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New Data on Carboniferous Xiphosurans (Xiphosura, Chelicerata) of the Donets Coal Basin

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Abstract—Descriptions of four xiphosuran species belonging to two genera, *Bellinurus* Pictet, 1846 and *Prestwichianella* Woodward, 1918 (currently included in *Euproops* Meek, 1867), which were described in the 1920s from the Carboniferous of the Donets Coal Basin, are reassessed based on modern knowledge of taphonomy and xiphosuran anatomy. *Prestwichianella zalesskii* Chernyshev, 1927 is here synonymized under *Euproops danae* (Meek et Worthen, 1865). New specimens of *E. danae* and *Bellinurus* sp. from the Carboniferous of the Donets Coal Basin are considered in view of associated floral and faunal assemblages and comparisons with floras and faunas from some previously described localities containing members of these genera.

Keywords: Xiphosura, *Euproops*, *Bellinurus*, Upper Carboniferous, Pennsylvanian, Bashkirian, Moscovian, ecology, Donets Coal Basin, Donetsk Region, Lugansk Region, Rostov Region, Russia, Ukraine

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INTRODUCTION

Remains of the xiphosuran families Bellinuridae Zittel et Eastman, 1913 and Euproopidae Meek, 1867 are common in the continental Carboniferous deposits of Euramerica (Schultka, 1994, 2000). The Donets Coal Basin is not an exception. In the 1920s, xiphosuran remains were described from different localities within this territory (Chernyshev, 1927, 1928) and, in some localities, there were tens of remains (Chernyshev, 1928). However, these records were not mentioned in *Fundamentals of Paleontology* (Novojilov, 1962); as a result, they were forgotten for a long time.

Describing the geographical position of localities, Chernyshev actively cites particular sheets of the Detailed Geological Map of the Donets Coal Basin published at the beginning of the 20th century by the Geological Committee. Unfortunately, at present, this map is not accessible to me, so that the position of a number of localities is only approximately given in this paper.

Chernyshev (1927) recorded one previously known xiphosuran species (*Prestwichia danae*) and described four new species, *Prestwichianella zalesskii, Bellinurus iswarinensis, B. metschetnensis,* and *B. stepanowi* from the Donets Coal Basin. At present, three last species are regarded as valid (Dunlop et al., 2013), while the first has probably been forgotten, since as far as I know, it has never been redescribed, synonymized, or even mentioned after the original description. The holotypes of the species described by Chernyshev have not been designated. Samples that were used for the descriptions of these species (and also the samples of previously known species, whose photographs were given in the publications cited above) are housed in the Chernyshev Central Research Geological Museum (TsNIGR Museum) in St. Petersburg, except for two species discussed below.

Table 1 shows the measurements of the specimens. The measurements follow those proposed by Filipiak and Krawczyński (1996) for description of xiphosurans and also one additional measurement, AW_1, i.e., the axis width at the level of the maximum opisthosoma width (Fig. 1). Because these specimens lack a complete telson, TL (telson length) was not included in the table. The measurements of fragmentary specimens and a rolled up xiphosuran (see below) are given in the text. The ratios of parameters proposed by Ambrose and Romano (1972) and Haug et al. (2012) are given in Table 2 with some additions. Nevertheless, it should be noted that some of these ratios may considerably depend on the preservation (Anderson, 1994).

The name *Prestwichia* turned out to be preoccupied (Cockerell, 1905) and the name *Prestwichianella* (Woodward, 1918) was proposed to replace it. Later, the genus *Prestwichianella* was synonymized under the genus *Euproops* Meek, 1867 (Stubblefield, 1947, cited after Størmer, 1955[1]). The specimens identified by Chernyshev as *Prestwichia danae* actually belong to

[1] Complete data have not been found; therefore, this work is excluded from the list of references.

Table 1. Measurements, mm; for designations, see Fig. 1

Specimen, no.	Species	PW	PL	ID	CLL	CLW	GSL	OSL	OW	OL	AW	AW_1	ORW
250/1874	*E. danae*	~21*	8.5	8.4	~5	~3	–	2.4	–	–	–	–	–
251/1874	*E. danae*	~17.6*	~8.5	7	5.8	3.1	–	~4.2	–	–	–	–	–
252/1874	*E. danae*	~20.3*?	~7.5	~7.4*	~5.2	~3.4	–	~6.6	–	–	–	–	–
253/1874	*E. danae*	–	–	–	–	–	–	–	12.8*	~8.4	~3.4	3.5*	~2.3
283/1874	*B. iswarinensis*	7.6*	3	3.1	2.2	1.9	~4	abs	~4.2*	–	1.7	1.6?	–
284/1874	*E. danae*	–	–	–	~6.5?	~3.4?	–	abs	15	~10.5	–	~4.2	–
1/2095	*E. danae*	–	–	–	–	–	–	–	23.5	14.7	~6.3*	~5,7	4
2/2095	*E. danae*	~20*?	~9.3?	~5.45*?	–	–	~7.2?	–	~14.2*?	~9?	~2.45?	~2.2?	~1.8?
3/2095	*B. iswarinensis*	–	–	–	–	–	–	–	~7*	5.4	~2.3*	~3	abs?
4/2095	*B. iswarinensis*	14*	–	–	–	–	–	abs	7.5*	5.2	~3.3	2.9	abs
7/2095 8/2095	*B. metchetnensis*	–	–	–	–	–	–	–	7.6*	7	1.2?	2.9*?	abs
9/2095 10/2095	*B. stepanovi*	11.6*	6.4	~4.3*	~4.2	~2.9*	~2.1?	1.6**	–	–	–	–	–
11/2095	*B. iswarinensis*	–	–	–	–	–	–	–	~7.4**	5.4	3.1**?	2.5**	abs
13/2095 14/2095	*B. stepanovi*	8.8*	~4.9?	~3	~2.5?	–	1.9?	1.3	–	–	–	–	–

(*) doubled size of preserved half; (**) average value; (abs) respective line is absent.

Table 2. Ratios of some morphological parameters

Specimen, no.	Species	PL/PW	OL/OW	PL/OL	PW/OW	ID/PW	CLL/PL	AW/OW	AW_1/OW
250/1874	*E. danae*	~0.4	–	–	–	~0.4	~0.59	–	–
251/1874	*E. danae*	~0.48?	–	–	–	~0.4?	~0.68	–	–
252/1874	*E. danae*	~0.37?	–	–	–	~0.36	~0.69	–	–
253/1874	*E. danae*	–	~0.66	–	–	–	–	~0.27	~0.27
283/1874	*B. iswarinensis*	~0.39	–	–	~1.81	~0.41	~0.73	~0.4	~0.38
284/1874	*E. danae*	–	~0.7	–	–	–	–	–	~0.28
1/2095	*E. danae*	–	~0.63	–	–	–	–	~0.27	~0.24
2/2095	*E. danae*	~0.47*	~0.63*?	~1.03*	~1.41*	~0.27*?	–	~0.17*	~0.15*
3/2095	*B. iswarinensis*	–	~0.77	–	–	–	–	~0.33	~0.43
4/2095	*B. iswarinensis*	–	~0.69	–	~1.87	–	–	~0.44	~0.39
7/2095 8/2095	*B. metchetnensis*	–	~0.92	–	–	–	–	~0.16?	~0.38
9/2095 10/2095	*B. stepanovi*	~0.55	–	–	–	~0.37	~0.66	–	–
11/2095	*B. iswarinensis*	–	~0.73	–	–	–	–	~0.42?	~0.34
13/2095 14/2095	*B. stepanovi*	~0.5	–	–	–	~0.34	~0.51	–	–

(*) ratios are calculated based on a photograph instead of measurements of a cast (Zalessky, 1907).

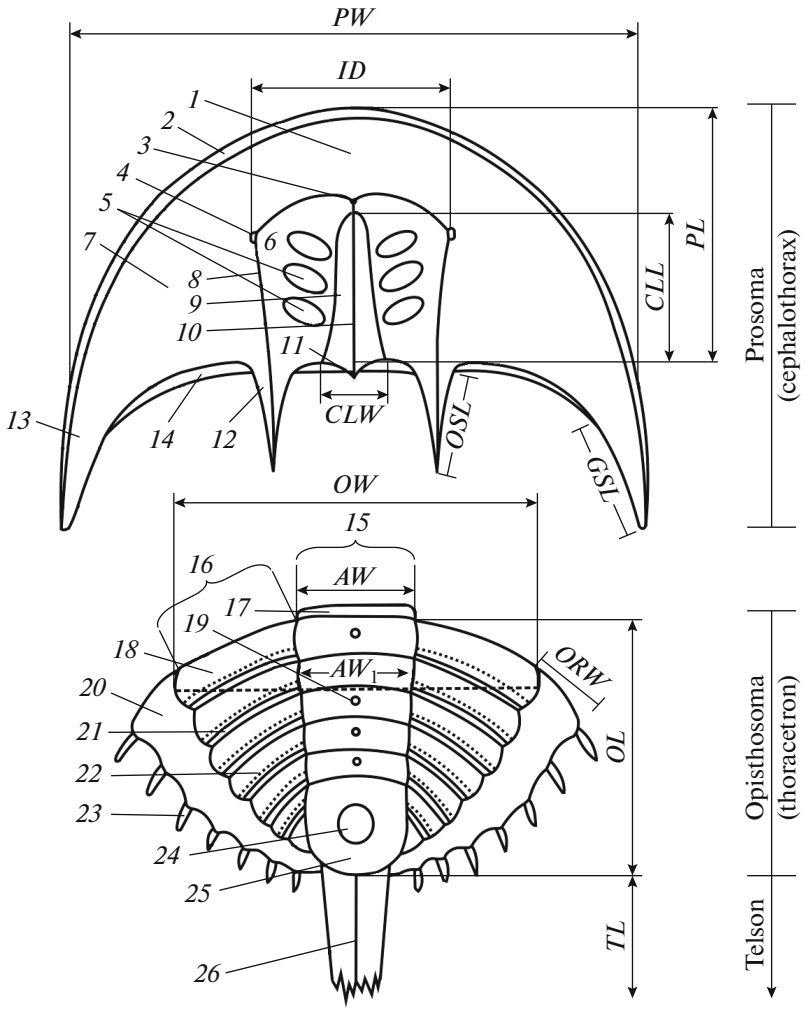


Fig. 1. Structure of Carboniferous xiphosurans and measured morphological parameters (after Filipiak and Krawczyński, 1995, with minor additions). Designations: (*1*) preophtalmic field; (*2*) marginal flange; (*3*) ocelli; (*4*) compound eyes; (*5*) muscular impressions; (*6*) cardiophthalmic region; (*7*) cheek; (*8*) ophthalmic ridge; (*9*) cardiac lobe; (*10*) cardiac ridge; (*11*) median tubercle; (*12*) ophthalmic spine; (*13*) genal spine; (*14*) occipital side of prosoma; (*15*) opisthosomal axis; (*16*) pleurae; (*17*) microtergite; (*18*) opisthosomal segment; (*19*) median axial node; (*20*) opisthosomal flange; (*21*) transverse ridge; (*22*) furrow; (*23*) pleural spine; (*24*) tubercle; (*25*) posterior axial lobe; (*26*) central ridge of telson; (*PW*) prosomal width; (*PL*) prosomal length; (*ID*) interocular distance; (*CLL*) cardiac lobe length; (*CLW*) cardiac lobe width; (*GSL*) genal spines length; (*OSL*) ophthalmic spines length; (*OW*) opisthosomal width; (*OL*) opisthosomal length; (*AW*) width of opisthosomal axis at the anterior part; (AW_1) axial width at the level of maximum width of opisthosoma; (*ORW*) opisthosomal flange width; (*TL*) telson length.

Euproops danae (Meek et Worthen, 1865). This is a negative imprint of the animals' opisthosoma from the roof of Coal Bed l_7 (Almaznaya Formation, Moscovian Stage) of the Ilovaiskogo Mine (Makeevka, Donetsk Region, Ukraine) (specimen TsNIGR Museum, no. 1/2095) (Pl. 9, fig. 1); the concretion containing the opisthosoma and small fragments of the prosoma, which were found during the mine development with penetration into Bed m_2 (Gorlovka Formation, Moscovian Stage) in the vicinity of the Trudovskoi Mine (Donetsk) (specimen no. 284/1874) and also numerous (about 50 (Chernyshev, 1928)) specimens from the shales above Coal Bed m_8 (Gorlovka Formation, Moscovian Stage) collected in a ravine that adjoins from the right the Gnilusha River valley (vicinity of the town of Krasnyi Sulin, Rostov Region, Russia), four of which (specimens nos. 250–253/1874) are also stored in the TsNIGR Museum.

The specimen used for description of the species *Prestwichianella zalesskii* Chernyshev, 1927 was found in the deposits of the Smolyaninovskaya Formation of the Bashkirian Stage in the vicinity of the village of Sofievka (presently Artemovka) of the Donetsk Region (Zalessky, 1907) (Pl. 9, fig. 2). It was housed in Karazin Kharkiv National University; to date, it is probably lost. The collection of the TsNIGR Museum contains a cast (specimen no. 2/2095), in which structural features of the animal are poorly pronounced.

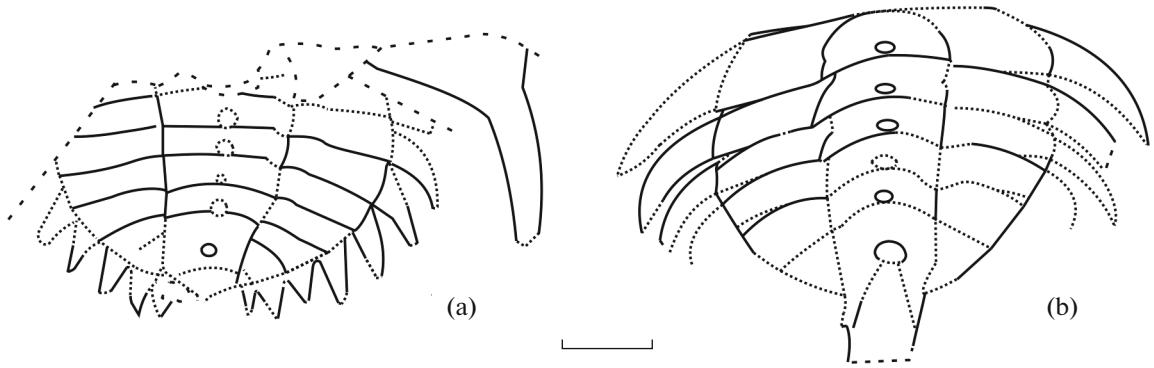


Fig. 2. Species of the genus *Bellinurus* from the Bashkirian Stage of the Upper Carboniferous: (a) *B. iswarinensis* Chernyshev, 1927, specimen TsNIGR Museum, no. 4/2095, negative imprint of opisthosoma and fragmentary prosoma; Rostov Region, Malyi Nesvetai River, vicinity of Verkhnii steading; Smolyaninovskaya (?) Formation; (b) *B. metschetnensis* Chernyshev, 1927, specimen TsNIGR Museum, no. 8/2095; Mechetnaya gully; Belaya Kalitva Formation. Scale bars in Figs. 2–5, 2 mm.

Nevertheless, the majority of characters that in opinion of Chernyshev distinguish this species from *Euproops danae* (the anterior margin of the opisthosoma lacking a straight segment, a smaller angle between the body axis and genal spines) depend on the extent of flattening (Anderson, 1994) (the straight posterior margin of the prosoma is obviously also dependent). The cardiac region (glabel) subdivided by a furrow, a character reported by Chernyshev to be characteristic of the genus *Prestwichianella* in opinion of Woodward (1918), seems rather strange. The cardiac region is hardly visible in the photograph and cast, but it is most likely subdivided by a ridge. Moreover, Raymond (1944) was the first to pay attention to the strangeness of Woodward's ideas concerning this question. Chernyshev also mentioned "the long tail spine unusual to *Pr. danae*" (Chernyshev, 1927, p. 648); however, at present, the extent to which the relative telson length can be considered as a distinctive species character in the genus *Euproops* remains uncertain (Schultka, 2000).

Thus, all the characters regarded by Chernyshev as distinctive for this species are either related to distortion during fossilization or unimportant. Therefore, it is expedient to regard *Prestwichianella zalesskii* as a synonym of *Euproops danae*.

Euproops danae (Meek et Worthen, 1865)

Bellinurus danae: Meek and Worthen, 1865, p. 44, text-figs. 4–7, pls. 9–13 (f).

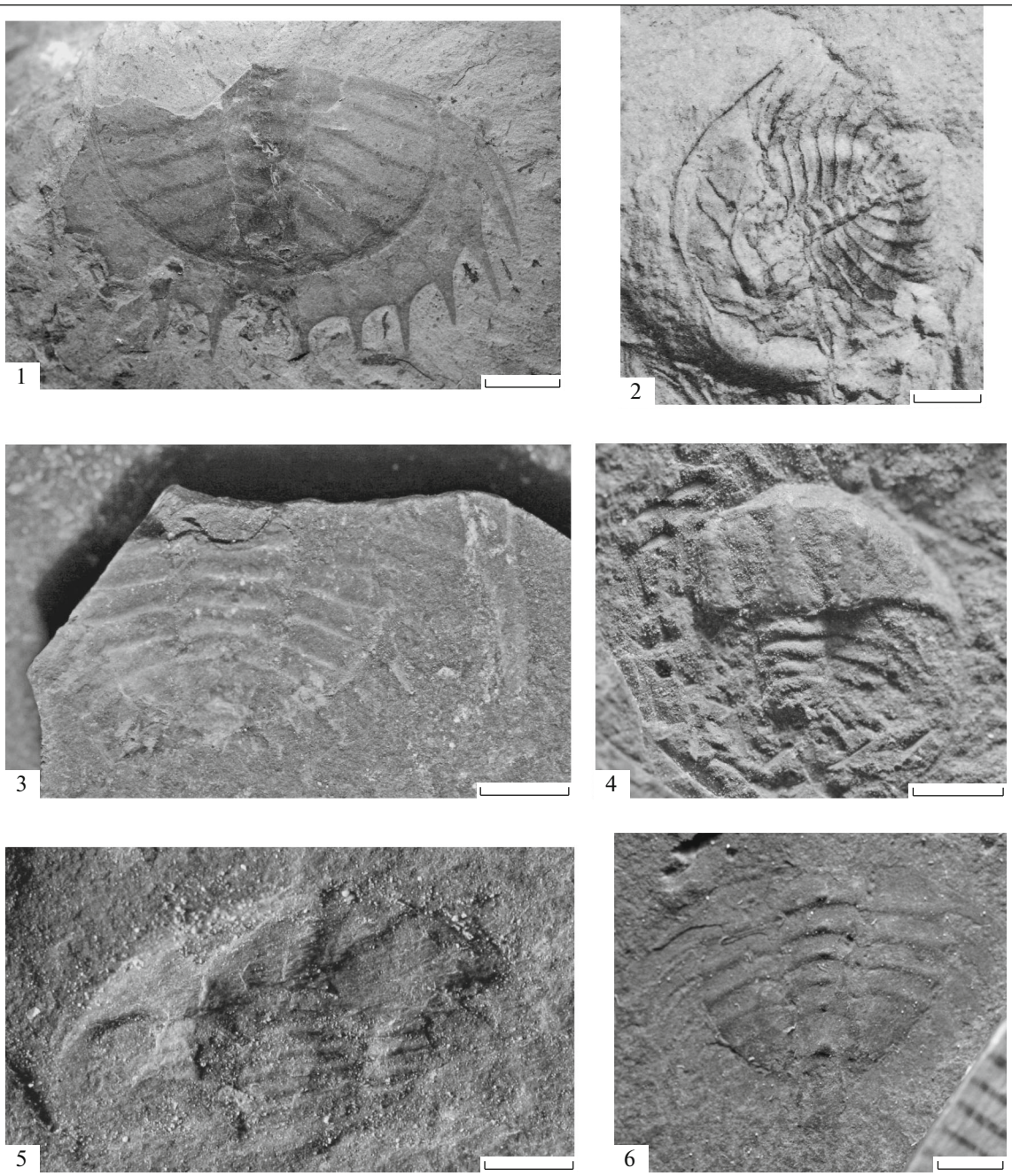
Euproops danae: Meek, 1867, p. 320; Anderson, 1994, p. 270, text-fig. 3 (diagnosis, other synonyms).

Prestwichianella zalesskii: Chernyshev, 1927, pp. 647–649, pl. 35, figs. 8 and 9.

As for the genus *Bellinurus* Pictet, 1846, a number of its species, especially those described in the 19th century, were described insufficiently thoroughly (Schultka, 1994); others were defined based on taphonomic characters (Anderson, 1994). It was repeatedly remarked that the genus requires a revision (Anderson, 1994; Schultka, 1994; Filipiak and Krawczyński, 1996), like that proposed by Anderson (1994) for the genus *Euproops*; however, such a revision has not been performed. That is why and also because the author failed to find descriptions of some species of the *Bellinurus*, it is objectionable to redescribe the species of this genus described by Chernyshev or synonymize them with other species in the present work. It seems expedient to discuss distinctive characters that were listed for the species and to evaluate them in view of modern knowledge of the xiphosurans and also to provide figures, measurements, and up-to-date photographs, which will hopefully be useful for a future revision of the genus.

Five specimens were assigned to the species *B. iswarinensis* Chernyshev, 1927. Four of them (and one more not mentioned in the literature) are stored in the TsNIGR Museum; the destiny of specimen no. 5/2095 coming from a dump of Pit no. 8 of the Gorlovskii Mine (Donetsk Region) is unknown. Specimen no. 3/2095 is a negative imprint of an opisthosoma from the roof of a coal interbed deposited below Limestone Bed L_7 and under Coal Bed l_6 (interbed l_6^0 after Chernyshev) (Almaznaya Formation, Moscovian Stage). As the linking point only the verst of the North Donetsk Railroad was given in the article, but the labels contain additional information on the disposition of the locality north of the Izvarino Station (Lugansk Region, Ukraine). Specimen no. 4/2095 (Fig. 2a; Pl. 9, fig. 3) is a negative imprint of an opisthosoma and fragmentary prosoma coming from a prospect-hole dump toward Coal Bed h_8 (Smolyaninovskaya Formation, Bashkirian Stage) on the Malyi Nesvetai River near the Verkhnii steading (Rostov Region, Russia). Specimen no. 11/2095 was found at the top of Coal Bed f_1 (Mandrykino Formation, Bashkirian Stage) in the Dubovaya gully near the town of Amvrosievka (Donetsk Region, Ukraine); this is a negative imprint of a large opisthosoma part. This

Plate 9



Explanation of Plate 9

Fig. 1. *Euproops danae* (Meek et Worthen, 1865), specimen TsNIGR Museum, no. 1/2095, negative imprint of opisthosoma; Ukraine, Donetsk Region, Makeevka; Upper Carboniferous, Moscovian Stage, Almaznaya Formation.

Fig. 2. *Euproops danae* (Meek et Worthen, 1865) (*Prestwichianella zalesskii*), negative imprint (after Zalessky, 1907); Ukraine, Donetsk Region, vicinity of the town of Artemovka; Upper Carboniferous, Bashkirian Stage, Smolyaninovskaya Formation.

Fig. 3. *Bellinurus iswarinensis* Chernyshev, 1927, specimen TsNIGR Museum, no. 4/2095, negative imprint of opisthosoma and prosoma fragment; Russia, Rostov Region, Malyi Nesvetai River, vicinity of Verkhnii steading; Upper Carboniferous, Bashkirian Stage, Smolyaninovskaya (?) Formation.

Fig. 4. *Bellinurus iswarinensis* Chernyshev, 1927, specimen TsNIGR Museum, no. 283/1874, negative imprint of prosoma and opisthosoma fragment; Ukraine, Donetsk Region, Dolgin'kaya gully, vicinity of the village of Zuevka; Upper Carboniferous, Bashkirian Stage, Mospinskaya Formation.

Fig. 5. Rolled up *Bellinurus* sp., specimen TsNIGR Museum, no. 6/2095, negative imprint; Dolzhik gully.

Fig. 6. *Bellinurus metschetnensis* Chernyshev, 1927, specimen TsNIGR Museum, no. 8/2095, negative imprint of opisthosoma; Mechetnaya gully; Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

Scale bars: (1, 2) 5, (3, 4, 6) 2, and (5) 1 mm.

locality has also yielded an imprint of an opisthosoma fragment of *Bellinurus,* which is unidentifiable to species (specimen no. 12/2095, 5.4 mm long and 5.9 mm wide). Finally, specimen no. 283/1874 is a negative imprint of prosoma and opisthosoma fragments in a concretion found above Coal Bed g_3 (Mospino Formation, Bashkirian Stage) in the Dolgin'kaya gully near the village of Zuevka (Donetsk Region) (Pl. 9, fig. 4). Because of the poor preservation, Chernyshev was not sure that the specimen belonged to *B. iswarinensis*. Apart from the specimens assigned to this species in the articles (Chernyshev, 1927, 1928), there is one more specimen in the collections, the label of which indicates the assignment to *B. iswarinensis*. This is specimen no. 6/2095, a negative imprint of prosoma and opisthosoma fragments of a partially rolled up xiphosuran (Pl. 9, fig. 5). The stratigraphical position is not indicated in the label; the geographical position is only the Dolzhik gully. This place-name is widely distributed in the Donets Coal Basin; therefore, it is presently impossible to localize the point of sampling. Because of the poor preservation, distortion of the proportions due to rolling up, and small size, it is hardly possible to recognize for sure the diagnostic characters; therefore, the assignment of this *Bellinurus* to a certain species is unjustified and, hence, it should be regarded as *Bellinurus* sp. It is 2.5 mm long and 5.5 mm wide. Based on the preserved left part of the prosoma, it is possible to conclude that the total width of this structure was about 4.7 mm. The opisthosomal axis is approximately 1.4 mm wide.

Chernyshev noted the strong similarity of *B. iswarinensis* and *B. trechmanni* Woodward, 1918. He mentioned the following characters distinguishing the first species from the second: "(1) the head shield of our species is straighter in the anterior part; (2) the genal spines are mush longer and parallel to the body axis; (3) the head shield is narrower than in *Bell. trechmani*; (4) there are tubercles on each segment of the toraceton axis" (Chernyshev, 1927, p. 650). It is now believed that the first character depends mainly on the extent of flattening (Anderson, 1994). However, the anterior margin of the prosoma becomes straightened if this flattening is rather strong and specimens of *B. iswarinensis* that display it [specimen no. 283/1874 and lost specimen no. 5/2095 shown in a photograph provided by Chernyshev (1927)] are volumetric negative imprints in concretions, in which flattening is minimum compared to other preservation forms. This means that the character considered can be distinctive in this case, although it should be used with caution. Probably, the third character also depends on flattening. The genal spines parallel to the body axis and the angle between them also depend on fossilization conditions. The length of genal spines and presence of tubercles on the axis of all segments can potentially be used as distinctive characters. The new species is also compared with *B. bellulus* Pictet, 1846, given as "*Bell. bellulus* König" in the text; the shape of the pleural spines, which are short and wedge-shaped in *B. iswarinensis* in contrast to *B. bellulus*, is regarded as the main difference [apart from the differences in "the general shape of the toraceton and genal spines" (Chernyshev, 1927, p. 650)]. This character can also be taken for distinctive.

Specimens nos. 7/2095 and 8/2095 from the TsNIGR Museum belong to the species *B. metschetnensis* Chernyshev, 1927; these are positive and negative imprints of the opisthosoma with a telson fragment (Fig. 2b; Pl. 9, fig. 6). The specimens come from the Mechetnaya gully (Rostov Region) from shales overlying the I_1 limestone bed (Belaya Kalitva Formation, Bashkirian Stage). Chernyshev remarked that *B. metschetnensis* is similar to *B. iswarinensis* and differs in the relatively narrower opisthosomal axis and some features of its spines ["The pleural spines are as wide as in *Bell. iswarinensis* sp. nov., but they are longer than the pleurae, more strongly curved, and remain equally wide throughout most of its extent; their lateral parts are thickened" (Chenyshev, 1927, pp. 650–651)]. The relative width of the axis seems to be an unreliable character, because it depends on flattening, which in turn depends on the rocks where animals are fossilized (Anderson, 1994). Moreover, even among specimens of *B. iswarinensis,* this character varies to a degree that can be compared to in opinion of Chernyshev to the difference between them and *B. metschetnensis*. The curvature of pleural spines possibly also depends on fossilization conditions (Schultka, 1994), while their length and shape can be considered with certainty as distinctive characters. Even Chernyshev noted that *B. metschetnensis* is similar to *B. trechmanni* Woodward, 1918 and *B. baldwini* Woodward, 1907, but differs in "the general outline of the thoracetron and the ratio of the axis width to the pleural length" (Chernyshev, 1927, p. 651).

Bellinurus stepanowi Chernyshev, 1927 is represented by specimens nos. 9/2095, 10/2095, 13/2095, and 14/2095 from the TsNIGR Museum. The first two are positive and negative imprints of a large part of the prosoma, respectively (Fig 3a; Pl. 10, fig. 1); they were found at the same point as specimen no. 3/2095 assigned to *B. iswarinensis*, at the top of the l_6^0 coal interbed lying below Limestone Bed L_7 and under Coal Bed l_6 (Almaznaya Formation, Moscovian Stage), north of the Izvarino Station of the North Donetsk Railroad (Lugansk Region). These specimens are interesting because of the presence of structures seen through the imprints of the xiphosuran prosoma, which are apparently a batch of eggs. In opinion of Chernyshev (1927), these eggs belong to *Bellinurus* and appeared to be covered with the prosomal shield after the death of this animal. However, there is no evidence that these eggs actually belong to a xiphosuran. Specimens nos. 13/2095 and 14/2095 are positive and negative imprints of a large part of a prosoma (Fig. 3b;

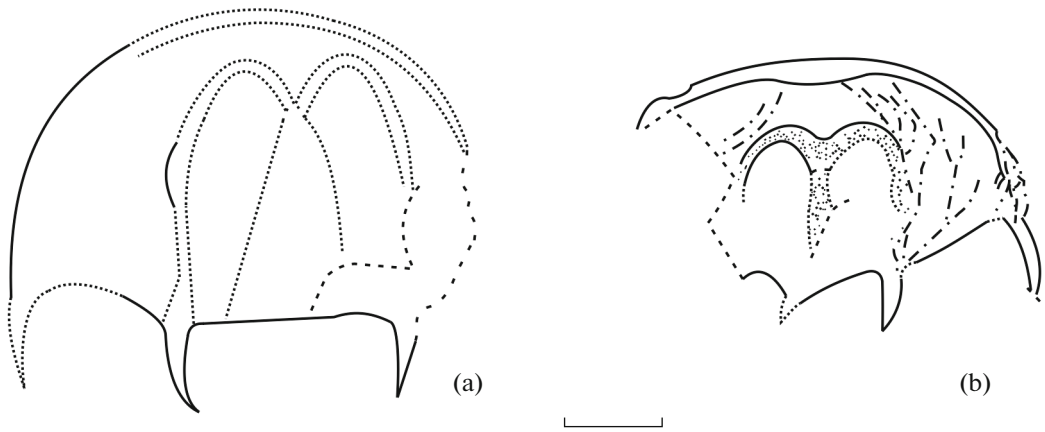


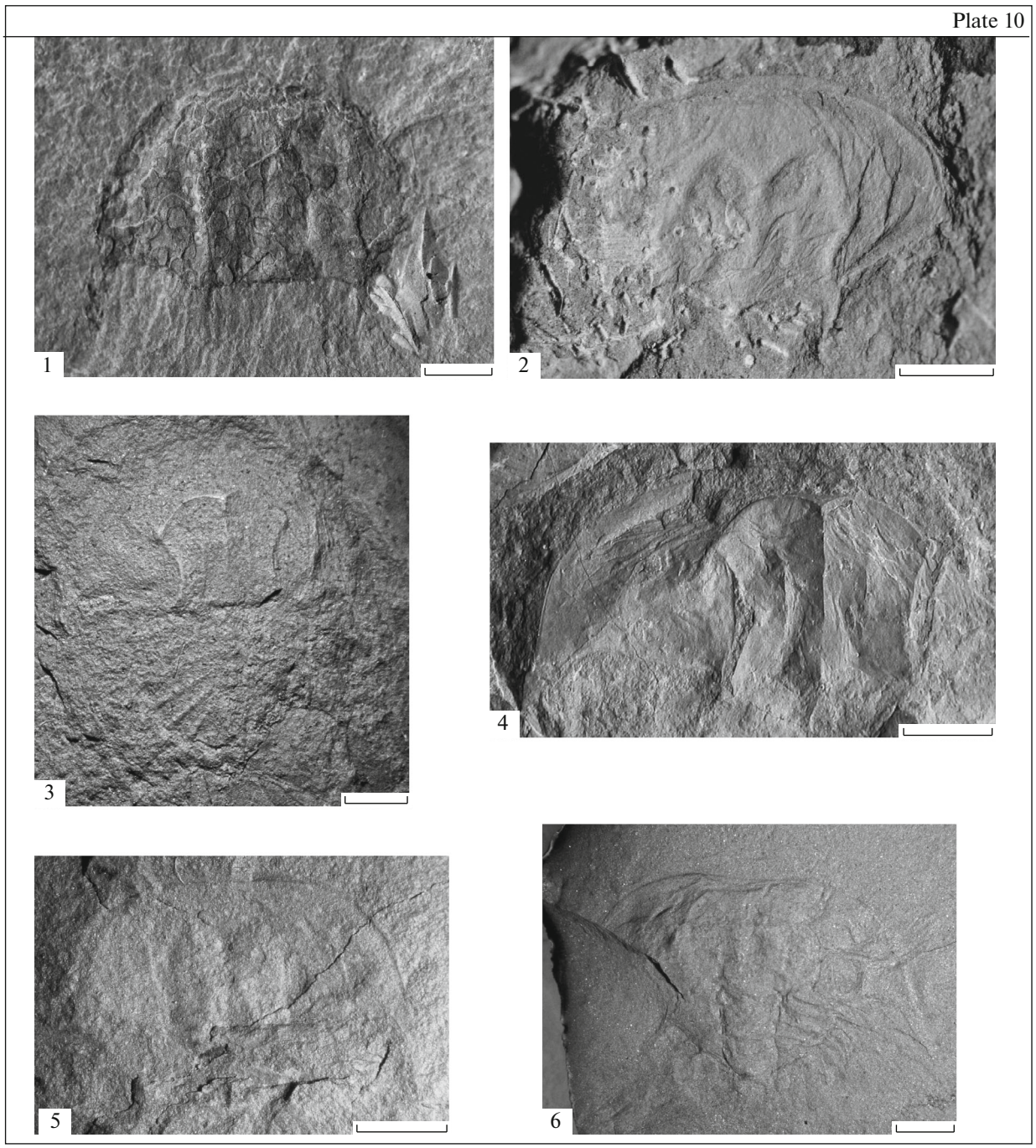
Fig. 3. *Bellinurus stepanowi* Chernyshev, 1927: (a) specimen TsNIGR Museum, no. 10/2095; Ukraine, Lugansk Region, vicinity of Izvarino station; Upper Carboniferous, Moscovian Stage, Almaznaya Formation; (b) specimen TsNIGR Museum, no. 13/2095; exact locality is unknown; Upper Carboniferous, Moscovian Stage, upper part of the Kamenskaya Formation.

Pl. 10, fig. 2). There are differences between the data in the publication and label concerning the sampling site and beds that have yielded the specimens. The only shared point is that the sampling site is located northwest of the Yumashevskii Mine. Additionally, in the text of the article, the left bank of the Bol'shaya Gnilysha River is indicated, which the label reads that it comes from the left bank of the Kundryuch'ya River. The latter river flows within the Lugansk Region of Ukraine and the Rostov Region of Russia. The first is a tributary of the second and situated in the Rostov Region. Further, we plan to ascertain the data on the sampling site. The label also contradicts the article in stratigraphy: the top of Bed k_5^5 is listed in the first and the top of Bed k_5^2 (Kamenskaya Formation, its upper part belonging to the Moscovian Stage) is in the second.

The differences of this species from the others are not discussed in detail; it is only noted that "this head shield differs from all others so much that does not correspond to any" (Chernyshev, 1927, p. 651). In opinion of Chernyshev, this xiphosuran is similar in prosoma shape to *B. kiltorkensis* Baily, 1869; however, as noted above, this character depends on the extent of flattening (Anderson, 1994) and, hence, not always can be considered as a diagnostic character. Chernyshev believed that *B. stepanowi* is similar to *B. koenigianus* in the presence of elevations in the posterior part of both halves of the cardiophthalmic region, but noted that, "in other characters, this latter strongly differs from *Bell. stepanowi*" (Chernyshev, 1927, p. 651). Similar elevations are not seen in specimens nos. 13/2095 and 14/2095; however, they are in general strongly distorted. Finally, in the presence and shape of ophthalmic spines, this species resembles *B. arcuatus* Baily, 1863. It should be noted that the presence of ophthalmic spines is a rare feature in the genus *Bellinurus*: they are absent in the majority of forms (Schultka, 1994). The ophthalmic spines of fossil xiphosurans are often broken off, especially in animals found in concretions (Anderson, 1994), but in this case, they are usually found in the negative imprint; consequently, they are supposedly uncharacteristic of *Bellinurus*. It is hard to say whether or not the shape of ophthalmic spines and the presence of the above-mentioned elevations are species-specific characters. It is also interesting to note the ornamentation of the cardiac region and ophthalmic ridges not mentioned by Chernyshev, which consists of tubercles varying in size and is well pronounced in specimen no. 13/2095.

In 2012, the Laboratory of Arthropods of the Borissiak Paleontological Institute of the Russian Academy of Sciences (PIN) conducted an expedition to the Donetsk Coal Basin, with the participation of the author; remains of xiphosurans were found in two localities, Kamensk-Shakhtinskii 1 and Zakhidnoe 1.

The Kamensk-Shakhtinskii 1 locality (also known as the Lesnaya gully) is situated in the vicinity of the town of Kamensk-Shakhtinskii town of the Rostov Region, in the Lesnaya gully between the southwestern outskirts of the town of Kamensk-Shakhtinskii and 1043 km of the North Caucasus Railroad. The xiphosurans are known from argillites replacing laterally Coal Bed i_3 under limestone I_4^1 (Belaya Kalitva Formation, Bashkirian Stage). Xiphosuran remains are represented by almost complete (without telson and with broken off right margin of the opisthosoma) positive and negative imprints of a small *Euproops* (although the first imprint is unsatisfactory preserved) (specimen PIN, no. 4431/35) (Fig. 4; Pl. 10, fig. 3); two prosoma fragments, one of which belongs to a larger *Euproops* (specimen PIN, no. 5431/37) and the second, to a considerably larger *Euproops* (specimen PIN, no. 5431/38) (Pl. 10, fig. 4); and also by positive and negative imprints of a prosomal fragment of a



Explanation of Plate 10

Fig. 1. *Bellinurus stepanowi* Chernyshev, 1927, specimen TsNIGR Museum, no. 10/2095, negative imprint of prosoma; Ukraine, Lugansk Region, north of the Izvarino station; Upper Carboniferous, Moscovian Stage, Almaznaya Formation.

Fig. 2. *Bellinurus stepanowi* Chernyshev, 1927, specimen TsNIGR Museum, no. 13/2095, negative imprint of prosoma fragment; Upper Carboniferous, Moscovian Stage, upper part of the Kamenskaya Formation.

Fig. 3. *Euproops danae* (Meek et Worthen, 1865), specimen PIN, no. 4431/35, negative imprint of prosoma and opisthosoma; Russia, Rostov Region, Kamensk-Shakhtinskii 1 locality (Lesnaya gully); Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

Fig. 4. *Euproops danae* (Meek et Worthen, 1865), specimen PIN, no. 4431/38, positive imprint of prosoma fragment; Russia, Rostov Region, Kamensk-Shakhtinskii 1 locality (Lesnaya gully); Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

Fig. 5. *Bellinurus* sp., specimen PIN, no. 4431/36, positive imprint of prosoma; Russia, Rostov Region, Kamensk-Shakhtinskii 1 locality (Lesnaya gully); Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

Fig. 6. *Bellinurus* sp., specimen PIN, no. 5527/2, negative imprint of opisthosoma and fragmentary prosoma; Ukraine, Lugansk Region, Lutuginskii District, Zakhidnoe 1 locality, abandoned coal pit 3.3 km south of the village of Zakhidnoe; Upper Carboniferous, Bashkirian Stage, Smolyaninovskaya Formation.

Scale bar: (1–3, 5, 6) 2 and (4) 5 mm.

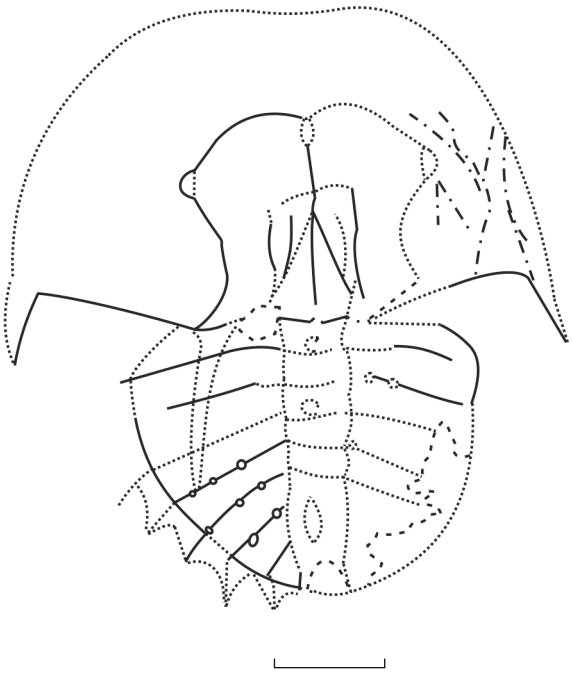


Fig. 4. *Euproops danae* (Meek et Worthen, 1865), specimen PIN, no. 4431/35; Rostov Region, Kamensk-Shakhtinskii 1 locality; Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

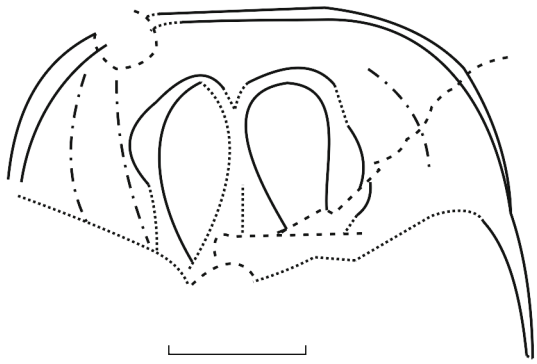


Fig. 5. *Bellinurus* sp., specimen PIN, no. 4431/36; Rostov Region, Kamensk-Shakhtinskii 1 locality; Upper Carboniferous, Bashkirian Stage, Belaya Kalitva Formation.

small *Bellinurus* (specimen PIN, no. 5431/36) (Fig. 5; Pl. 10, fig. 5).

Some specialists (Schultka, 2000; Haug et al., 2012) believe that even those *Euproops* species which remained valid after the revision by Anderson (1994) differ from each other insufficiently clear; remains of *Euproops* from the Kamensk-Shakhtinskii 1 locality determined to species lack evident differences from *E. danae* and, in my opinion, should be assigned to this species.

The measurements of xiphosurans from both localities are given in Table 3; the data on the morphological ratios are in Table 4. Because of poor preservation, specimen PIN, no. 5431 is not included in the tables. It is about 6.8 mm of total length; the prosoma is 4.8 mm long; the genal spine is 1.8 mm long.

Among qualitative features of the xiphosuran from specimen PIN, no. 4431/35, the presence of tubercles resembling "knots" on the ridges separating the segments of opisthosoma deserve mentioning; this feature was recorded by Schultka (2000) in some specimens of *Euproops* sp. from the well-known locality of Piesberg in the vicinity of Osnabrück city, Germany. Other specimens from the same bed of the locality lack ornamentation of this kind; therefore, Schultka proposed that this is manifestation of sexual dimorphism. However, in the same work, Schultka mentioned *Euproops* from the collection of Van der Heide with the "knots" arranged far less regularly (Schultka, 2000).

The conditions of finding of *Euproops* are rather typical. It was repeatedly remarked (Fischer, 1979; Todd, 1991; Schultka, 2000) that these xiphosurans are confined to the beds rich in plant remains usually clearly dominated by lycopods. In the Kamensk-Shakhtinskii 1 locality, in the beds containing xiphosurans, pteridosperms (mainly *Mariopteris*, *Neuropteris*, *Laveineopteris*) distinctly prevail, root remains of arthrophytes (formal genus *Radicites*) and their stems are less abundant, and ferns are rare. Such plant associations correspond to the landscape E sensu Fisunenko (1987). This landscape (which is dissected, weakly hilly area, with a weaker water supply than in the other parts of the coastal plain existing in the Middle Carboniferous in the Donets Coal Basin) is characterized by plant associations dominated by pteridosperms. The shores of freshwater lakes, encountered within the landscape E, were overgrown with arthro-

Table 3. Measurements, mm; for designations, see Fig. 1

Specimen, PIN, no.	Species	PW	PL	ID	CLL	CLW	GSL	OSL	OW	OL	AW	AW_1	ORW
5431/35	*E. danae*	11*	5.5	4.2*	1.8	~1.4*	1.4**	~3?	~7.1*	5.1	~1.2	1.3	–
5431/36	*B.* sp.	8.1*	~3.7	~2.6	~2	~1.5	2.2	abs	–	–	–	–	–
5431/38	*E.* danae	32.8*	~12.8	11.7*	~6.6	4.2*	–	–	–	–	–	–	–
5527/2	*B.* sp.	~11.7*	4	~1.8	–	–	–	abs	6.5*?	3.8	–	2.3?	abs

(*) doubled size of preserved half; (**) average value; (abs) respective line is absent.

Table 4. Ratios of some morphological parameters

Specimen, PIN, no.	Species	PL/PW	OL/OW	PL/OL	PW/OW	ID/PW	CLL/PL	AW/OW	AW_1/OW
5431/35	*E. danae*	0.5	0.72	1.08	1.55	0.38	0.33	0.17	0.18
5431/36	*B.* sp.	0.46	–	–	–	0.32	~0.54	–	–
5431/38	*E. danae*	0.39	–	–	–	0.36	~0.52	–	–
5527/2	*B.* sp	0.34	0.58?	1.05	1.8?	0.15	–	–	0.35?

phytes. The domination of lycopods is typical for more lowland and wet landscapes B and C. This landscape division was proposed by Fisunenko (1987) just for the Middle Carboniferous of the Donets Coal Basin; however, the confinement of the associations dominated by lycodops and pteridosperms to more and less humid habitats, respectively, was probably characteristic of the entire equatorial zone during most of that time (Fisunenko and Snigirevskaya, 1981; Pfefferkorn and Thomson, 1982). The occurrence of *Euproops* under conditions of the landscape E shows that it existed in the Middle Carboniferous in different parts of the coastal plains and suggests that it was either more plastic ecologically than considered before or independent of the composition of plant communities surrounding the water bodies inhabited by them (which can hardly be regarded as unexpected). The first variant is supported by cases of co-occurrence of *Euproops* and brackish-water bivalves (Schultka, 2000), which were interpreted by Schultka as a result of drifting.

Concerning the habitat conditions of *Euproops*, it is interesting to note the following. Schultka (2000) indicated that this genus is abundant in the deposits formed under coastal conditions and absent in intermontane depressions. Based on this, he proposed that *Euproops* was only adapted to conditions of wet coastal lowlands. Certainly, these animals are abundant in the group of mid-Pennsylvanian localities of the Mazon Creek (Raymond, 1944; Mikulic, 1997), from the Westphalian coal basins of England and Wales (Anderson, 1994), northwestern Germany (Schultka, 2000; Haug et al., 2012), and the Netherlands (Van der Heide, 1951) and also from the Moscovian Stage of the Donets Coal Basin (Chernyshev, 1928). All of these localities are considered to be formed in the coastal plains (Cleal and Shute, 1995; Baird, 1997; Cleal, 2008). However, rear records of *Euproops* are known in the Upper Silesian Coal Basin (Filipiak and Krawczyński, 1996). Cleal and Shute (1995) believed that this was an intermontane basin, but, later, Cleal (2008 p. 169) more accurately determined that it "probably occupied marginal, somewhat elevated parts of the Foreland" based on the closeness of the flora of medullosalean pteridosperms to that of paralic basins in the absence of marine deposits characteristic of these basins. It is noteworthy that, despite the rarity of *Euproops* in this basin (five specimens), their "density" is rather high, all five specimens come from the dump of one mine and, possibly, from one bed (Filipiak and Krawczyński, 1996). Moreover, a single record of *Euproops* is known from the Upper Stephanian beds of the Graissessac Coal Basin in France, which were formed in conditions of an intermontane depression (Crônier and Courville, 2005). All this suggests that, although *Euproops* was actually adapted for the coastal lowland plains, it also penetrated deep into the continent and, not later than at the end of the Carboniferous, colonized the water bodies of the mountain regions. This indirectly confirms the above assumptions.

Based on the material from the Piesberg locality, Schultka (2000) concluded that juvenile and older *Euproops* differ in ecological preferences. Juveniles usually occur on the bedding surfaces abundantly covered with unsatisfactory preserved plant remains, which, in opinion of Schultka, are evidence that they dwelt mainly in coastal aggregations of plant remains (Spülsaümen) at the edge of water bodies. Adult *Euproops* are more frequent in the deposits impoverished in plant remains, but better preserved, suggesting that there were deeper (although also coastal) parts of water bodies, with rapider sedimentation. The material from the Lesnaya gully does not follow this pattern; *Euproops* specimens varying considerably in size are found here in identical or almost identical deposits rich in well-preserved plant remains. However, the number of presently known records is insufficient to make reliable conclusions.

As for the fauna, the localities with *Euproops* frequently enclose remains of insects, arachnids, myriapods and their relatives, different crustaceans, nonmarine bivalves, and, rarely, fishes and amphibians (e.g., Jarzembowski, 1989; Lomax et al., 2016). Many of these groups occur in the Kamensk-Shakhtinskii 1 locality (although few in number). This locality has yielded insects (a few representatives of Palaeodyctioptera, Odonata, Hypoperlida, Megasecoptera, Ephemeroptera, and insects incertae sedis:

D.E. Shcherbakov, D.V. Vasilenko, personal communication), crustaceans, and the bivalve *Antracosia* sp. A single specimen of each of the following forms has been recorded here: an arachnid (Selden et al., 2014), trigonotarbid (Shcherbakov, personal communication), egg capsule of the cartilaginous fish *Fayolia* sp., and coelacanth scale.

It is interesting that the same beds have yielded an incomplete prosoma of a juvenile *Bellinurus* sp. It was previously generally believed that *Euproops* and *Bellinurus* lived in different habitats (Van der Heide, 1951; Anderson, 1994; Schultka, 1994). As mentioned above, *Euproops* is usually associated with abundant plant remains and terrestrial fauna, while *Bellinurus* co-occurs with freshwater faunas (Schultka, 1994). If *Bellinurus* is recorded along with plant remains, they are usually poorly preserved (Schultka, 1994). This suggests that xiphosurans of the genus *Bellinurus* inhabited large and rather deep water bodies and stayed far from the coast (Schultka, 1994). At the same time, both *Euproops* and *Bellinurus* have been recorded in sideritic concretions from coal mine dumps (Filipiak and Krawczyński, 1996; Anderson et al., 1997) and from a clay pit (Baldwin, 1906). Probably, these concretions come from the same bed, although in the latter case, there are data contradicting this statement (Parker, 1910). It is also noteworthy that, in the Bickershaw locality (England), xiphosurans are distinctly dominated by *Bellinurus* (Anderson et al., 1997), although the composition of the associated fauna corresponds to that usually including *Euproops*. These facts cast doubt on the hypothesis that the two genera radically differed in ecological preferences. However, in this case, we should search for other explanations for the fact that they only rarely co-occur (Anderson et al., 1997). As far as the author knows, xiphosurans from the Kamensk-Shakhtinskii 1 locality are the first case of co-occurrence of *Euproops* and *Bellinurus* directly in an outcrop rather than concretions. This additionally confirms the assumption that representatives of the genus *Bellinurus* could have lived in the same habitats as *Euproops*.

It is also interesting to discuss a rather completely preserved *Euproops* in the light of the study of the ontogeny of representatives of this genus reported by Haug et al. (2012). This study involved mass material from the above-mentioned Piesberg locality. The authors, as noted above, carefully treat even the modern systematics of the genus *Euproops* and do not assign the studied specimens to any known species, preferring to consider them as *Euproops* sp. They recognized ten growth stages of *Euproops*, which, however, only slightly differ in morphology. The most pronounced changes concern the shape of epimera of the opisthosomal segments, resulting in the formation in ontogeny of an entire flange. In juvenile *E. danae* from the Kamensk-Shakhtinskii 1 locality (specimen PIN, no. 4431/35), the epimera of the opisthosomal segments are only preserved on the left side of the posterior half of the opisthosoma; in addition, they are poorly preserved. Nevertheless, they display the ridges, which continue the ridges separating the segments. Additionally, the flange seems to be approximately half as wide as the epimera taken together, as far as possible to conclude notwithstanding the poor preservation. Such characters are typical for stage 6 of *Euproops* from Piesberg (Haug et al., 2012); however, our specimen corresponds in size to a younger ontogenetic stage.

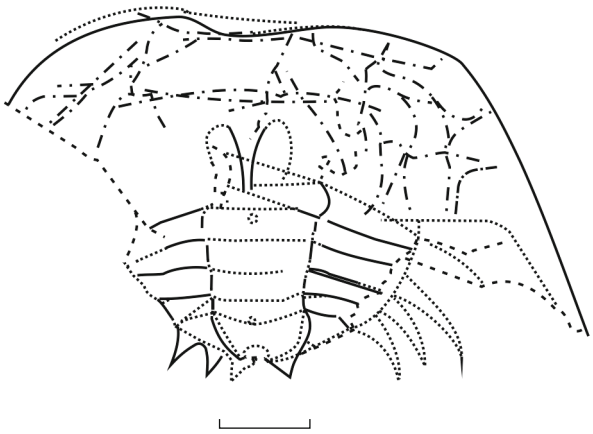


Fig. 6. *Bellinurus* sp., specimen PIN, no. 5527/2; Ukraine, Lugansk Region, Lutuginskii District, Zakhidnoe 1 locality; Upper Carboniferous, Bashkirian Stage, Smolyaninovskaya Formation.

The Zakhidnoe 1 locality is an abandoned coal pit situated 3.3 km south of the village of Zakhidnoe of the Lutuginskii District of the Lugansk Region. The xiphosuran in question comes from the Smolyaninovskaya Formation of the Bashkirian Stage and is a negative imprint of a small (possibly juvenile) strongly flattened *Bellinurus* with an incomplete prosoma and almost complete opisthosoma (specimen PIN, no. 5527/2) (Fig. 6; Pl. 10, fig. 6). The prosoma is heavily squeezed, suggesting that it may be exuviae. The preservation state prevents the assignment of this xiphosuran to any previously known species of the genus or description of a new species; therefore, it is appropriate to regard it as *Bellinurus* sp. At present, it is impossible to ascertain the location conditions of this xiphosuran.

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