C_2^5 (K) Suite) (Fig. 2).

The Krasnodonian Horizon is represented by predominantly marine rocks with thin coal seams. Dark-grey mudstones, packstones and wackestones within the terrigenous strata contain foraminifers, conodonts, brachiopods, algae, pelecypods and rare ammonoids of the *Diaboloceras-Axinolobus* Genozone (Popov, 1979). Grainstones with diverse detrital material and algal limestones occur in places.

The Kamiankian Horizon consists of thick, grainy sandstones alternating with marshes deposits that contain numerous limestone interlayers and coal seams. In general, shallow marine and lagoon deposits dominate in the lower part of the C_2^5 (K) Suite. The limestones are grey and dark-grey platy wackestones and packstones; algal in places. Conodonts, foraminifers, brachiopods, crinoids, ostracods, some corals and other marine fossils are characteristic of this lower part of the C_2^5 Suite. The greater number of conodonts occurs in the upper parts of the limestone beds, especially in limestones K_1 and K_3. A coal seam occurs at the base of limestone K_3 (Fig. 7a).

Ammonoids of the *Diaboloceras – Axinolobus* Genozone were found in the lower part of the C_2^5 (K) Suite (Popov, 1979). Above limestone K_1 that contains abundant *Donezella* algae in places, thick graywacke sandstone with an admixture of effusive volcanic material, so-called tobacco-sandstone, occurs. Fissunenko (1991) found numerous remains of a Duckmantian flora (Westphalian B). In the middle part of the formation, Fissunenko (1991) found a Bolsovian flora (Westphalian C) and ammonoids of the *Diaboloceras – Winslowoceras* Genozone (Popov, 1979).

Conodonts in the lower half of the C_2^5 (K) Suite are identical to the Vereian conodonts of the Moscow Syneclise, basal part of the Bolsovian or Westphalian C of Europe, lower Dalaun of China and Atokan of North America. The upper part of the suite is characterized by the wide distribution of alluvial sandstones, thick limestones, microbial limestones in places, and a great number of coal seams.

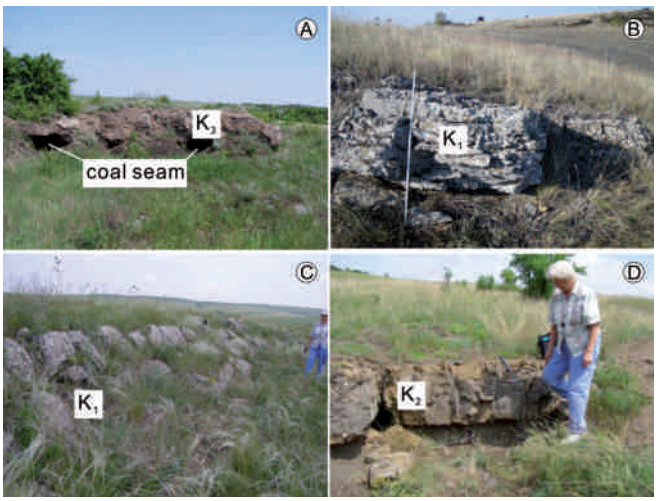


Figure 7. a) K_3 limestone and coal seam of the Malo-Mykolaivka section. **b)** K_1 limestone of the Malo-Mykolaivka section. **c)** K_1 limestone of the Zolota Valley section. **d)** K_2 limestone of the Zolota Valley section.

3.1. The sections

The most complete sections, which contain the stratigraphically important conodonts are as follows (Figs 1-2): 1) The Zolota Valley (N48°21.5', E39°00.0'), left bank of the Olkhova River, not far from the southeastern side of Yelisavetovka Village, 2.5 km south of Illiria Village, Lugansk County; 2) The Karaguz Valley and Pashenna Valley (N48°26.2', E39°14.3'), 1.5 km from each other, left bank of the Olkhova River. North-northeastern side of Lutugino, Lugansk County; 3) The Malo-Mykolaivka section (N48°18.9', E39°01.1'), northern side of Malo-Mykolaivka Village, along the Lugansk-Krasny Luch road, Lugansk County; 4) The Sorocha Valley (N48°15.2', E38°18.7'), left side of the Bulavin River, northeastern side of Bulavinske Village, Yenakievo District, Donetsk County; and, 5) The Kholodna Valley (N48°09'32", E38°28'18"), left tributary of Kharcyzsk stream, close to the northern side of Kirovskoje, Shakhtersk District, Donetsk County.

Two additional sections spanning the Bashkirian-Moscovian transition are in the process of investigation. In this paper, attention is paid to three sections, which are considered to be the most complete in the Donets Basin. They contain the most representative fauna (at least conodonts and foraminifers) of the Bashkirian-Moscovian boundary interval. These are the Zolota Valley (Fig. 4) and the Malo-Mykolaivka sections (Fig. 3) where all the limestones of the C_2^4 (I) Suite and the lower limestones (K_1, K_2 and K_3) of the C_2^5 (K) Suite are well exposed. We use the data of the lower half of the Karaguz and Pashenna sections (Fig. 6), up to limestone K_6^3, where new conodont species appeared, including "*Streptogathodus*" *transitivus* Kossenko *in* Kozitskaya *et al.*, 1978, the name-bearer of the younger, second zone of the Moscovian Stage.

The short descriptions of the limestones of the Malo-Mykolaivka, Zolota Valley, Karaguz and Pashenna sections is given below. The Malo-Mykolaivka and Zolota Valley sections are located close and will be described together.

3.1.1. Malo-Mykolaivka and Zolota Valley sections (Figs 3-4; Tables 1-2)

The distance between limestones of the Malo-Mykolaivka section was measured by Prof. K. Ueno (Ueno & Nemyrovska, 2008).

The limestone I_1 is float shales, dark grey wackestone, yellowish-brownish mineralized in places. Conodonts were not found.

The lowest limestone of the studied interval, yielding the conodonts, in the Zolota Valley and Malo-Mykolaivka sections is limestone I_2.

Limestone I_2, 4 m thick in the Malo-Mykolaivka and 1 m thick in the Zolota Valley sections. It is dark-grey, bioclastic wackestone in the uppermost part of the member and grainstone at the base. The conodont sample was taken from the top of the limestone in the Malo-Mykolaivka section. The conodont association is dominated by *Declinognathodus noduliferus*. The FAD of *D. marginodosus* is registered in this limestone. This species is represented here by small number of specimens. In the Zolota Valley, the conodont samples were taken in the middle and close to the base of limestone. *Declinognathodus marginodosus* was not found. *Idiognathoides sinuatus* Harris & Hollingsworth, 1933 dominate. Several specimens of *Idiognathodus* were also found. Algae and brachiopods occurred in the uppermost part of the limestone. Brachiopods occur also in the middle part of the limestone.

Limestone I_2^1, 1.0 m thick in the Malo-Mykolaivka section and 0.2 m thick in the Zolota Valley section. In the Malo-Mykolaivka section, it occurs 40 m above the limestone I_2. It is dark-grey packstone with algae and grainstone with silty and muddy interbeds, grainy at the bottom. In the Zolota Valley, it contains a numerous conodont association dominated by diverse species of *Idiognathoides*. *Idiognathodus* species are also common. Fragments of brachiopods occur.

Limestone I_2^2, 0.5 m thick in the Malo-Mykolaivka and Zolota Valley sections. In Malo-Mykolaivka section, it occurs 30 m above the limestone I_2^1. It is dark-grey bioclastic partly algal, partly crinoidal limestone with *Zoophycus* at the top. Brachiopods and corals occur. This limestone in the Zolota Valley section contains a numerous and diverse conodont association of idiognathoidids. Only several specimens of *Id. sinuatus* together with fish remains and ostracods were received from a small sample of limestone I_2^2 of the Malo-Mykolaivka section.

Limestone I_3, 0.55 m thick, mostly chucks in the Malo-Mykolaivka section, and 0.3 m thick in the Zolota Valley section. In Malo-Mykolaivka section it occurs 85 m above the limestone I_2^2. It is dark-grey bioclastic packstone and thinly bedded grainstone with conodont association, consisting mostly of *Idiognathoides* species. *Declinognathodus marginodosus* is common. *Idiognathodus* species also occur.

Table 1. Numerical chart of the conodonts from the Malo-Mykolaivka section (updated from Nemyrovska, 1999).

Stage	Bashkirian						Moscovian						
Limestone	I_2	I_2^1	I_2^2	I_3	I_4	K_1 base	K_1	K_1 top	K_2 grey	K_2	K_3 base	K_3	K_3 top
Declinognathodus noduliferus	50												
Declinognathodus marginodosus	7			9		9		34	5	17	58	20	5
D. marginodosus – D. donetzianus												1	
Declinognathodus donetzianus								2					1?
Idiognathoides sinuatus	6	10		47	18	3	6	46		6			
Idiognathoides corrugatus				4	5						2		
Hindeodus minutus	4												
Idiognathoides fossatus		16	4	50	156		29	140		21			
Idiognathoides sulcatus sulcatus		3											
Idiognathoides sulcatus parvus				9									
Id. sinuatus – Id. tuberculatus		2											
Idiognathoides tuberculatus				2	60			31					
Idiognathoides lanei				5									
Idiognathodus simuosus	8			7	5	11	7	16		36	2		
Idiognathodus volgensis							5	65					
Idiognathodus aljutovensis				1	21		6	70		10	3		
Idiognathodus incurvus					3								
Diplognathodus ellesmerensis												1	
Diplognathodus coloradoensis				1									
Idiognathodus spp.	1	9					4			5			
Total weight of the sample (kg)	10	10	3	10	12	6	10	14	8	12	12	12	12

Table 2. Numerical chart of the conodonts from the Zolota Valley section (updated from Nemyrovska, 1999, fig. 22).

Stage	Bashkirian						Moscovian			
Limestone	I_2	I_2^1	I_2^2	I_3	I_4	I_4^1	K_1	K_1 top	K_2	K_3
Declinognathodus marginodosus				3			15	18	10	70
Declinognathodus donetzianus								1	7	8
Idiognathoides sulcatus sulcatus	4	1	4	2			1			
Idiognathoides sinuatus	48	45	112	22	37	4	13	>200	12	
Idiognathoides corrugatus	36	32	55	11	19	2	4	4	5	1
Idiognathoides fossatus	7	19	49	22	34		21	>200	9	20
Idiognathoides postsulcatus									2?	2
Idiognathoides tuberculatus	3	1	2			3	1	170	8	
Idiognathoides lanei	10	10	2	3						
Adetognathus lautus	1									
"Streptognathodus" parvus	2	3	2		1		2		1	
"Streptognathodus" aff. *"S." parvus*										2
Idiognathodus aljutovensis		12						1		1
Idiognathodus incurvus					4				2	
Idiognathodus sinuosus	3	5		6	18		20	15	3	5
Idiognathodus volgensis								1		
Idiognathodus praedelicatus	3		1	2	8					
Idiognathodus aff. *I. klapperi*	7	11		1	2					
Idiognathodus spp.	6				20				14	5
Neognathodus kanumai		1								
Neognathodus sp.				1						
Diplognathodus coloradoensis					1					
Diplognathodus ellesmerensis										1
Total weight of the sample (kg)	9	9	9	9	11	4	12	10	15	12

Limestone I_4, 0.4 m thick in the Malo-Mykolaivka section and 0.3 m thick in the Zolota Valley section. In the Malo-Mykolaivka section, it occurs 45 m above the limestone I_3. It is dark-grey bioclastic packstone and grainstone with silty layers, with thin beds in places. *Idiognathoides* species dominate but the species of *Idiognathodus* also common in both sections. Algae, ostracods, foraminifers, fish remains and coral fragments occur.

Limestone I_4^1, 0.2 m thick in the Zolota Valley sections. In the Malo-Mykolaivka section, this limestone was not found. In the Zolota Valley, this limestone is brownish-grey packstone, bedded, silty, with small number of conodonts of *Idiognathoides* and corals.

Limestone K_1, 0.9 m thick in the Malo-Mykolaivka section (Fig. 7B) and 1.2 m thick in the Zolota Valley section (Fig. 7C). Grey and dark grey bioclastic packstone, fine grained grey peloidal wackestone, crinoidal at the top, in the middle part lense-like algae interlayer occurs, the base with crinoids, rare brachiopods and ostracods. Rich conodont association contains abundant conodonts of the *Idiognathoides* genus and rather numerous species of *Idiognathodus*. The top of limestone K_1 is much more productive for conodonts than the middle part or the base. The same conodont association is characteristic of the top of limestone K_1 in the Zolota Valley section. Here the FAD of *Declinognathodus donetzianus* was established by only single specimens of *D. donetzianus* in both sections.

Limestone K_2, 0.7 m thick in the Zolota Valley section and 0.6 m thick in the Malo-Mykolaivka section (Fig. 7D). In the Malo-Mykolaivka section, the limestone occurs 85 m above the limestone K_1. Between these limestones a thick green-brownish sandstone (Fig. 8), which is so-called

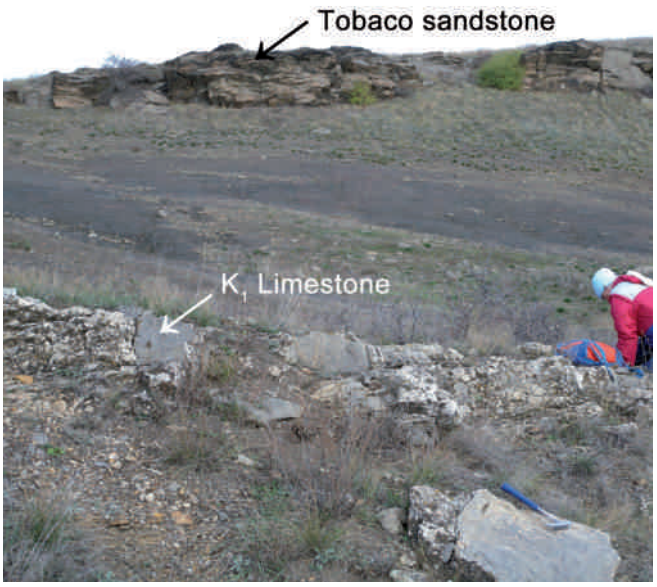


Figure 8. K_1 limestone and "tobacco sandstone" of the Malo-Mykolaivka section, marine shales between them. Estwing hammer for scale = 33 cm length.

"tobacco sandstone" due to its colour, with flora occurs. In the Zolota Valley section, K_2 is grey wackestone/packstone with *Idiognathoides* and *Declinognathodus* species. Seven specimens of *D. donetzianus* were identified. In the Malo-Mykolaivka section, it is mostly grainstone and packstone. The upper part is dolomitized, middle part with *Donezella*, dolomitic layer at the bottom. The conodonts are not numerous. *Idiognathoides* species dominate. Algae, bryozoans and crinoids occur.

Limestone K_3, 1.3 m thick in the Malo-Mykolaivka section (Fig. 7A). This dark nodular limestone occurs 60 m above the K_2 limestone. It is sandy at the base. In the Malo-Mykolaivka section, 15 cm above the base it is a dark grey wackestone with *D. marginodosus* (58 specimens), higher thinly bedded grey and dark grey wackestone/packstone occur. Below the base of this limestone in both sections a coal seam occurs. In both sections *D. marginodosus* dominate. *Idiognathoides* species play subordinate role. In the Zolota Valley, 8 *D. donetzianus* were found. Crinoids and ostracods occur.

3.1.2. Karaguz (KA) and Pashenna (PA) sections (Fig. 5; Table 3)

Limestone K_2 (KA), 0.65 m to 1.1 m thick. It is bioclastic grainstone/packstone found mostly in chunks. *Idiognathoides* species dominate. *Declinognathodus donetzianus* and *D. marginodosus* are common. Few *Idiognathodus* species occur.

Limestone K_3 (KA), 1.5 m thick bioclastic grainstone with some algae in places, *Idiognathoides* species and *Idiognathodus sinuosus* Ellison & Graves, 1941 are common. *Declinognathodus donetzianus* is rare. *Declinognathodus marginodosus* dominates in Limestone K_3 of the Pashenna section. In the Karaguz section it contains foraminifers *Eofusulina triangula* (Rauzer-Chernousova & Beljaev *in* Rauzer-Chernousova *et al.*, 1936), brachiopods, crinoids, ostracods, gastropods and others. These fossils are common in the Pashenna K_3 Limestone.

Limestone K_3^1 (PA), 0.35 m thick. It is grey to dark grey bioclastic limestone with conodonts mostly *Declinognathodus marginodosus*, few *D. donetzianus* and foraminifers (*Ozawainella* abundant, *Eofusulina triangula* common).

Limestone K_4 (PA), float 2.1 m thick. Bioclastic limestone. Mostly crinoidal and fusulinid grainstone. Conodonts are not numerous, *Declinognathodus marginodosus* is common, few *D. donetzianus* and *Idiognathoides corrugatus* (Harris & Hollingsworth, 1933) occur. Brachiopods (*Choristites*) occur.

Limestone K_5 (PA), float 0.8 m thick. Grey wackestone, partly dolomitized, partly with fine sand-carbonate muddy interlayers. Conodont association contains *Declinognathodus donetzianus* and *Idiognathodus* species.

Table 3. Numerical chart of the conodonts from the Pashenna Valley and Karaguz Valley sections (updated from Nemyrovska, 1999, figs 24, 25).

	Karaguz		Pashennaya Valley					
Stage	Moscovian		Moscovian					
Limestone	K_2	K_3	K_3	K_3^1	K_4	K_5	K_6	K_6^3
Declinognathodus marginodosus	19	1	18		11	1	95	
Declinognathodus donetzianus	27	2		8	2	5	12	
Idiognathoides sinuatus	18	11		4			30	
Idiognathoides corrugatus					5		34	
Idiognathoides fossatus	97	12				4	45	
Idiognathoides postsulcatus							5	
Idiognathoides tuberculatus	71						32	
Idiognathodus sinuosus	78	16						
Idiognathodus aljutovensis	6			3		2	1	
Idiognathodus aff. *I. klapperi*				3				
Idiognathodus sp. A Grubbs	2							1
Idiognathodus spp.	8	3	5	15		11	2	50
"*Streptognathodus*" *parvus*	15	7						
"*Streptognathodus*" aff. "*S.*" *parvus*						3	4	85
"*Streptognathodus*" *transitivus*							4	18
"*Streptognathodus*" sp. 1						4	5	
Neognathodus aff. *N. bothrops*				2				
Idiognathodus volgensis						1		
Idiognathodus aff. *I. volgensis*		1						
Neognathodus aff. *N. caudatus*							2	
Neognathodus atokaensis							1	3
Neognthodus sp.							1	
Adetognathus lautus	3							
Diplognathodus ellesmerensis						1		
Mesogondolella donbassica								15
Total weight of the sample (kg)	13	10	8	6	10	6	10	10

The FOD of *Diplognathodus ellesmerensis* (1 specimen) is registered. Fusulinids are abundant, and ostracods are common.

Limestone K_6 (PA), float, 0.4 m thick. Bioclastic limestone, mostly platy, thinly bedded wackestone, some interlayers of packstone occur. *Declinognathodus marginodosus* and *Idiognathoides sinuatus* and *Id. fossatus* (Branson & Mehl, 1941) dominate. The FOD of "*Streptognathodus*" *transitivus* is recorded at this level.

Limestone K_6^3 (PA), float, the chunks of bioclastic limestone, grey and yellow-brownish, sandy in places, rarely muddy in places. Abundant conodonts, "*Streptognathodus*" aff. "*S.*" *parvus* dominates. FODs of *Neognathodus atokaensis* and *Mesogondolella donbassica* (Kossenko, 1975) are recorded at this level.

The numerical distribution of conodonts in the studied sections show that the most common conodonts are *Idiognathoides sinuatus* and *Id. corrugatus*. *Idiognathoides fossatus* and *Id. tuberculatus* join them in the upper Bashkirian in the upper part of the C_2^4 (I) Suite. An insignificant quantity of *Id. sulcatus* and *Id. sulcatus parvus* are also recorded at that level. Several specimens of *Id. postsulcatus* were found in limestones K_2-K_6 of the C_2^5 (K) suite of the lower Moscovian. Numerous conodonts of *Declinognathodus* are found in all limestones of the upper part of the Bashkirian through the lower half of the C_2^5 (K) Suite of the Moscovian. The lineage *D. noduliferus – D. marginodosus – D. donetzianus* is traced from the basal limestones of the C_2^4 (I) Suite through the middle of the C_2^5 (K) Suite (limestones I_2– K_7).

Declinognathodus donetzianus was found in the Zolota Valley and Malo-Mykolaivka sections in the uppermost part of limestone K_1 of the C_2^5 (K) Suite, which in the Ukrainian Regional Stratigraphic Scheme still belongs to the uppermost Kayalian Regiostage of the uppermost Bashkirian (Fig. 2) (Poletaev *et al*., 2013). Although only a single specimen of *D. donetzianus* was found in limestone K_1, it had fully developed features of the species (Fig. 6). As the lineage *D. marginodosus – D. donetzianus* can be traced in other regions as well, although not as distinct as in the Donets Basin, the FAD of *D. donetzianus* can serve as a most reliable level for recognition of the Bashkirian-Moscovian boundary. In fact, it is reasonable as *D. donetzianus* occur at the base of the Moscovian Stage in its type area. The distribution pattern of conodonts in the Zolota Valley is very close to that of the Malo-Mykolaivka section and of the Kholodna Valley as well (Figs 3-5).

3.2. The conodonts

Most sections were first measured and sampled for conodonts in the 1970s and 1980s. Later in 1990s, when the Carboniferous Subcommission started to work on the refinement of the Carboniferous stage boundaries, they were re-studied along with additional new good sections spanning the Bashkirian-Moscovian transition. The detail studies of some of them are still in progress.

One of such new sections is the Malo-Mykolaivka section found about twelve years ago by advice of famous late Ukrainian Carboniferous paleobotanist Prof. O. Fissunenko (Lugansk State University, Donets Basin). It contains probably the most complete conodont and fusulinid succession of the Bashkirian-Moscovian transition in the Donets Basin (Ueno & Nemyrovska, 2008; Nemyrovska *et al*., 2010).

The samples from all sections were treated with formic acid and subsequently separated with heavy liquid. More than a thousand conodont elements were recovered. Most of them are the platform elements. Ramiform elements are rare.

Twenty-three conodont species belonging to nine genera were identified. Several platform elements are in open nomenclature. The studied interval is characterized by rather rich taxonomically and numerically conodont association, in which the idiognathoidids dominate (Tables 1, 2, 3). The most conservative species *Idiognathoides sinuatus* (= *Id. corrugatus*) and *Id. sulcatus sulcatus* are known from the beginning of the Bashkirian and dominate throughout the Bashkirian and early Moscovian in the Donets Basin. The majority of idiognathoidids in the Donets Basin became extinct by the top of the Kam'iankian Horizon of the lower Lozovian. *Idiognathoides sinuatus*, *Id. sulcatus*, *Id. tuberculatus* Nemirovskaya *in* Kozitskaya *et al*., 1978, *Id. lanei* Nemirovskaya *in* Kozitskaya *et al*., *Id. fossatus* [= *Id. ouachitensis* (Harlton, 1933)], are characteristic of the uppermost Bashkirian (all limestones of the C_2^4 (I) Suite) and *Id. postsulcatus* of the C_2^5 (K) Suite.

The species of the *Declinognathodus* are common in the Lower Pennsylvanian. They dominate in different parts of Bashkirian and lower Moscovian. Their importance for biostratigraphy is difficult to overestimate. The mid-Carboniferous or Mississippian-Pennsylvanian boundary is defined by the evolutionary appearance of *D. noduliferus* s. l. (Lane *et al*., 1985, 1999; Nemirovskaya, 1982; Nemyrovska, 1999). A few specimens of *D. noduliferus* occur for the last time in the basal beds of the C_2^4 (I) Suite (limestone I_2). In the Bashkirian-Moscovian boundary interval, the youngest species of *Declinognathodus* represented by the *D. marginodosus* and *D. donetzianus*. The lineage *D. noduliferus – D. marginodosus – D. donetzianus* is well documented in the Zolota Valley (Nemyrovska, 1999) and Malo-Mykolaivka sections (Ueno & Nemyrovska, 2008; Nemyrovska *et al*., 2010) (Figs 3-4, 6).

The species of *Idiognathodus* occurring in the Bashkirian-Moscovian boundary interval are: *I. sinuosus*, *I. incurvus* Dunn, 1966, *I. aljutovensis* Alekseev *et al*., 1994, *I. volgensis* Alekseev *et al*., 1994 and a number of species in the open nomenclature. The entry of genus *Idiognathodus* is recorded in the mid-Bashkirian in the Donets Basin and in a whole Europe and China.

The *Neognathodus* species are not common in the Bashkirian-Moscovian boundary interval. These are as follows: *N. kanumai* Igo, 1974, *N. atokaensis*, *N.* aff. *N. bothrops*, *N.* aff. *N. caudatus* Lambert, 1992, and some forms in open nomenclature. Among others, *N. atokaensis* is more common and first recorded at the top of the studied interval (Table 3).

In the lower part of the Moscovian, i.e., the lower part of the Lozovian Regiostage or C_2^5 (K) Suite, the first species of the genera *Diplognathodus* and *Mesogondolella* were recorded. The FOD of *Di. ellesmerensis* is in limestone K_3 of the Zolota Valley section. A currently lost specimen of *Di. coloradoensis* (Murray & Chronic, 1965) (or *Di.* aff. *Di. coloradoensis*) was previously found in limestone I_3 of the Malo-Mykolaivka section. FOD of *Mesogondolella donbassica* is registered in limestone K_6^3. These species are rare in this part of the Moscovian. They are widely distributed and are successfully used for correlation by their occurrence.

3.3. Systematic palaeontology

Only the most stratigraphically important species (platform elements) for the Bashkirian-Moscovian boundary are described here.

Family **Gnathodontidae** Sweet, 1988

Genus *Declinognathodus* Dunn, 1966

Type species *Cavusgnathus nodulifera* Ellison & Graves, 1941 [according to the first description (identification)]; lower Pennsylvanian (Morrowan) of North America.

Declinognathodus donetzianus Nemirovskaya, 1990
(Figs 9K-9M, 9Q)

1984 *Declinognathodus noduliferus*, Goreva, pl. 1, figs 15b, 16, 22-23 (non cet.).

1985 *Idiognathoides tuberculatus*, van den Boogaard & Bless, pl. 8, fig. 8 (non cet.).

1985 *Idiognathoides sulcatus*, Savage & Barkelly, p. 1467, figs 10.1-10.4, 10.9-10.12 (non cet.).

1990 *Declinognathodus donetzianus*, Nemirovskaya, p. 40, pl. 1, figs 1-4.

1999 *Declinognathodus donetzianus*, Nemyrovska, p. 53, pl. 2, figs 7, 9, 14.

1999 *Declinognathodus donetzianus*, Nemyrovska *et al*., fig. 3.2.

2001 *Declinognathodus donetzianus*, Alekseev & Govera, p.116, pl. 13, fig. 26; pl. 14, figs 9-11.

2006. *Declinognathodus donetzianus*, Pazukhin *et al*., p. 18, fig. 1.

2009 *Declinognathodus donetzianus*, Kulagina *et al*., pl. 8, figs. 2-3.

2010 *Declinognathodus donetzianus*, Nemyrovska *et al*., fig. 3.2.

2012 *Declinognathodus donetzianus*, Work *et al*., fig. 8.1.

2017 *Declinognathodus donetzianus*, Nemyrovska, pl. 2, figs 22-23.

Material. 65 specimens.

Holotype. IGS NASU, No. 597a-1, Ukraine, Donets Basin, Lugansk County, Lutugino district, the Olkhova River, Pashenna Valley, Moscovian Stage, Lozovian Regio-stage, C_2^5 (K) Suite, limestone K_6 (Nemirovskaya, 1990, pl. 1, fig. 1).

Diagnosis. P_1 elements of arrow-like shape, elongated, narrow. Carina is short, it declines to the rostral parapet in a ventral quarter of the platform. This parapet is reduced down to several nodes. The ventral one or two nodes are parallel to the axis of element, the rest node/nodes declines rostrally and are located up to almost perpendicular to the platform axis or under the acute angle to it.

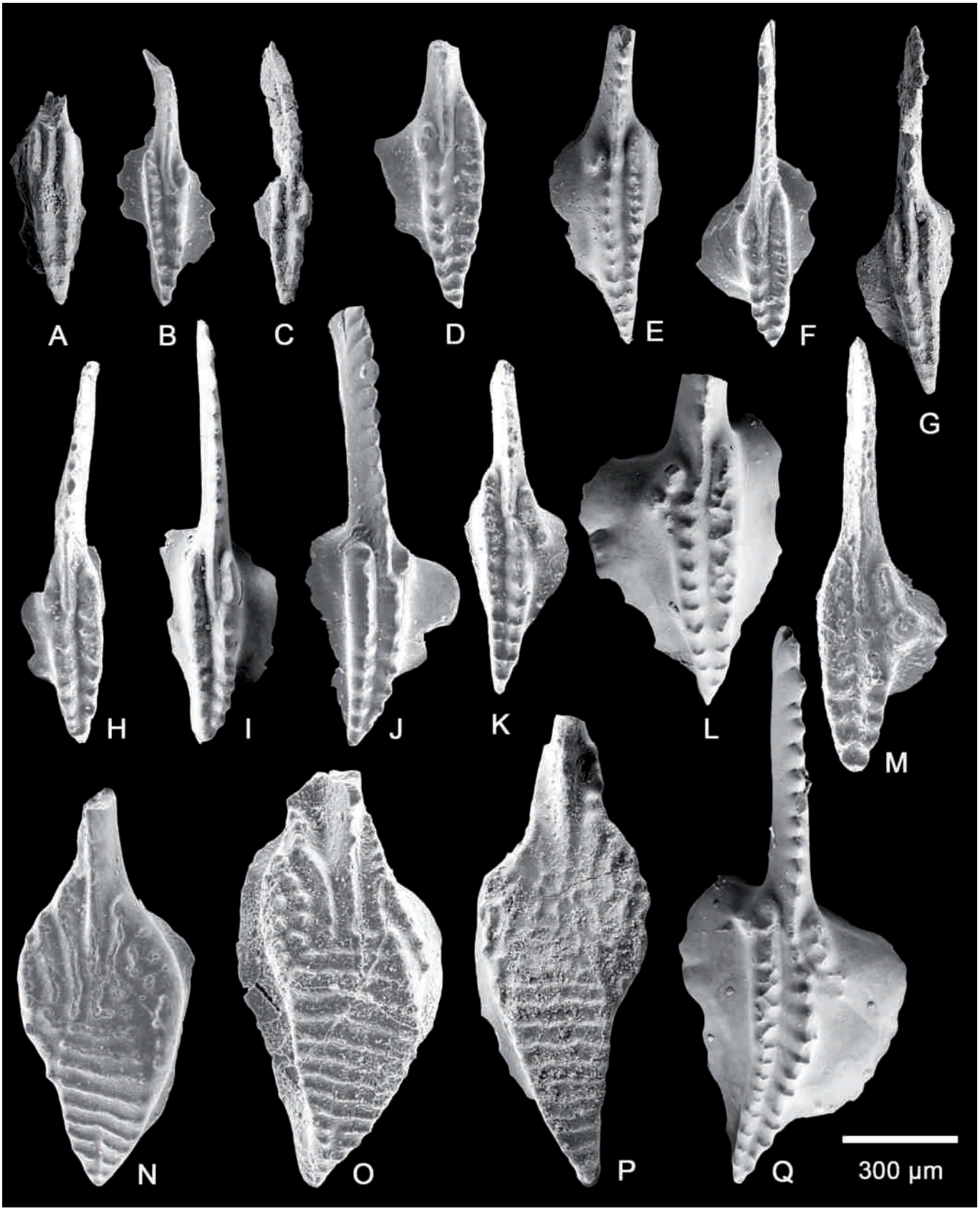
Description. The free blade connects to the oblong narrow platform in the middle position and passes into a short carina that declines to the rostral parapet in the ventral quarter of the platform. The degree of declination of the carina varies. The ventral part of the rostral parapet is reduced to 3-6 nodes. Ventral one or two nodes are parallel to the axis of the element, the rest are deflected outwards and are located perpendicular to the axis of the element or at an angle to it (Figs 9K-9M, 9Q).

The deflecting nodes are usually discrete. Short carina is nodular, sometimes represented by merged nodes and looks like a longitudinal rib. The caudal parapet is also nodular, the distances between the nodes increase on the parapets towards the dorsal end.

Remarks. The main difference from the closely related *Declinognathodus marginodosus* and the group of species *D. noduliferus* is the presence of deflection of the rostral reduced parapet rostrally at an angle to the longitudinal axis of the element and the associated additional nodes on the rostral side of the platform. The illustrated specimens of *D. donetzianus* from the Moscow Syneclise (Alekseev & Goreva *in* Makhlina *et al*., 2001, pl. 13, figs 26; pl. 14, figs 9-11) are almost identical to our specimens. In general, the conodont association of early Lozovian (early Moscovian) of the Donets Basin is very similar to the early Vereian conodonts of the Moscow Basin. The illustrated specimens of *D. donetzianus* from the Volga-Ural region (see Sungatullina, 2014, text-figs 11-13) are similar to ours. The first author has examined the specimens illustrated by van den Boogaard & Bless (1985, pl. 8, fig. 8) from the Bolsovian of Western Europe and considered that those specimens belong to *D. donetzianus* as well. As to the illustrated specimens of *D. donetzianus* from the Basu section, South Urals (Kulagina *et al*., 2009, pl. 8, figs 2-3), but the presence of the rostrally deflected nodes permits to refer them to *D. donetzianus* although their ventral part including carina and free blade is broken. One specimen of *D. donetzianus* from the lower Atokan of the Appalachian Basin in the eastern U.S.A. (Work *et al*., 2012, fig. 8.1) displays main features of *D. donetzianus*, however, it is not identical to the typical ones from the Donets Basin by a thick ridge (not additional nodes) deflected rostrally on the ventral part of the expansion of the basal cavity.

Range. Middle Pennsylvanian - the lower part of the Moscovian Stage, the Vereian Substage (Horizon) of Russia (Moscow Syneclise, the South Urals, Volga-Urals region), Ukraine (the Donets Basin), the lower part of the Bolsovian Stage (Aegiranum marine Band) of Great Britain, the upper part of the Atokan of North America (Alaska).

Occurrence. The lower part of the lower Moscovian Stage (lower Lozovian, the C_2^5 (K) Suite, limestones K_1-


A
B
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K
L
M
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Q
300 µm

K_7 of the Donets Basin. The FAD of *Declinognathodus donetzianus* was recorded first at limestone K_3 in the Karaguz section, later 10 specimens were found in limestone K_2 of the Karaguz and 7 specimens in the Zolota Valley section. After 1999 single specimens of *D. donetzianus* were found at the top of limestone K_1 in the Zolota and Malo-Mykolaivka sections. *Declinognathodus donetzianus* occurs in every limestone up to limestone K_7.

Declinognathodus marginodosus (Grayson, 1984)
(Figs 9A-9J)

1978 *Declinognathodus noduliferus*, Nemirovskaya *in* Kozitskaya *et al*., p. 30, pl. 25, figs 10-14 (non cet.).

1981 *Declinognathodus noduliferus inaequalis*, Méndez & Menéndez-Álvarez, fig. 3.1.

1981 *Declinognathodus noduliferus noduliferus*, Méndez & Menéndez-Álvarez, fig. 3.2.

1984 *Idiognathoides marginodosus*, Grayson, 50, pl. 1, figs 3-4, 7, 9-11, 13-14 (non figs 16, 18 = *Idiognathoides sulcatus*); pl. 2 figs 8, 9, 17 (non fig. 4 = *Id. sulcatus*).

1984 *Declinognathodus noduliferus*, Goreva, pl. 1, figs 14, 17-21.

1990 *Declinognathodus marginodosus*, Nemirovskaya, 42, pl. 1, figs 5-11.

1990 "*Declinognathodus*" *marginodosus*, Grayson *et al*., 365, pl. 1, fig. 28 (non cet.).

1992 *Declinognathodus marginodosus*, Sutherland & Grayson, pl. 2, fig. 11.

1993 *Declinognathodus marginodosus*, Nemirovskaya & Alekseev, pl. 3, figs 5-6.

1995 *Declinognathodus marginodosus*, Nemirovskaya & Alekseev, pl. 1, figs 9-10.

1999 *Declinognathodus marginodosus*, Nemyrovska, p. 54, pl. 2, figs 2, 8, 11-12, 17.

1999 *Declinognathodus marginodosus*, Nemyrovska *et al*., fig. 3.8.

2001 *Declinognathodus marginodosus*, Alekseev & Goreva in Makhlina *et al*., p. 117. pl. 13, figs 21-25; pl. 14, figs 4-6.

2009 *Declinognathodus marginodosus*, Kulagina *et al*., pl. 8, fig. 1.

2010 *Declinognathodus marginodosus*, Nemyrovska *et al*., fig. 3.2.

2016 *Declinognathodus marginodosus*, Qi *et al*., figs. 9D-9F, 9K

2017 *Declinognathodus marginodosus*, Hu *et al*., figs 4R, 4S.

2017 *Declinognathodus marginodosus*, Nemyrovska, pl. 2 figs 20-21

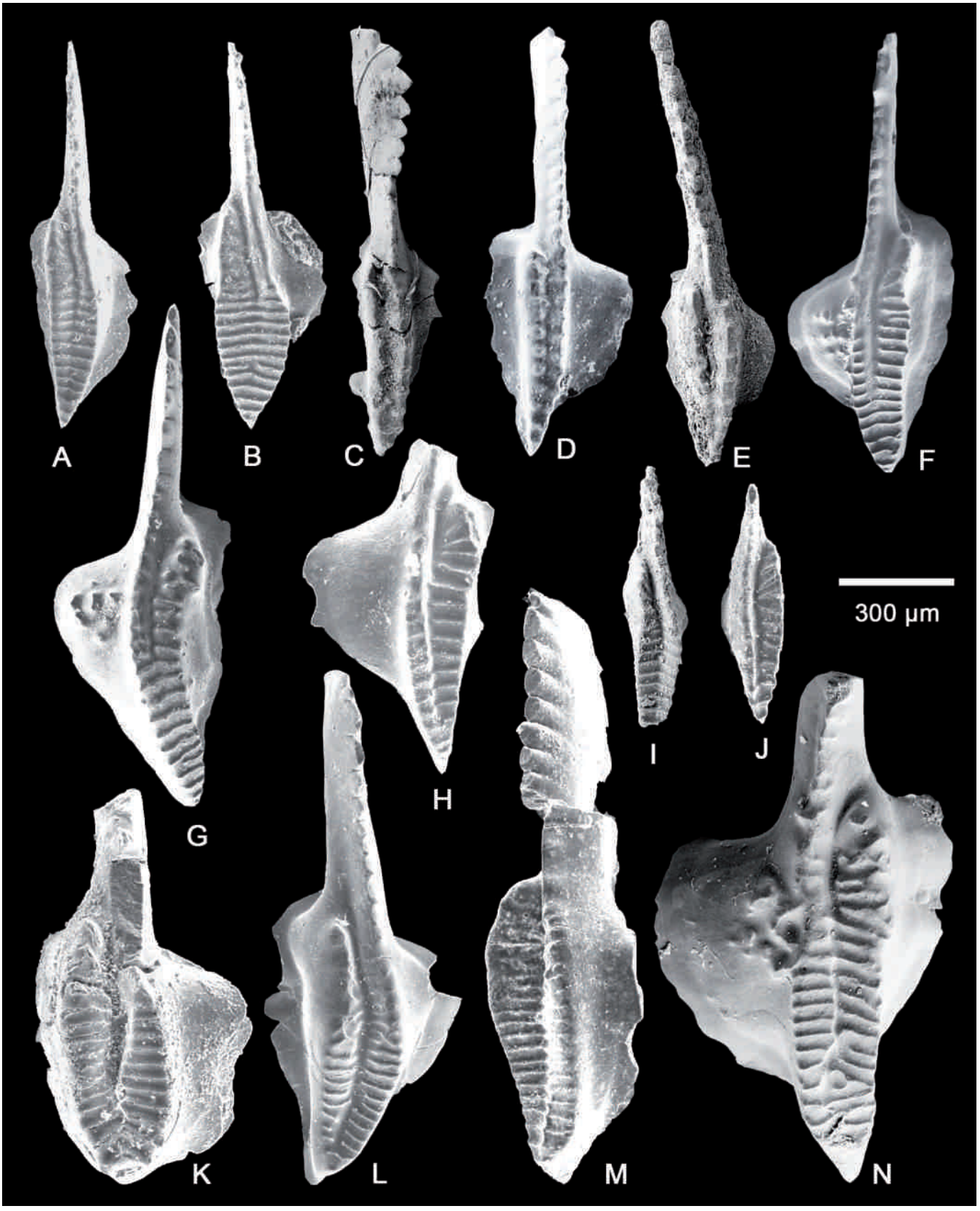
Material. 423 specimens.

Holotype. OU7151 (sample No. 274-17C), U.S.A., Arbuckle Mountains, Southern Oklahoma, Atokan Stage, Pennsylvanian, Atoka Formation (Grayson, 1984, pl. 1, fig. 13).

Diagnosis. The platform is elongated, narrow, with a pointed dorsal end. A short carina declines to the rostral parapet and merges with it in the ventral quarter of the platform. The reduced ventral part of the rostral parapet is represented by a node or a short longitudinal ridge and is isolated from the rest of the parapet-carina. The median groove is wide and deep.

Remarks. The majority of specimens in our collection and those illustrated from the other area have a distinct

Figure 9. *Declinognathodus* and *Idiognathodus* species from the studied sections. All specimens are with the same magnification; scale bar = 300 μm. **a)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0914, Limestone K_4, Pashenna Valley section. **b)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0935, Limestone K_1, Malo-Mykolaivka section. **c)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0936, Limestone K_3, Karaguz Valley section. **d)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0937, Limestone K_2, Malo-Mykolaivka section. **e)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0915, Limestone K_2, Zolota Valley section. **f)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0890, Limestone K_1, Malo-Mykolaivka section. **g)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0916, Limestone K_4, Pashenna Valley section. **h)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0891, Limestone I_2, Malo-Mykolaivka section. **i)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0918, Limestone K_5, Pashenna Valley section. **j)** *Declinognathodus marginodosus* Grayson, 1984, IGSU-0892, Limestone K_1, Malo-Mykolaivka section. **k)** *Declinognathodus donetzianus* Nemirovskaya, 1990, IGSU-0853, Limestone K_1, Malo-Mykolaivka section. **l)** *Declinognathodus donetzianus* Nemirovskaya, 1990, IGSU-0938, Limestone K_6, Pashenna Valley section. **m)** *Declinognathodus donetzianus* Nemirovskaya, 1990, IGSU-0852, Limestone K_2, Zolota Valley section. **n)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0939, Limestone K_1, Malo-Mykolaivka section. **o)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0940, Limestone K_1, Malo-Mykolaivka section. **p)** *Idiognathodus* aff. *I. volgensis* Alekseev *et al*., 1994, IGSU-0910, Limestone K_3, Karaguz Valley section. **q)** *Declinognathodus donetzianus* Nemirovskaya, 1990, IGSU-0941, Limestone K_6, Pashenna Valley section.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isolation of a node or ridge in the ventral part of a rostral parapet. But there occur the morphs with the node or ridge connected to the rest of the parapet or not isolated completely. By the other features they are a part of population of *D. marginodosus* (Figs 9G, 9I).

Declinognathodus marginodosus differs from *D. noduliferus* s. l. by having a distinct isolation of a large node that is a reduced ventral part of the rostral parapet, a smooth, strong carina and larger distances between the nodes on the parapets. *Declinognathodus marginodosus* differs from the very similar *D. donetzianus* in the absence of rostrally deflected additional nodes located at an angle to the rostral parapet on the rostral platform expansion.

Range. The uppermost part of the Bashkirian Stage–lower part of the Moscovian Stage of Europe and Asia. Upper part of the Morrowan – Atokan of North America.

Occurrence. Upper part of the upper Bashkirian (Upper Kayalian)– lower part of lthe lower Moscovian Lower Lozovian, C_2^4(I) – C_2^5 (K) suites, limestones I_2 – K_6 of the Donets Basin.

Genus *Idiognathoides* Harris & Hollingsworth, 1933

Type species *Idiognathoides sinuata* Harris & Hollingsworth, 1933 (according to the first designation); Lower Pennsylvanian (Morrowan) of North America.

Idiognathoides postsulcatus Nemyrovska, 1999.
(Fig. 10D)

1964 *Gnathodus opimus*, Igo & Koike, 189, pl. 28, figs 15-17 (only).

1965 *Gnathodus opimus*, Igo & Koike, 89, pl. 9, figs 1-3 (only).

1980 *Gnathodus opimus sensu lato* Morphotype 1, Bender, p. 12-13, pl. 2, figs 8-9, 15-16, 23-24, 29-31, 34, 38.

1981 *Idiognathoides sulcatus sulcatus*, Méndez & Menéndez-Álvarez, fig. 3.7.

1984 *Idiognathoides marginodosus* morphotype C, Grayson, 50, pl. 1, figs 16, 18; pl. 2, fig. 19; pl. 3, figs 4, 10, 12, 14; pl. 4, figs 16, 21, 23.

1985 *Idiognathoides sulcatus*, van den Boogaard & Bless, p. 150, fig. 9: 6-7.

1985 *Idiognathoides sulcatus*, Savage & Barkeley, p. 1467-1469, fig. 10: 5-8 (only).

1995 *Idiognathoides sulcatus*, Nemirovskaya & Alekseev, pl. 1, fig. 19 (only).

1999 *Idiognathodus postsulcatus*, Nemyrovska, p. 68, pl. 3, figs 9, 18.

1999 *Idiognathodus postsulcatus*, Nemyrovska *et al*., fig. 3.3.

2016 *Idiognathodus postsulcatus*, Qi *et al*., figs 11K-11M.

2017 *Idiognathodus postsulcatus*, Hu *et al*., figs 5F-5G.

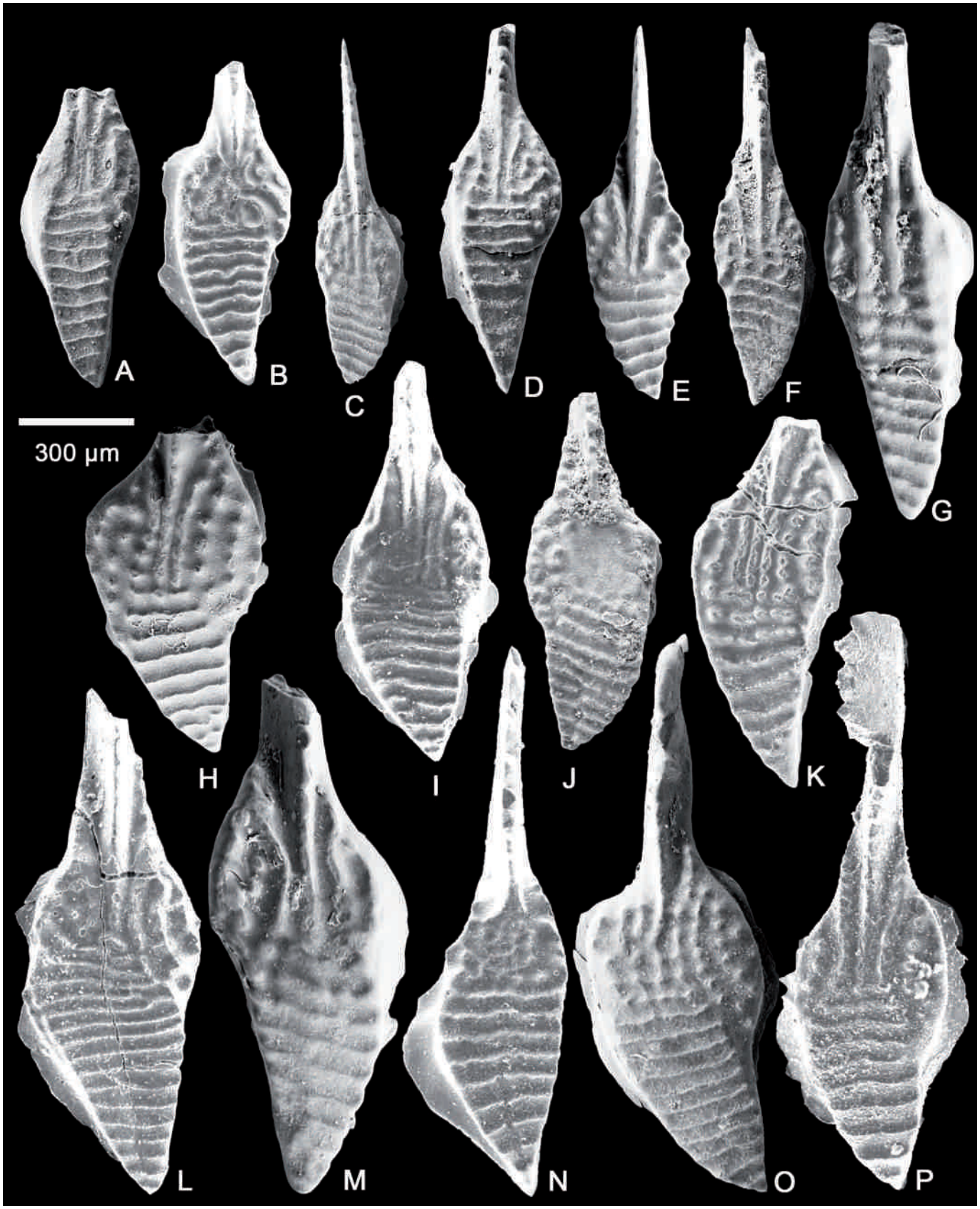
2017 *Idiognathodus postsulcatus*, Nemyrovska, pl. 2, figs 18, 19.

Material. 24 specimens.

Holotype. IGSU-Pash-1, Ukraine, Donets Basin, Lugansk County, Lutugino district, the Olkhova River, Pashenna Valley, Moscovian Stage, Lozovian Regiostage, C_2^5 (K) Suite, limestone K_6 (Nemyrovska, 1999, pl. 3, fig.18).

Diagnosis. P_1 elements with long nodular parapets of equal height and narrow and shallow groove between them. The nodes of the parapets are tightly spaced. Both platform sides asymmetrically convex.

Figure 10. *Idiognathoides* species from the studied sections. All specimens are with the same magnification; scale bar = 300 μm. **a)** *Idiognathoides corrugatus* (Harris & Hollingsworth, 1933), IGSU-0901, Limestone I_2^1, Malo-Mykolaivka section. **b)** *Idiognathoides corrugatus* (Harris & Hollingsworth, 1933), IGSU-0911, Limestone K_1, Malo-Mykolaivka section. **c)** *Idiognathoides* aff. *postsulcatus* Nemyrovska, 1999, IGSU-0917, Limestone K_2, Zolota Valley section. **d)** *Idiognathoides postsulcatus* Nemyrovska, 1999, IGSU-Pash-1, Limestone K_6, Pashenna Valley Section. **e)** *Idiognathoides* aff. *postsulcatus* Nemyrovska, 1999, IGSU-0929, Limestone K_2, Zolota Valley section. **f)** *Idiognathoides tuberculatus* Nemirovskaya *in* Kozitskaya *et al*., 1978, IGSU-597a/7, Limestone K_6, Pashenna Valley section. **g)** *Idiognathoides tuberculatus* Nemirovskaya *in* Kozitskaya *et al*., 1978, IGSU-0903, Limestone I_3, Malo-Mykolaivka section. **h)** *Idiognathoides sinuatus* Harris & Hollingsworth, 1933, IGSU-0902, Limestone I_3, Malo-Mykolaivka section. **i)** *Idiognathoides corrugatus* (Harris & Hollingsworth, 1933), IGSU-0930, Limestone K_2, Zolota Valley section. **j)** *Idiognathoides sinuatus* Harris & Hollingsworth, 1933, IGSU-0931 Limestone K_2, Malo-Mykolaivka section. **k)** *Idiognathoides fossatus* (Branson & Mehl, 1941), IGSU-0932, Limestone I_3, Malo-Mykolaivka section. **l)** *Idiognathoides fossatus* (Branson & Mehl, 1941), IGSU-0904, Limestone K_1, Malo-Mykolaivka section. **m)** *Idiognathoides fossatus* (Branson & Mehl, 1941), IGSU-0933, Limestone I_3, Malo-Mykolaivka section. **n)** *Idiognathoides tuberculatus* Nemirovskaya *in* Kozitskaya *et al*., 1978, IGSU-0934, Limestone I_3, Malo-Mykolaivka section.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Description. P_1 elements are straight, narrow, elongated, sometimes they are slightly curved caudally. The parapets are equal in height and separated mostly by narrow and shallow groove. Both sides of platform are asymmetrical and very convex. The greater convexity is in the ventral part of the platform. The blade and the platform are almost of equal length. In our small collection only dextral elements were found.

Remarks. *Idiognathoides postsulcatus* is very similar to its ancestor *Id. sulcatus sulcatus* and was assigned to the latter as a rule. Nevertheless *Id. postsulcatus* differs from its ancestor by its longer parapets, narrower platform, very asymmetrical convex platform sides. 2 specimens (Figs 10C, 10E) were identified as *Id.* aff. *Id. postsulcatus*. The main reason why they are not assigned to *Id. postsulcatus* is presence of wide and rather deep groove. The latter features make them closer to *Id. sulcatus sulcatus*. *Idiognathoides postsulcatus* differs from *Id. sulcatus parvus* by equal length of parapets and very convex platform sides.

Range. Lower Moscovian of Donets Basin, Ukraine, Urals, Russia (Nemirovskaya & Alekseev, 1995), Omi and Akioshi Limestones, Japan (Igo & Koike, 1964). It was found in the Cantabrian Mountains, Spain (Méndez & Menéndez-Álvarez, 1981), Atokan, North America (Sverdrup Group of the Canadian Arctic (Bender, 1980), and Arbuckle Mountains, Oklahoma (Grayson, 1984), Klavak Formation of Alaska (Savage & Barkeley, 1985), North America, Aegiranum marine Band, basal Bolsovian of Western Europe (van den Boogaard & Bless, 1985) and upper Bashkirian and lower Moscovian of China (Qi *et al*., 2016; Hu *et al*., 2017).

Occurrence. Lower part of the Moscovian, lower part of the Lozovian, C_2^5 (K) Suite, limestones K_2 – K_6 of the Karaguz and Pashenna Valley, Donets Basin.

Family **Sweetognathidae** Ritter, 1986

Genus *Diplognathodus* Kozur & Merrill *in* Kozur, 1975

Type species *Spathognathodus coloradoensis* Murray & Chronic, 1965 (according to the first designation); Pennsylvanian, Demoinsian of North America.

Diplognathodus ellesmerensis Bender, 1980
(Figs 12G, 12H)

1980 *Diplognathodus ellesmerensis*, Bender, p. 9, pl. 4, figs 5-7, 11, 15-21, 23-25.

1985 *Diplognathodus ellesmerensis*, van den Boogaard & Bless, p. 23, pl. 1, fig. A.

1999 *Diplognathodus ellesmerensis*, Nemyrovska, pl. 11, figs 14, 15

1999 *Diplognathodus ellesmerensis*, Nemyrovska *et al*., fig. 6.6.

2001 *Diplognathodus ellesmerensis*, Goreva & Alekseev *in* Makhlina *et al*., p. 116, pl. 14, fig. 17; pl. 17, fig. 21.

2003 *Diplognathodus ellesmerensis*, Wang & Qi, pl. 4, figs 6, 7.

2004 *Diplognathodus ellesmerensis*, Wang *et al*., pl. 3, fig. 8.

2007 *Diplognathodus ellesmerensis*, Nemyrovska *in* Fohrer *et al*., figs 15.2, 15.4, 15.7.

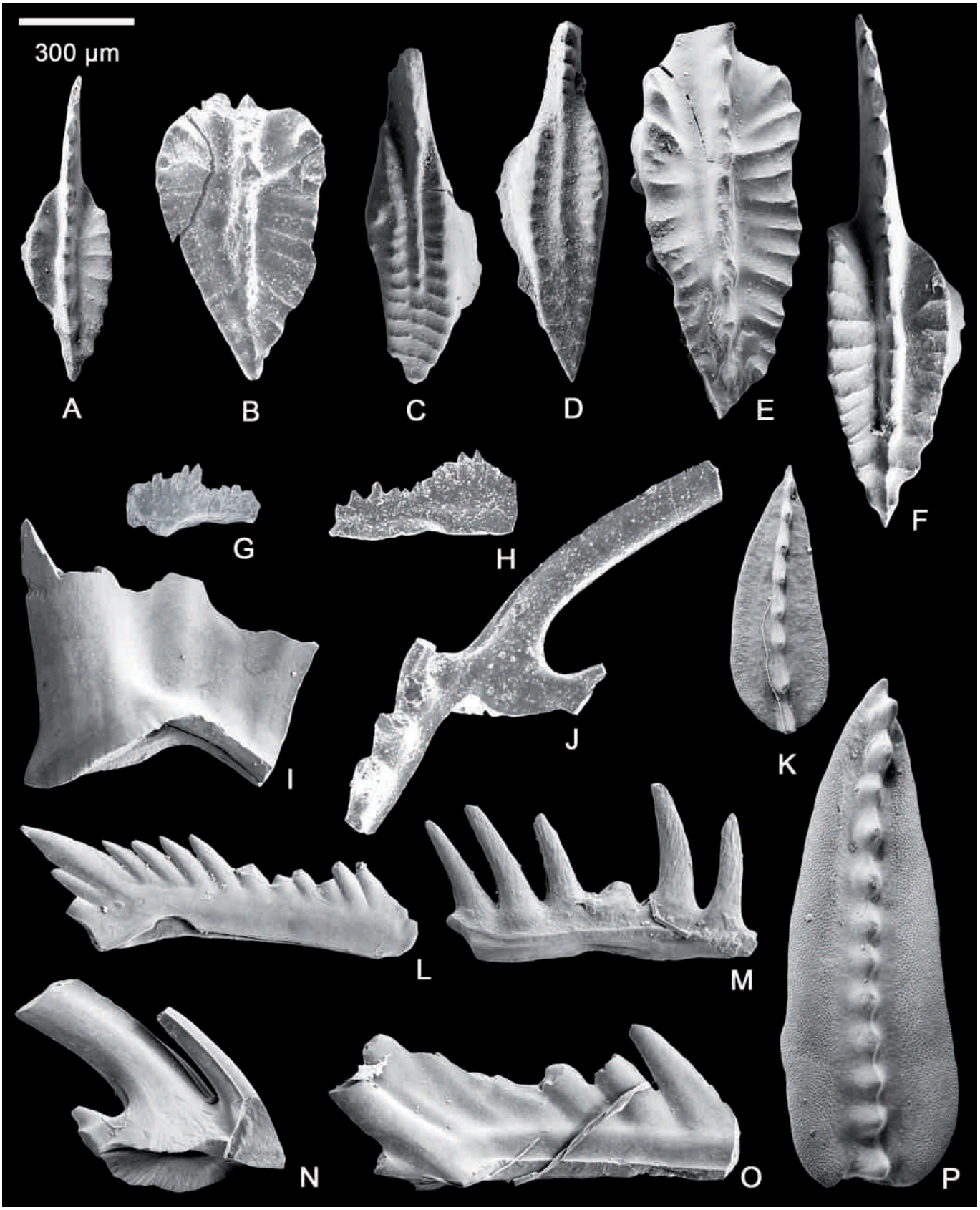
2016 *Diplognathodus ellesmerensis*, Qi *et al*., figs 7A, 7B.

2016 *Diplognathodus ellesmerensis*, Scomazzon *et al*., figs. 10.27-10.31.

2017 *Diplognathodus ellesmerensis*, Nemyrovska, pl. 3, figs 10-11.

2017a *Diplognathodus ellesmerensis*, Cardoso *et al*., p. 81, fig. 4.13.

Figure 11. *Idiognathodus* species from the studied sections. All specimens are with the same magnification; scale bar = 300 μm. **a)** *Idiognathodus* sp., IGSU-0945, Limestone K_3, Karaguz Valley section. **b)** *Idiognathodus* sp., IGSU-0946, Limestone I_2, Malo-Mykolaivka section. **c)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0907, Limestone K_5, Karaguz Valley section. **d)** *Idiognathodus* sp., IGSU-0947, Limestone K_3, Karaguz Valley section. **e)** *Idiognathodus* sp., IGSU-0948, Limestone K_6, Pashenna Valley section. **f)** *Idiognathodus* sp., IGSU-0949, Limestone K_3, Karaguz Valley section. **g)** *Idiognathodus* sp., IGSU-0909, Limestone K_6, Pashenna Valley section. **h)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0950, Limestone K_6, Pashenna Valley section. **i)** *Idiognathodus sinuosus* Ellison & Graves, 1941, IGSU-0892, Limestone I_3, Malo-Mykolaivka section. **j)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0908, Limestone K_5, Karaguz Valley section. **k)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0893, Limestone I_3, Malo-Mykolaivka section. **l)** *Idiognathodus sinuosus* Ellison & Graves, 1941, IGSU-0900, Limestone I_3, Malo-Mykolaivka section. **m)** *Idiognathodus* sp. A Grubbs, 1984, IGSU-0913, Limestone K_6^3, Karaguz Valley section. **n)** *Idiognathodus* sp., MN-30, IGSU-0927, Limestone K_1, Malo-Mykolaivka section. **o)** *Idiognathodus volgensis* Alekseev *et al*., 1994, IGSU-0912, Limestone K_5, Karaguz Valley section. **p)** *Idiognathodus aljutovensis* Alekseev *et al*., 1994, IGSU-0931, Limestone K_1, Zolota Valley section.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2017b *Diplognathodus ellesmerensis*, Cardoso *et al*., pl. 1, fig. 11.

Material. 11 specimens.

Holotype. GSC, № 49280, Canadian Arctic, Elsmere Island, Middle Pennsylvanian, lower part of the Khea-fiord Formation (Bender, 1980, pl. 4, figs 23-25).

Diagnosis. Small P_1 elements with low subelliptical platform (cup) and high free blade. Carina and blade are decorated by denticles. Between blade and platform there is a distinct notch with several small denticles.

Description. P_1 elements of small size. The platform (cup) with is low, subelliptical, enlarged. The blade is twice or three times higher than the platform, it is ornamented by 5-7 laterally compressed denticles. Carina is covered by rounded unequally high 4-6 denticles. Some of them are tilted forwards. The distance between them is unregular. A distinct notch located between the blade and carina bears several very small denticles. Basal cavity is wide, symmetrical, occupies about three quarter of element length.

Remarks. *Diplognathodus ellesmerensis* differs from the close *Di*. *orphanus* by longer platform and larger basal cavity, higher denticles of free blade, their different shape and by presence of notch between blade and platform. It differs from *Di*. *coloradoensis* by having a longer platform and by different shape and order of the denticles on carina and also by different height of the blade and carina.

Range. *Diplognathodus ellesmerensis* is widely distributed. It is common in the Atokan of North America, Canadian Arctic and lower Moscovian of Europe and Asia (Moscow Syneclise and Urals of Russia; Donets Basin of Ukraine; Cantabrian Mountains of Spain and South China).

Occurrence. Lower Moscovian, lower part of the Lozovian Regiostage, C_2^5 (K) Suite, limestone K_3 of the Zolota Valley section and limestones K_3 – K_6^3 of the Karaguz and Pashenna Valley, Donets Basin.

3.4. Biostratigraphy of the Bashkirian-Moscovian boundary beds by conodonts

Analysis of the conodont distribution across the Bashkirian-Moscovian boundary in the Donets Basin resulted in recognition of several conodont zones in this interval. They are range zones that were established at the end of 1990s (Nemyrovska, 1999) and updated recently (Nemyrovska, 2017).

3.4.1. Idiognathoides tuberculatus – Id. fossatus Zone (Figs 9-11)

The lower boundary is defined by the FAD of the late representatives of the *Idiognathoides* species, *Id*. *tuberculatus* and *Id*. *fossatus*. The upper boundary is determined by the FAD of one of the late species of *Declinognathodus* - *D*. *marginodosus.*

The zone overlaps the interval of the greater part of the C_2^3 (H) Suite and the lower part of the C_2^4 (I) Suite, i.e., the interval between limestones H_3 and I_2. This interval corresponds to the middle part of the Kayalian Regiostage of the Bashkirian Stage of the Ukrainian Stratigraphic Scheme (Poletaev *et al*., 2013). It corresponds to the upper part of the Cheremshanian Substage of the East European Platform (Resolution, 1990).

Besides the name bearers characteristic species in this zone are *Idiognathoides sinuatus* (*Id*. *corrugatus*), *Id*. *sulcatus sulcatus*, *Id*. *sulcatus parvus*, *Id*. *lanei*, *Idiognathodus sinuosus*, *I*. *praedelicatus* Nemyrovska, 1999, *I*. *aljutovensis*, "*Streptognathodus*" *expansus*, "*S*." *suberectus* Dunn, 1966 and others. Such species as "*S*." *expansus* and "*S*." *suberectus* were not found above limestone I_1. *Idiognathoides sinuatus* (*Id*. *corrugatus*) dominates.

Figure 12. *Neognathodus*, *Mesogondolella* and *Diplognathodus* species and ramiforms from the studied sections. All specimens are with the same magnification; scale bar = 300 μm. **a)** *Neognathodus* sp., IGSU-0942, Limestone K_6, Pashenna Valley section. **b)** *Neognathodus* aff. *bothrops* Merrill, 1972, IGSU-174-1, Limestone K_2, Kholodna Valley section. **c)** *Idiognathodus* sp., IGSU-0925, Limestone K_6^3, Pashenna Valley section. **d)** "*Streptognathodus*" *transitivus* Kossenko *in* Kozitskaya *et al*., 1978, IGSU-0854, Limestone K_6^3, Pashenna Valley section. **e)** *Neognathodus* sp., IGSU-0943, Limestone K_6, Pashenna Valley section. **f)** *Neognathodus atokaensis* Grayson, 1984, IGSU-0929, Limestone K_6, Karaguz Valley section. **g)** *Diplognathodus ellesmerensis* Bender, 1980, IGSU-590-2, limestone K_3, Zolota Valley section. **h)** *Diplognathodus ellesmerensis* Bender, 1980, IGSU-0851, Limestone K_3, Malo-Mykolaivka section. **i)** *Idioprioniodus conjunctus* (Gunnell, 1931), M element, IGSU-0920, Limestone K_6^3, Pashenna Valley section. **j)** DE - *Ligonodina roundyi* (Hass, 1953), IGSU-0924, Limestone K_1, Zolota Valley section. **k)** *Mesogondolella donbassica* (Kossenko *in* Kozitskaya *et al*., 1978), IGSU-0944, limestone K_6, Pashenna Valley section. **l)** *Ozarkodina* sp., IGSU-0921, Limestone K_6^3, Pashenna Valley section. **m)** *Ubinates* sp., IGSU-0919, Limestone K_6^3, Pashenna Valley section. **n)** DE - *Roundya* sp., IGSU-0923, Limestone K_6^3, Pashenna Valley section. **o)** DE - ?*Ozarkodina* sp., IGSU-0922, Limestone K_6^3, Pashenna Valley section. **p)** *Mesogondolella donbassica* (Kossenko *in* Kozitskaya *et al*., 1978), IGSU-0926, limestone K_6, Pashenna Valley section.

3.4.2. Declinognathodus marginodosus Zone (Figs 9-11)

The lower boundary of the zone is defined by the FAD of *Declinognathodus marginodosus*. The upper boundary is determined by the FAD of the youngest species of the genus, *D. donetzianus*, which is a direct descendant of *D. marginodosus*.

This zone ranges from limestone I_2 of the upper part of the C_2^4 (I) Suite up to limestone K_1 of the C_2^5 (K) Suite. This interval corresponds to the upper part of the Kayalian Regiostage of the Bashkirian Stage of the Ukrainian Stratigraphic Scheme (Poletaev *et al.*, 2013). It corresponds to the Melekessian Substage of the Unified Scheme of the East European Platform. The lower boundary of this zone was lowered from limestone I_3 down to limestone I_2 since *Declinognathodus marginodosus* was found recently below the limestone I_3 boundary indicated by Nemyrovska (1999).

The conodont association consists mainly of *Idiognathoides* and *Idiognathodus* species that are most abundant in the underlying beds. These are *Id. sinuatus, Id. fossatus, Id. tuberculatus, Id. lanei, I. sinuosus, I. praedelicatus, I. aljutovensis, I. incurvus* and others. *Idiognathoides sinuatus* and *Id. fossatus* dominate. *Idiognathoides corrugatus* still occurs but its role is gradually reduced as it is supplanted by *Id. fossatus*. The index species *D. marginodosus* is found at every level but not in significant quantities.

3.4.3. Declinognathodus donetzianus Zone (Figs 9-12)

The lower boundary of the zone is defined by the FAD of *Declinognathodus donetzianus*. Its upper boundary is determined by the FOD of "*Streptognathodus*" *transitivus* and more advanced species of *Neognathodus*.

The zone overlaps the greater part of the lower C_2^5 (K) Suite. According to the Ukrainian Carboniferous Stratigraphic Scheme this interval corresponds to the uppermost part of the Kayalian Regiostage of the Bashkirian Stage and the lower part of the Lozovian Regiostage of the Moscovian Stage (Poletaev *et al.*, 2013). It corresponds to the uppermost part of the Melekessian Substage and to the Vereian Substage of the Moscovian Stage of the East European Platform (Resolutions, 1990).

The characteristic zonal species are *Id. sinuatus, Id. fossatus,* and *Id. tuberculatus*, known from the previous zone, along with a new early Moscovian species, *Id. postsulcatus*. *Declinognathodus marginodosus* and *D. donetzianus* also play an essential role. Among the *Idiognathodus* species *I. sinuosus, I. aljutovensis, I. praedelicatus, I. incurvus* and *I. volgensis* still occur. Among the new elements, the FOD of *Diplognathodus ellesmerensis* (limestone K_3 in the Zolota and Karaguz valleys) is important. It should be noted that one specimen of *Diplognathodus* aff. *Di. coloradoensis* was found in limestone I_3. Unfortunately, it was lost during SEM photography. Additional collections are necessary to get more *Diplognathodus* specimens.

3.4.4. "Streptognathodus" transitivus Zone (Figs 10-12)

The lower boundary of the zone is defined by the FOD of "*Streptognathodus*" *transitivus*, which was found at the level of limestone K_6. The origin of this species is not known. But discrete, characteristic features and persistent occurrence of this species in the lower Moscovian beds in the Donets Basin and Moscow Syneclise permitted us to distinguish the conodont zone.

Characteristic conodonts of this zone continue to be species of *Idiognathoides*: *Id. sinuatus*, *Id. fossatus*, *Id. tuberculatus, Id. postsulcatus,* and new taxa of *Neognathodus*: *N. atokaensis* and *N.* aff. *N. bothrops*, along with *Diplognathodus coloradoensis* and *Mesogondolella donbassica*. Species of *Declinognathodus* become extinct by that time.

4. SUMMARY

A fairly large variety of conodonts occurring in the Bashkirian-Moscovian boundary interval of the most complete sections in the Donets Basin allow us to refine the biostratigraphy of the above-mentioned deposits. Two conodont lineages established in the Donets Basin and proposed as potential markers for the definition of the Bashkirian-Moscovian boundary are better documented. The additional study has shown that in the Donets Basin, Moscow Syneclise and Urals only one lineage is acceptable with *Declinognathodus donetzianus* as a marker of the Bashkirian-Moscovian boundary but *Idiognathoides postsulcatus* was not found. *Idiognathoides postsulcatus* is distributed in Britain, Spain, China and North America. The entry of *Id. postsulcatus* in South China is much below the FOD of *Diplognathodus ellesmerensis*, another potential marker for the boundary, which occurs close to the traditional Bashkirian-Moscovian boundary. Numerous cosmopolitan species found in the Donets Basin are useful for correlation with other areas. This makes the study of Donets Basin conodonts important for establishing a Bashkirian-Moscovian boundary GSSP.

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