Revista Brasileira de Paleontologia, 27(2):e20240433, 2024
A Journal of the Brazilian Society of Paleontology

doi:10.4072/rbp.2024.2.0433

A LOW-DIVERSE VISEAN (MISSISSIPPIAN) CEPHALOPOD ASSEMBLAGE FROM THE DNIPRO-DONETS DEPRESSION (UKRAINE)

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ABSTRACT – A small Visean cephalopod faunule from the Dnipro-Donets Depression (NE Ukraine) consisting of the nautiloids *Brachycycloceras scalare*, *Br*. cf. *normale*, ?*Phacoceras* sp., *Catastroboceras* sp., and the ammonoid *Anthracoceras* sp. is described. The surfaces of some cephalopod conchs examined bear the trace fossils *Cyclopuncta girtyi* and *Talpina* isp., as well as a possible ventral bite mark. Macroborings may indicate a prolonged postmortem exposure of cephalopod conchs on the seafloor surface as a hard substrate or, more likely, in a drifting state. The similar taxonomic composition of the Visean cephalopod assemblage indicates a unhindered connection between the Visean paleobasin of the Dnipro-Donets Depression and the paleobasins of modern Western Europe.

Keywords: Visean, Carboniferous, paleoecology, taphonomy.

RESUMO – É descrita uma pequena fauna de cefalópodes do Viseano da Depressão Dnipro-Donets (nordeste da Ucrânia), composta pelos nautiloides *Brachycycloceras scalare*, *Br*. cf. *normale*, ?*Phacoceras* sp., *Catastroboceras* sp. e o amonoide *Anthracoceras* sp. As superfícies de algumas conchas de cefalópodes examinadas mostram restos fósseis de *Cyclopuncta girtyi* e *Talpina* isp. bem como uma possível marca de mordida ventral. Os macrofósseis podem indicar exposição pós-morte prolongada das conchas de cefalópodes do fundo do mar como substrato duro ou, mais provavelmente, em um estado de deriva. A composição taxonômica semelhante do conjunto de cefalópodes de Viseano indica uma conexão perdida entre a paleobacia do Viseano da Depressão de Dnipro-Donets e as paleobacias da Europa Ocidental moderna.

Palavras-chave: Viseano, Carbonífero, paleoecologia, tafonomia.

INTRODUCTION

The Carboniferous macrofauna of the Dnipro-Donets Depression (Ukraine), a Carboniferous-Cenozoic syneclise that lies on the Late Devonian paleorift (Vasylenko, 2013), is poorly understood, as the multi-kilometer-thick Carboniferous succession occurs here at considerable depths (*c*. 3000–6000 m) (Bilyk *et al*., 2002; Lukin, 2020). The Mississippian biostratigraphy of the Dnipro-Donets Depression is based mainly on studies of foraminifers (Brazhnikova & Rostovtseva, 1967; Brazhnikova *et al*., 1967; Vdovenko, 1967, 1978, 2009a, b; Brazhnikova & Vdovenko, 1973; Raznitsyn & Ivanyshyn, 1979; Poletaev *et al*., 1991), ostracods (Ershova, 1968), calcareous algae (Berchenko, 1985, 1997; Berchenko & Sukhov, 2013; Sukhov, 2016), and palynomorphs (Ischenko, 1958; Sorokina, 1968; Kononenko *et al*., 1984; Raznitsyn *et al*., 1992). Corals, bryozoans, brachiopods, bivalves, and other marine fauna are known mainly from faunistic lists in some published works (*e.g*., Aizenverg *et al*., 1941, 1953; Brazhnikova *et al*., 1969; Vakarchuk *et al*., 1969; Vinnichenko & Voloshyna, 1969; Vdovenko *et al*., 1988, 1992; Poletaev *et al*., 1991; Bilyk *et al*., 2002; Yefimenko & Ogar, 2008; Vdovenko, 2009a; Klevtsovskiy & Ogar, 2013; Poletaev & Vdovenko, 2013) or unpublished technical reports. Studying the Carboniferous macroscopic fossils from the Dnipro-Donets Depression is important for detailed paleoecological and paleobiogeographic research and for improving the Carboniferous biostratigraphy of this region.

The Mississippian cephalopods of the Dnipro-Donets Depression are also insufficiently studied because their remains are rarely found, are frequently poorly preserved, and a multi-kilometer cover of Pennsylvanian, Permian, and Meso-Cenozoic rocks overlies the deposits themselves. However, Brazhnikova et al. (1969) reported, but not described or figured, orthocerid species "*Protocycloceras*" ex gr. *boltoni* Demanet, 1938 from the upper Visean deposits of the eastern part of the Dnipro-Donets Depression. The ammonoids *Dimorphoceras dnieperense* Kuzina in Kuzina & Poletaev, 1991, *Glyphiolobus pulcher* Kuzina in Kuzina & Poletaev, 1991, *Nomismoceras spirorbis* (Phillips, 1836), *Girtyoceras* sp. 1, and *G*. sp. 2 were described from the upper Visean Solokhy Formation (*Beyrichoceras-Goniatites* Genozone) of the Dnipro-Donets Depression by Kuzina & Poletaev (1991). Unfortunately, this ammonoid assemblage cannot be attributed to the smaller Visean ammonoid genozones (*Goniatites, Entogonites,* or *Bollandites-Bollandoceras* (pars)) proposed by Nikolaeva (2021) because it does not contain key taxa of any particular genozone. A single specimen of a nautiloid *Lispoceras* sp. was figured but not described by Kuzina & Poletaev (1991: pl. 4, fig. 16) from the Solokhy Formation.

The Visean non-ammonoid cephalopods have been well studied from the deposits of epicontinental paleobasins of the southern and southeastern margins of Laurussia and are known from North Africa (Delépine, 1939; Korn & Bockwinkel, 2022; Korn *et al*., 2022; Korn & Klug, 2023), Ireland (Sowerby, 1825; M'Coy, 1844; Foord, 1891a, b, 1897–1903; Foord & Crick, 1893, 1897; Ramsbottom & Moore, 1961; Histon, 1997–1998, 1999), Isle of Man (Turner, 1954), England (Phillips J., 1836; Foord, 1891a; Foord & Crick, 1897; Hind, 1910, 1920; Phillips D., 1985), Scotland (Phillips, 1985), Belgium (Koninck, 1842–1844, 1878, 1880; Demanet, 1938, 1941; Phillips, 1985), Germany (Holzapfel, 1889; Nebe, 1911; Hüffner, 1914; Schmidt, 1951, 1956), Austria (Andrée, 1908; Aigner & Heritsch, 1930; Schraut, 1999, 2018), Poland (Zakowa, 1958, 1960, 1974), the European part of Russia (Tsvetaeva, 1898; Shimansky, 1967, 1968; Shimansky & Shkolin, 1994), Urals and Kazakhstan (Shimansky, 1967). Ammonoids are even more widespread in the Visean deposits than nautiloids (see review in Nikolaeva (2021) and the online database goniat.org). In summary, it should be noted that the Visean cephalopod assemblages of Europe and North Africa are quite well studied, but much of the available data, especially those published in very old works, need to be revised.

Here, a low-diverse Visean cephalopod assemblage from the Dnipro-Donets Depression (Ukraine) is described. It consists of the nautiloids *Brachycycloceras scalare* (d'Archiac & Verneuil, 1842), *Br.* cf. *normale* Miller, Dunbar & Condra, 1933, ?*Phacoceras* sp., *Catastroboceras* sp., and ammonoids assigned to *Anthracoceras* sp. Even though the studied material is very sparse and poorly preserved, this study supplements the previously almost unknown Mississippian cephalopod fauna of the Dnipro-Donets Depression, broadens the known paleontological characteristics of the Carboniferous sedimentary succession in the Dnipro-Donets Depression, and expand data on the paleoecology and taphonomy of the Mississippian cephalopods.

GEOLOGICAL SETTING

Localities

The studied material was collected from 12 boreholes that recovered the Visean rocks of the Dnipro-Donets Depression (Figure 1A, B). These sites are briefly described below.

(**1**) Ukraine, Poltava region, Lubny district, Gubs'ka-2 borehole in the village of Gubs'ke. The fossil-bearing rock is the black shale of the Yablunivka Formation (upper Visean) with a conch fragment of *Brachycycloceras scalare* (d'Archiac & Verneuil, 1842) (specimen IGS NASU-9/07) and small fragments of undetermined ammonoid conchs and poorly preserved remains of undetermined cephalopods, recovered at the depth interval 4740.0–4745.0 m.

Brachiopods typical of the upper Visean *Chonetipustula carringtoniana* Zone of the Donets Basin and the Tulian Horizon of the European part of Russia, such as *Carringtonia carringtoniana* (Davidson, 1861), *Echinoconchus punctatus* (Martin, 1809), *Echinoconchella elegans* (M'Coy, 1844), *Productina margaritacea* (Phillips, 1836), *Datangia maximus* (M'Coy, 1844), were found in the depth interval 4843.0–4848.0 m, which is assigned to the XIII microfaunistic horizon (= Yablunivka Fm.) (Bilyk *et al*., 2002). The depth interval 4740.0–4745.0 m, in which *Brachycycloceras scalare* was found, belongs to the XIII microfaunistic horizon (= Yablunivka Fm.) according to Bilyk *et al*. (2002).

(**2**) Sumy region, Okhtyrka district, Bugruvativs'ka-16 borehole in the village of Bugruvate. The fossil-bearing rock is the black shale of the Andriyashivka Formation (XII microfaunistic horizon, upper Visean) with a conch fragment of the orthocerid cephalopod *Brachycycloceras scalare* (specimen IGS NASU-9/06) and rare ammonoids, brachiopods, and bivalves, recovered at the depth interval 3650.0–3654.0 m.

(**3**) Poltava region, Myrhorod district, the village of Pisky, Piskovs'ka-371 borehole. The fossil-bearing rock is a black shale with a conch fragment of *Brachycycloceras scalare* (specimen IGS NASU-22/11), recovered at 4400.0–4410.0 m depth.

Brachiopods typical of the lower part of the Tulian Horizon of the Moscow Syneclise were found in this borehole at the depth interval of 5143.0–5153.0 m, which is assigned to the XIII microfaunistic horizon (= Yablunivka Fm.) (Bilyk *et al*., 2002). Late Tulian brachiopods (XIIa microfaunistic horizon; Solokhy Fm.) were found in the depth intervals of 4971.0–4974.0 m and 5055.0–5065.0 m (Bilyk *et al*., 2002). The upper Visean brachiopods (*i.e*., XII and XI microfaunistic horizons or Andriyashivka and Perekopivka formations) were found in the depth intervals of 4419.0–4434.0 m and 4780.0–4800.0 m (Bilyk *et al*., 2002). The Visean ammonoids *Girtyoceras* sp. and *Nomismoceras vittiger* (Phillips, 1836) were found in the depth interval 4780.0–4890.0 m, and the ammonoids *Glyphiolobus pulcher* Kuzina in Kuzina & Poletaev, 1991 were described from the depth interval 5006.0–5016.0 m by Kuzina & Poletaev (1991). Thus, the age of the rocks with *Brachycycloceras scalare* is defined as late Visean (Andriyashivka Formation).

(**4**) Poltava region, Poltava district, the village of Vasylivka, Vasylivka-14 borehole. The fossil-bearing rock is an upper Visean (Solokhy or Andriyashivka Formation) black shale with a conch fragment of an ammonoid *Anthracoceras* sp. (specimen IGS NASU-22/04) and a conch fragment of *Brachycycloceras scalare* (specimen IGS NASU-22/12), recovered at the depths 4810.0–4820.0 m.

In a section of this borehole, at depths of 4859.0–4871.0 m and 4807.0–4820.0 m, palynomorphs typical of the Kizelovian Horizon (upper Tournaisian) and an early Visean foraminifer assemblage were found (Bilyk *et al*., 2002). It is possible that Tournaisian spores were redeposited in the lower Visean deposits. The rocks of the depth interval 4810.0–4820.0 m here classified as lower Visean since the

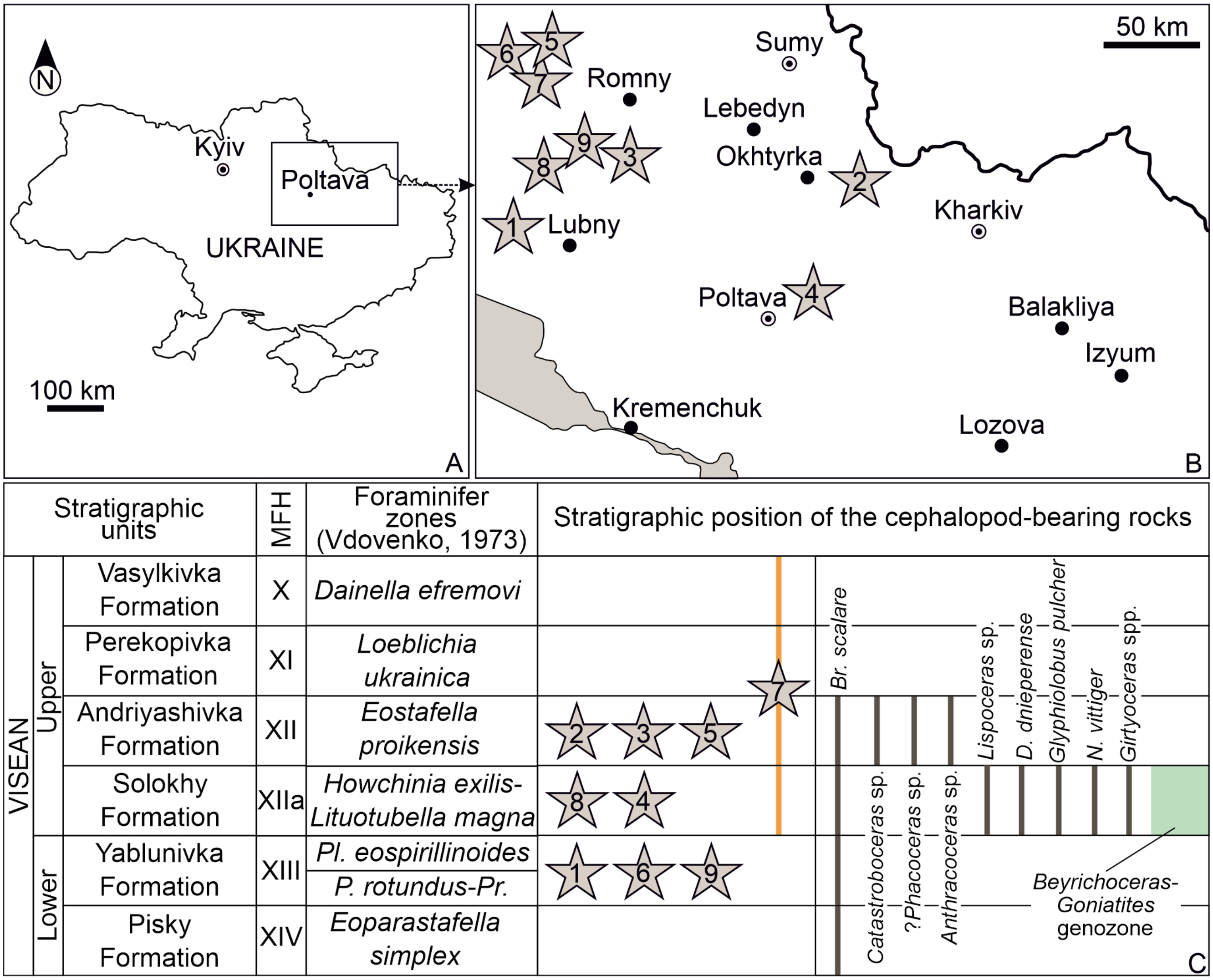

Figure 1. Geographical location of the cephalopod-bearing boreholes in the Dnipro-Donets Depression (marked by numbered stars) (**A**, **B**) and stratigraphy of the Visean succession in the Dnipro-Donets Depression modified from Poletaev *et al*. (1991: fig. 2) with stratigraphic position of the cephalopod-bearing levels and a stratigraphic range of the cephalopod fauna after Kuzina & Poletaev (1991) and this study (**C**). The orange vertical lines show the possible stratigraphic intervals in which the cephalopod-bearing level is located. **Abbreviations**: **MFH**, microfaunistic horizon; **P**., *Permodiscus*; **Pl**., *Planodiscus*; **Pr**., *Propermodiscus*.

genera *Anthracoceras* and *Brachycycloceras* are not known from the Tournaisian; Bilyk *et al*. (2002) assigned it to the XIII or XIV microfaunistic horizon (Yablunivka or Pisky Formation).

(**5**) Poltava region, Romny district, the village of Holinka, Holikovs'ka-9 well. The fossil-bearing rock is an upper Visean (Solokhy or Andriyashivka Formation) black shale with conch fragments of ?*Phacoceras* sp. (specimen IGS NASU-22/01) and *Catastroboceras* sp. (specimen IGS NASU-22/02) recovered at 3810.0–3822.0 m depth.

In a section of this borehole, at the depth intervals 3755.0–3761.0, 3810.0–3822.0, and 3802.0–3810.0, upper Visean brachiopods were found (Bilyk *et al*., 2002). These depth intervals are assigned to the XI and XII microfaunistic horizon, but the interval 3810.0–3822.0 m, bearing ?*Phacoceras* sp. and *Catastroboceras* sp. here assigned to the lower part of the XII microfaunistic horizon (Andriyashivka Formation).

(**6**) Chernihiv region, Pryluky district, Voloshky oil and gas field near the village of Talalayivka, Voloshky-314 borehole. The fossil-bearing rock is an upper Visean black shale with brachiopods typical of the Tulian Horizon (Bilyk *et al*., 2002) and a conch fragment of *Anthracoceras* sp. (specimen IGS NASU-22/03), recovered at the depths 5081.0–5092.0 m. This depth interval of the Voloshky-314 well is assigned to the XIII microfaunistic horizon (Solokhy Fm.) (Gavrish *et al*., 1987; Bilyk *et al*., 2002).

(**7**) Chernihiv region, Pryluky district, Voloshky oil and gas field near the village of Talalayivka, Voloshky-2 well. The fossil-bearing rock is the upper Visean black shale with cnidarians *Sphenothallus* sp. (Dernov, 2023b), a single ammonoid ?*Anthracoceras* sp. (specimen IGS NASU-22/05), and one undetermined ammonoid conch fragment bearing bioerosions (specimen IGS NASU-22/05a), recovered at the depths 4799.0–4811.0 m (Solokhy Fm.).

(**8**) Sumy region, Romny district, Kampans'ke oil and gas field near the village of Hlyns'k, Kampans'ka borehole. The fossil-bearing rock is a lower Visean black shale with cf. ?*Phacoceras* sp. (specimen IGS NASU-22/01a), recovered at 4926.0–4933.0 m depth.

Brachiopods typical of the lower part of the Tulian Horizon of the Moscow Syneclise were found in the depth interval 4978.0–4979.0 m (XIII microfaunistic horizon) of this borehole, and brachiopods of the upper part of the Tulian Horizon were found in the depth intervals 4843.0–4848.0 m and 4921.0–4926.0 m (XIIa microfaunistic horizon) (Bilyk *et al*., 2002). Thus, the rocks with cf. ?*Phacoceras* sp. are assigned to the XIIa microfaunistic horizon (Solokhy Fm.).

(**9**) Poltava region, Myrhorod district, the village of Zirka, Zor'kovs'ka-370 well. The fossil-bearing rock is a lower Visean black shale with an undetermined cephalopod conch bearing trace fossils *Talpina* isp. (specimen IGS NASU-22/07), recovered at the depth interval 5807.0–5821.0 m.

Unfortunately, the location of the Yagovka-311 (depth interval 4998.0–4913.0 m with *Brachycycloceras* cf. *normale* Miller, Dunbar & Condra, 1933) and Verkhneozerne-312 (depth interval 3982.0–3985.0 m with an undetermined orthocerid cephalopod) boreholes and the age of their fossil-bearing rocks could not be determined. Also, the age of the rocks in the depth interval 4865.0–4880.0 m of the Krasnozayars'ka borehole could not be determined, and these likely belong to the Tournaisian XV microfaunistic horizon (Ivanyshyn, 1988; Bilyk *et al*., 2002). The studied collection also contains one small pyritized conch of the ammonoid *Nomismoceras vittiger* (Phillips, 1836) (specimen IGS NASU-22/09; Figure 2) from the Piskovs'ka-371 well, locality previously studied by Kuzina & Poletaev (1991) and, therefore, this species is not described in the paper.

STRATIGRAPHY

According to the biostratigraphic scheme proposed by Brazhnikova *et al*. (1967), the lower Visean includes XIII and XIV microfaunistic "horizons" (= foraminifer zones), and the upper Visean includes the XIIa, XII, XI, and X microfaunistic horizons (see Figure 1C).

In summary, the lower Visean includes the Pisky (= Bakumivka) and Yablunivka (= Artyukhivka) formations; the upper Visean includes the Solokhy, Andriyashivka, Perekopivka, and Vasylkivka formations (Poletaev *et al*., 1991; Poletaev & Vdovenko, 2013). The thickness of the Visean rock succession in the Dnipro-Donets Depression varies from 1800 m in the axial part of the depression to 100–150 m on its slopes (Vdovenko *et al*., 1988).

The Pisky Formation is represented by a 200-m-thick sequence of dark grey, sometimes calcareous mudstones with plant debris and dark gray, pelitomorphic and bioclastic, sometimes clayey, often sideritized and pyritized limestone interlayers; limestones are dolomitized in the lower part of the formation. Carbonate rocks contain foraminifers (*Pseudolituotubella tenuissima* Vdovenko, 1954, *Omphalotis minima* (Rauser-Chernousova & Reitlinger, 1937), *Eoendothyranopsis donica* Brazhnikova & Rostovtseva, 1967, *Dainella* cf. *chomatica* (Dain in Brazhnikova, 1962), *Eoparastaffella simplex* (Vdovenko, 1954)), bryozoans, brachiopods, ostracods, crinoids, and calcareous algae. The Pisky Formation lies unconformably over older rocks; it is overlapped by the Yablunivka Formation (Poletaev *et al*., 1991; Babko & Kononenko, 2003; Poletaev & Vdovenko, 2013).

The Yablunivka Formation is composed of dark grey to black, clayey, bioclastic limestones, sometimes limonitized

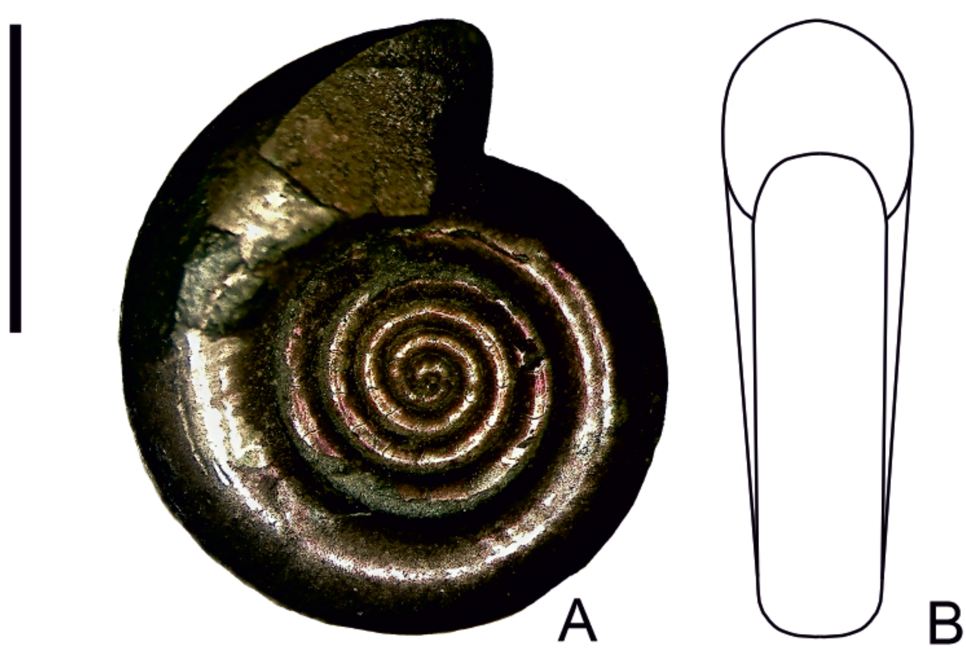

Figure 2. Pyritized conch of *Nomismoceras vittiger* (Phillips, 1836): **A**, lateral view; **B**, septal projection (specimen IGS NASU-22/09). Scale bar = 2 mm.

and with fine debris of ostracod and brachiopod shells and calcareous algae, which occasionally form small (up to 15 m in width) bioherms. Foraminifers (*Ammarchaediscus* cf. *eospirillinoides* (Brazhnikova in Brazhnikova *et al*., 1967), *Uralodiscus* cf. *rotundus* (Chernyshova, 1948), *Eoparastaffella simplex* (Vdovenko, 1954), *E*. cf. *rotunda* (Vdovenko, 1971)) and brachiopods (*Carringtonia carringtoniana* (Davidson, 1862), ?*Linoprotonia* ex gr. *bisati* (Paeckellman, 1931)) have been identified at this formation (Poletaev & Vdovenko, 2013). The thickness of the Yablunivka Formation is 50–250 m (Poletaev *et al*., 1991; Babko & Kononenko, 2003; Poletaev & Vdovenko, 2013).

The Solokhy Formation is represented by a 400-m-thick succession of interbedded dark grey and black micaceous mudstones and siltstones and less frequently light grey and grey, fine to coarse-grained, quartz and micaceous sandstones. The late Visean age of this formation is substantiated by the foraminifer and palynomorph assemblages (Poletaev *et al*., 1991; Babko & Kononenko, 2003; Poletaev & Vdovenko, 2013).

The Andriyashivka Formation, in contrast to the underlying formations, is represented by a succession of rocks similar to the flyschoid strata, where the marine and continental sedimentary units interbedded rhythmically. The marine rocks are represented by dark grey mudstones with interlayers of bioclastic limestones, siltstones, sandstones, and sometimes gravelites. The continental rocks are represented by grey mudstones, siltstones, and sandstones containing fine plant debris and lycopsid roots *Stigmaria*, among others (Poletaev *et al*., 1991; Babko & Kononenko, 2003; Poletaev & Vdovenko, 2013).

The Perekopivka Formation is composed mainly of shallow marine dark grey carbonaceous mudstones with interlayers of grey, clayey, quartz, and micaceous siltstones, grey and dark grey, clayey, crystalline, and bioclastic limestones, and less frequently grey, quartz, micaceous, fine-grained sandstones. The thickness of the Perekopivka Formation is 40–190 m, up to 300 m (Poletaev *et al*., 1991; Poletaev & Vdovenko, 2013).

The Vasylkivka Formation is composed of dark grey, sometimes calcareous mudstones with interlayers of dark grey dolomitized limestones. Limestones and mudstones contain remains of brachiopods, ostracods, bryozoans, foraminifers, and crinoids. The thickness of this formation is 20–135 m (Poletaev *et al*., 1991; Poletaev & Vdovenko, 2013).

PALEOGEOGRAPHY

A significant transgression and expansion of the area of the epicontinental paleobasin occurred in the Dnipro-Donets Depression at the beginning of the Visean (Machulina, 2016). This warm marine basin with normal salinity was quite shallow, with a maximum depth of less than 200 m (Vdovenko *et al*., 1993). These conditions remained until the late Visean when frequent changes in shallow coastal and marine bays and lagoons characterized the basin. Sea regression and decrease in sea depth and salinity began in the terminal late Visean. The accumulation of continental sediments occurred on the margins of the Dnipro-Donets Depression (Vdovenko *et al*., 1993; see Figure 3).

Several lithofacies were identified among the Visean interval of the Dnipro-Donets Depression, among which the group of marine sedimentary rocks includes onshore carbonate and terrigenous rocks (sandstones, mudstones, and siltstones), offshore black shales (mudstones and siltstones with 3.6% organic carbon (Machulina, 2016)), siliceous calcareous-clayey bituminous sediments of local depressions of the basin, as well as turbidites (Makogon, 2008). Black shale beds play an important role in the structure of the Carboniferous succession of the Dnipro-Donets Depression (Machulina, 2015, 2016; Lukin, 2020) and the Donets Basin (Poletaev *et al*., 1991).

MATERIAL AND METHODS

In this study, 19 specimens of conch fragments and steinkerns were observed in the core samples of black shales (Table 1). Unknown geologists donated these fossils to the Department of Paleontology and Stratigraphy of the Paleozoic Sediments of the Institute of Geological Sciences (National Academy of Sciences of Ukraine, Kyiv) at different times but remained unstudied. Since these core samples were stored unexamined for a long time, it was impossible to locate the positions of some boreholes from which they were taken.

For comparison purposes of bioerosion traces *Cyclopuncta girtyi* Elias, 1958, several specimens of ammonoid, orthocerid, and coiled nautiloid conch fragments from black shale sequences of the Mospyne Formation (upper Bashkirian, Pennsylvanian) of the Donets Basin and Serpukhovian or Bashkirian of the Lviv Paleozoic Trough (western Ukraine) were also studied. The stratigraphic subdivisions of the boreholes, and hence the age of the fossil-bearing rocks, are based mainly on the views of Bilyk *et al*. (2002).

For a scheme of dimensions of coiled nautiloids and ammonoid conchs, see the article of Korn & Bockwinkel (2022: fig. 3) and the work of Korn (2010: fig. 1), respectively. The keys for the description of the morphology of the cephalopods used in this paper: Korn (2010) and Klug *et al*. (2015) for ammonoids and coiled nautiloids (adapted); Shimansky (1968) and Niko & Mapes (2009, 2018) for orthocerids. The abbreviations used in the cephalopod species description are dm – conch diameter, wh – whorl height, ap – apertural height, and uw – umbilical width. The values of WER and IZR (see Korn (2010) and Klug *et al*. (2015)) and whorl width (ww) are unknown because of the poor preservation of the available material.

The taxonomy of nautiloids proposed by Kummel (1964) and ammonoids proposed by Bogoslovskaya *et al*. (1999), with some changes concerning the spelling of the endings of superfamily and subclass names (Hoffmann *et al*., 2022), are used in this work. The spatial orientation of the nautiloids *Brachycycloceras* in life position, *i.e*., the position of the

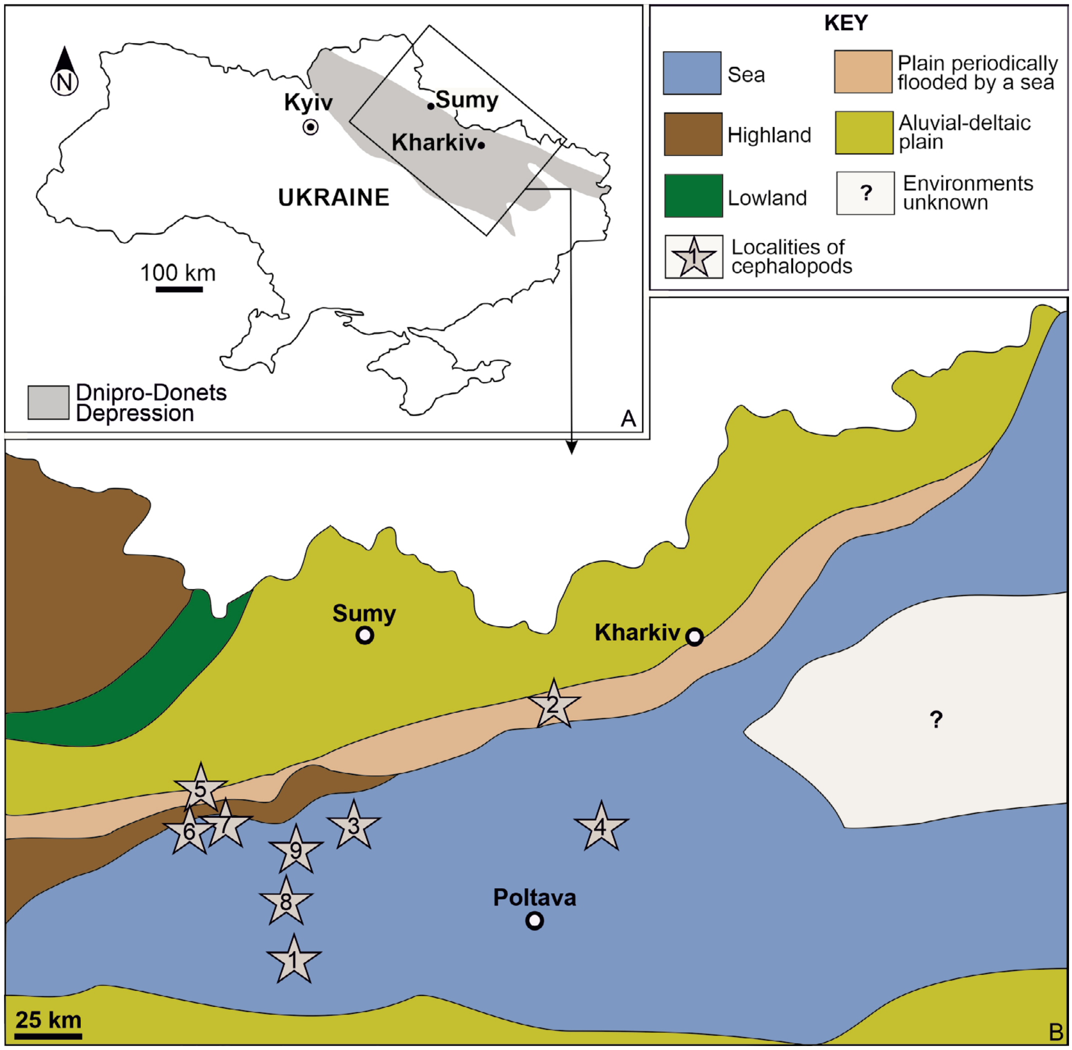

Figure 3. Visean paleoenvironental conditions in the Dnipro-Donets Depression, modified from Vdovenko *et al*. (1993: fig. 26).

Table 1. Studied cephalopod remains from the Visean of the Dnipro-Donets Depression.

Taxa	Specimens	Number
Nautiloids		
Brachycycloceras scalare (d'Archiac & Verneuil, 1842)	IGS NASU-9/06, IGS NASU-9/07 and IGS NASU 22/11, 22/12	4
Brachycycloceras cf. *normale* Miller, Dunbar & Condra, 1933	IGS NASU 22/10	1
?*Phacoceras* sp.	IGS NASU-22/01	1
cf. ?*Phacoceras* sp.	IGS NASU-22/01a	1
Catastroboceras sp.	IGS NASU-22/02	1
Undetermined orthocerid nautiloid	IGS NASU-22/11a	1
Undetermined coiled nautiloids	IGS NASU-22/08	1
Undetermined coiled nautiloid (part)	IGS NASU 22/13-1	1
Undetermined coiled nautiloid (counterpart)	IGS NASU 22/13-2	1
Undetermined coiled nautiloid	IGS NASU 22/14	1
Undetermined coiled nautiloid	IGS NASU 22/17	1
Ammonoids		
Anthracoceras sp.	IGS NASU-22/03, 22/04	2
?*Anthracoceras* sp.	IGS NASU-22/05	1
Nomismoceras vittiger (Phillips, 1836)*	IGS NASU-22/09	1
Undetermined ammonoid	IGS NASU-22/05a	1

* Not described

venter, dorsum, and flanks of the conch, is taken according to Mapes & Niko (2009). The parataxonomy of bioerosion ichnotaxa proposed by Wisshak *et al*. (2019) is used here.

The studied material (collections IGS NASU-7, IGS NASU-9, and IGS NASU-22) is stored at the Department of Paleontology and Stratigraphy of the Paleozoic Sediments of Institute of Geological Sciences (National Academy of Sciences of Ukraine, Kyiv).

SYSTEMATIC PALEONTOLOGY

Cephalopods

Class CEPHALOPODA Cuvier, 1797
Subclass NAUTILOIDEA Agassiz, 1847
Order ORTHOCERIDA Kuhn, 1940
Family BRACHYCYCLOCERATIDAE
Furnish, Glenister & Hansman, 1962

Brachycycloceras Miller, Dunbar & Condra, 1933

Type-species. *Brachycycloceras normale* Miller, Dunbar & Condra, 1933; by original designation.

Brachycycloceras scalare (d'Archiac & Verneuil, 1842)
(Figure 4C–E, G)

1831 *Orthoceras striolatum*: von Meyer, pl. 55, figs. 1, 2.
1836 *Orthoceras annulatum*: Phillips, p. 239, pl. 21, fig. 10.
1842 *Orthoceras scalare*: d'Archiac & Verneuil, p. 345.
1852 *Orthoceras annulare*: Roemer, p. 92, pl. 13, fig. 25.
1870 *Orthoceras scalare*: Roemer, p. 55, pl. 6, fig. 4.
1880 *Orthoceras annulosolineatum*: Koninck, p. 71, pl. XLI, figs. 1–3.
1889 *Orthoceras scalare*: Holzapfel, p. 45, pl. 1, fig. 3.
1910 *Orthoceras scalare*: Sommer, p. 643, pl. 28, fig. 10.
1911 *Orthoceras scalare*: Nebe, p. 461, pl. 16, fig. 12.
1914 *Orthoceras scalare*: Hüffner, p. 471, pl. 21, figs. 4–5.
1929 *Orthoceras scalare*: Schmidt, p. 57, pl. 14, fig. 2.
1929 *Orthoceras scalare*: Patteisky, p. 238, pl. 16, fig. 15.
1941 *Brachycycloceras scalare*: Demanet, p. 110, figs. 30, 31.
1956 *Brachycycloceras scalare*: Schmidt, p. 47.
1958 *Brachycycloceras scalare*: Zakowa, pl. 8, fig. 12.
1960 *Brachycycloceras scalare*: Zakowa, pl. 1, fig. 4.
1960 *Orthoceras scalare*: Gunia & Górecka, p. 323, pl. 37, fig. 20.
1968 *Brachycycloceras scalare*: Bednarczyk et al., pl. 2, fig. 4;
2021b *Brachycycloceras scalare*: Dernov, figs. 3, 4.

Material. Four poorly preserved deformed juvenile conch fragments and their impressions in carbonaceous mudstone (specimens IGS NASU-9/06, IGS NASU-9/07, IGS NASU-22/11, and IGS NASU-22/12).

Description. Conch is a longiconic orthocone with a maximum length of 45 mm, a rounded cross section, and a probably slight apical angle. The conch surface is covered with coarse transverse annular ribs, 0.6–2.0 mm thick, spaced by 1.8–4.5 mm thick interrib spaces with thin, very weakly curved, 0.10–0.15-mm-thick growth lines, which are spaced about 0.4–0.5 mm apart. The body chamber is not preserved. Due to the poor preservation of the material, it is impossible to describe the morphological features of the conch's flanks, dorsum, and venter.

Remarks. It should be noted that the assignment of the available material to the species *Brachycycloceras scalare* is somewhat conditional, as the species itself needs to be revised.

The specimens of *Brachycycloceras scalare* described above differ from *Brachycycloceras* cf. *normale* Miller, Dunbar & Condra, 1933 described below in several morphological features, such as the absence of growth lines on the transverse annular ribs and straight, slightly pointed transverse ribs. However, as can be seen in the images of the type species of the genus *Brachycycloceras* (*Br. normale* Miller, Dunbar & Condra, 1933) given by Furnish *et al*. (1962: pl. 179, figs. 2–4) and Niko & Mapes (2009: fig. 1), the straight shape of the transverse ribs can probably be a diagnostic species character.

Brachycycloceras scalare differs from *Brachycycloceras subquadratum* Shimansky, 1968 in the rounded cross-section of the conch. *Brachycycloceras scalare* is distinguished from *Brachycycloceras mirabile* Shimansky, 1968 by the more frequent transverse ribs and their perpendicular placement relative to the axis of the conch. *Brachycycloceras scalare* differs from *Brachycycloceras obtusum* (Brown, 1841) in the presence of the massive transverse ribs.

It should be noted that the above-described specimens of *Brachycycloceras scalare* differ significantly morphologically from the representatives of the genus *Brachycycloceras* from the Pennsylvanian of England described by Phillips (1985), namely *Brachycycloceras koninckianum* (d'Orbigny, 1850) and *Br. obtusum*. The conch's surface ornamentation of the specimens of *Brachycycloceras koninckianum* illustrated by Phillips (1985, pl. 25, figs. 12–14) is even more similar to that of the specimen of *Brachycycloceras* cf. *normale* described below. Still, the cross-section of the conch figured by Phillips (1985) is almost square, whereas in *Brachycycloceras* cf. *normale,* it is ellipsoidal.

Comparison of *Brachycycloceras scalare* with the only figured poorly preserved specimen of *Brachycycloceras koninckianum* from Ireland described by Histon (1997–1998, fig. 1.3) is impossible precisely because of the poor preservation of Histon's material; the assignment of the Irish specimen to the species *Brachycycloceras koninckianum* is also doubtful, since the diagnostic morphological features of the genus *Brachycycloceras* were not preserved in Histon's material.

The most recent revision of the genus *Brachycycloceras* (Niko & Mapes, 2009) notes that the earliest representatives of this genus are known from the Serpukhovian, but *Brachycycloceras scalare* was found in the Visean of the Czech Republic (Patteisky, 1929), Poland (Zakowa, 1958, 1960; Gunia & Górecka, 1960; Bednarczyk *et al*., 1968), and Ukraine (this study). However, Niko & Mapes (2009) refer *Brachycycloceras scalare* to the genus *Brachycycloceras* with doubts; in addition, Polish specimens

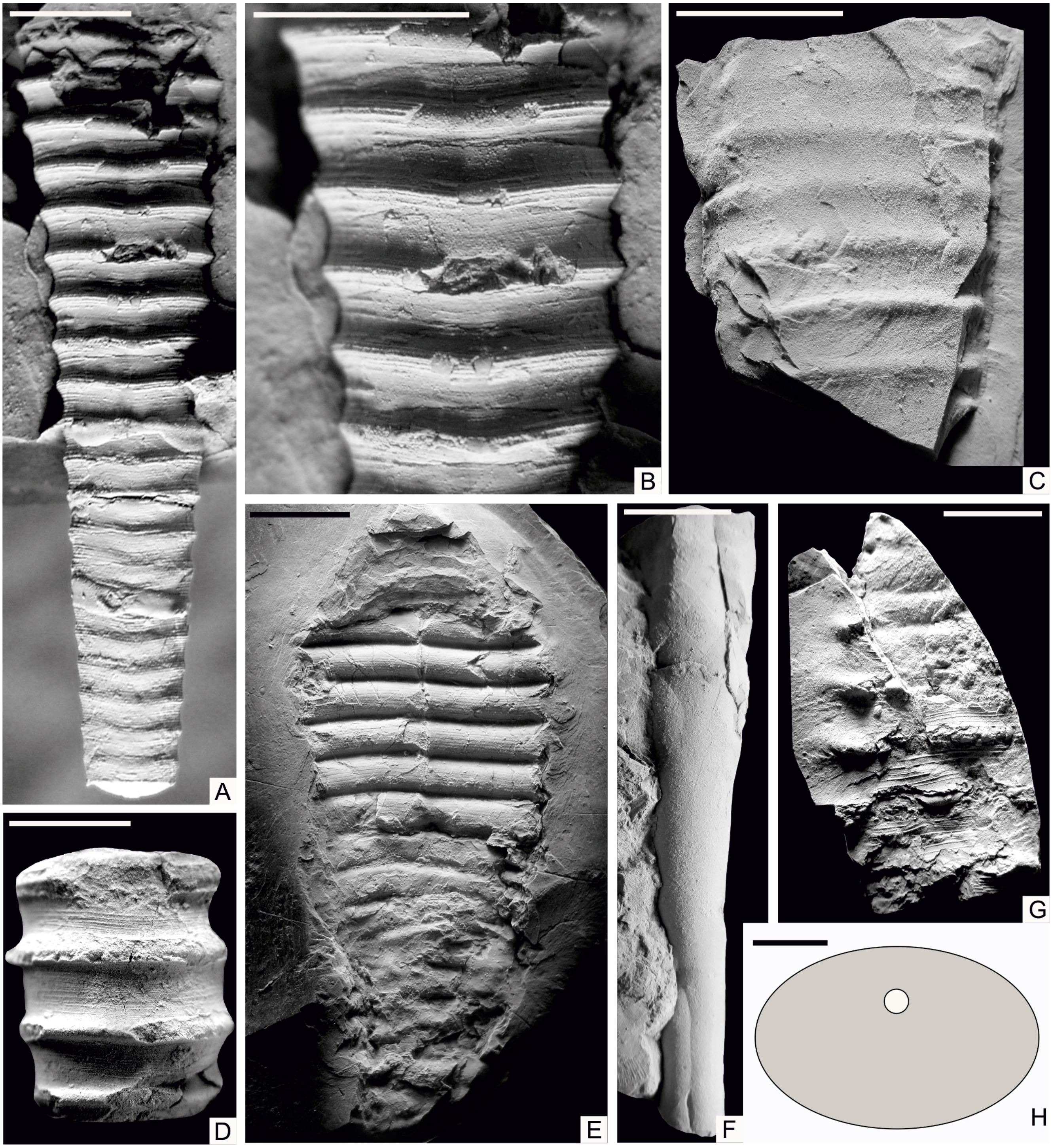

Figure 4. Visean orthocerids from the Dnipro-Donets Depression: **A**, **B**, **H**, *Brachycycloceras* cf. *normale* Miller, Dunbar & Condra, 1933 (specimen IGS NASU-22/10, Yagovka-311 well, Visean): **A**, dorsal view of the conch; **B**, enlarged part of the Figure 4A, which shows ornamentation of the conch surface; **H**, cross-section of the conch; **C–E**, **G**, *Brachycycloceras scalare* (d'Archiac & Verneuil, 1842): **C**, specimen IGS NASU-22/11, dorsal view (Piskovs'ka-370 well, upper Visean); **D**, specimen IGS NASU-9/07, dorsal view (Gubs'ka-2 borehole, upper Visean); **E**, specimen IGS NASU-9/06, dorsal or ventral view (Bugruvativs'ka-160 borehole, upper Visean); **F**, undetermined orthocerid nautiloid, specimen IGS NASU-22/11a (Verkhneozerne-312 borehole, depth interval 3982.0–3985.0 m); **G**, specimen IGS NASU-22/12 (Vasylivka-14 well, lower Visean). Scale bars: A–G = 10 mm; H = 5 mm.

of *Brachycycloceras scalare* are poorly preserved, and their images are low-resolution, so the attribution of this specimens to *Brachycycloceras scalare* is also doubtful.
Localities. Gubs'ka-2, Bugruvativs'ka-16, Piskovs'ka-370, and Vasylivka-14 boreholes (see "Geological setting" for more details).
Occurrence. Namurian of Belgium (Demanet, 1941), Visean of the Czech Republic (Patteisky, 1929) and Poland (Zakowa, 1958, 1960; Gunia & Górecka, 1960; Bednarczyk *et al*., 1968), Mississippian of Germany (Schmidt, 1956) and England (Phillips, 1836).

Brachycycloceras cf. *normale*
Miller, Dunbar & Condra, 1933
(Figure 4A, B, H)

Material. One poorly preserved specimen (IGS NASU 22/10).
Description. The specimen IGS NASU-22/10 is a fragment of an external mold of a longiconic orthocone conch with an apical angle of 18° and a length of 30.0 mm (Figure 4A). The cross-section of the conch is ellipsoidal; the siphuncle is almost central (slightly displaced from the center of the septum to it dorsal part) (Figure 4H). The conch surface is covered with slightly meandering transverse ribs perpendicular to the conch axis, ranging in thickness from 0.5 mm on the young part of the preserved conch to 0.8 mm on the latest part of the conch, which is spaced 1.0–1.5 mm apart (Figure 4B); between the transverse ribs and on it are thin, straight *c*. 0.05-mm-thick growth lines; Figure 4A clearly shows a rather strong increase in the coarseness of transverse ribs during ontogeny.
Remarks. The conch surface ornamentation of the described specimen does not differ from that of *Brachycycloceras normale*, figured by Furnish *et al*. (1962: pl. 179, figs. 2–4) and Niko & Mapes (2009: fig. 1), but a poor preservation and insufficient material prevents the assignment of the specimen IGS NASU 22/10 to this species.

A morphologically very similar orthocerids under the names *Perigrammoceras sulcatum* (Fleming, 1828) and *Reticycloceras* cf. *sulcatum* (Fleming, 1828) were figured by Korejwo & Teller (1968: pl. 16, fig. 3; 1972: pl. 13, fig. 9) and Korejwo (1969: pl. 21, figs. 3–4; 1976: pl. 6, fig. 10; 1979: pl. 10, fig. 8) from the Famenian and Namurian A of Western Pomerania and the Lublin Basin in Poland. Klebelsberg (1912) described a similar or identical Mississippian orthocerid under the name *Orthoceras undatum* (Fleming, 1828).
Localities. The Yagovka-311 borehole, depth interval 4998.0–4913.0 m (Visean).
Occurrence. *Brachycycloceras normale* ranges from the Desmoinesian to Missourian (middle–lower part of the Upper Pennsylvanian) of the USA (Niko & Mapes, 2009).

Order NAUTILIDA Agassiz, 1847
Family CENTROCERATIDAE Hyatt in Zittel, 1900

Phacoceras Hyatt, 1884

Type species. *Nautilus oxystomus* Phillips, 1836; by original designation.

?*Phacoceras* sp.
(Figure 5A)

Material. One conch fragment (specimen IGS NASU-22/01) in the core sample of the black carbonaceous mudstone with remains of brachiopods and bivalves.
Description. The only studied specimen (IGS NASU-22/01) is represented by a crushed, probably extremely discoidal, involute conch, *c*. 46.5 mm in diameter and *c*. 22.0 mm whorl height. The flanks are wide and probably flattened; the umbilical margin is rectangular, and the umbilicus is narrow (uw = 6.0 mm, uw/dm ~ 0.13). The ornamentation is represented by very thin transverse ribs, which form a wide low projection on the flank and a narrow shallow sinus near the umbilical margin and a shallow wide sinus in the ventrolateral area. On the midflank, these ribs are spaced about 0.2 mm apart. On the surface of the flank, there are clusters of *Cyclopuncta* (see Figure 6C) described in detail below.
Remarks. It should be noted that the assignment of the described specimen to the genus *Phacoceras* is rather tentative and is based mainly on the presumably extremely discoidal, involute conch, fine ornamentation, presented by the very thin transverse ribs, and the relatively narrow umbilicus. However, the latter morphological feature is not typical for all species of the genus *Phacoceras* (Shimansky, 1967).

?*Phacoceras* sp. is similar to *Ph. semirutum* Shimansky, 1967 in the conch's surface ornamentation, but it cannot be attributed to this species due to insufficient preservation of the studied material. ?*Ph.* sp. is quite similar to *Ph. roemeri* Schmidt, 1951, but the inability to compare the form of the conchs of these nautilids and the shape of the suture line does not allow to assign ?*Ph*. sp. to this species. ?*Ph.* sp. differs from *Ph. electrum* Shimansky, 1967 by the absence of transverse lateral ribs. The ornamentation of ?*Ph*. sp. and *Ph. oxystomum* (Phillips, 1836) figured by Delépine (1939: pl. 3, figs. 1, 2) is very similar, but the umbilicus in Delépine's specimens of *Ph. oxystomum* is much wider than in ?*Ph*. sp. and, moreover, the umbilical margin of this species is not as sharp as in ?*Ph.* sp.
Localities. The Holikovs'ka-9 borehole (upper Visean). A similar or even identical coiled nautiloid cf. ?*Phacoceras* sp. (IGS NASU-22/01a; not figured) was found in the black shale with remains of brachiopods, bivalves, and undeterminated orthocerids recovered by the Kampans'ka borehole at the depth interval 4926.0–4933.0 m (lower Visean).
Occurrence. *Phacoceras* ranged from Visean (Mississippian) to Cisuralian (Permian) of Western and Eastern Europe, North Africa, and Australia (Shimansky, 1967).

Family TRIGONOCERATIDAE Hyatt, 1884

Catastroboceras Turner, 1965

Type species. *Nautilus quadratus* Fleming, 1828; by original designation.

Catastroboceras sp.
(Figure 5B)

Material. One fragmentary conch impression (specimen IGS NASU-22/02) was found in the core sample of a black carbonaceous mudstone, which contained bivalves, brachiopods belonging to the genus *Orbiculoidea*, ammonoids, orthocerid nautiloids, and pyritized trace fossils assigned to *Planolites*.

Description. The specimen IGS NASU-22/02 is an incomplete conch impression, *c.* 22.5 mm in diameter, with flattened broad flanks and 8.0 mm whorl height. The umbilicus is wide (uw = 11.0 mm, uw/dm ~ 0.49). The umbilical margin is rounded; umbilical wall is not preserved. The flanks bear two longitudinal narrow (0.5–0.6 mm thick) ridges, which gradually disappear during ontogeny. Near the ventrolateral shoulder is a wide (1.0–1.5 mm in width) furrow with a rounded cross-section. The conch's surface is covered with thin (*c.* 0.1 mm on the ventrolateral shoulder) sharp transverse ribs spaced about 0.8 mm apart, but their form is not known due to poor preservation of the material.

Remarks. The described nautilid, despite its poor preservation, is quite confidently assigned to the genus *Catastroboceras* since this fossil bears the ornamentation typical for this genus, *e.g.*, longitudinal ridges, very thin transverse ribs, and a relatively wide umbilicus. In addition, the available poor material represents the remains of a shell that is very close or even identical in form to those of representatives of the genus *Catastroboceras*.

The described *Catastroboceras* sp. morphologically similar to the specimen of *Coelonautilus quadratum* (Fleming, 1828) (=*Catastroboceras quadratum* (Fleming, 1828)), described by Demanet (1938: pl. 12, fig. 2) from the Visean of Belgium. In particular, thin transverse ribs on the ventrolateral longitudinal ridge are observed both in the described *Catastroboceras* sp. and in Demanet's specimen. However, such clearly visible transverse thin ribs on the ventrolateral ridge are also characteristic of other representatives of the genus "*Coelonautilus*." For example, they are clearly visible on the poorly preserved specimens of "*Coelonautilus*" *subsulcatus* (Phillips, 1836) from the Visean of Germany, illustrated by Schmidt (1951, pl. 5, figs. 6, 7). It should be noted that "*Coelonautilus*" *quadratum* and "*Coelonautilus*" *subsulcatus* may be synonyms (Schraut, 1999). The specimens of "*Coelonautilus*" *subsulcatus* figured by Koninck (1878, pl. 27, fig. 14) also bear such thin transverse ribs on the longitudinal ridge and the flanks. Unfortunately, the ornamentation of the flanks of the studied specimen of *Catastroboceras* sp. are not preserved. The same specimen, *i.e.*, figured by Koninck (1878: pl. 27, fig. 14), is referred to as the species "*Coelonautilus*" *quadratum* by Schraut (1999). The specimens of *Catastroboceras quadratum* from the Visean and Serpukhovian strata of the Southern Urals, figured by Shimansky (1967: pl. 19, figs. 8, 9), also bear thin transverse ribs on the ventrolateral shoulder, but the flanks, unlike the Koninck's specimens, bear only very thin growth lines.

Range. *Catastroboceras* is known from the Mississippian of Western Europe and Southern Urals (Shimansky, 1967) and Lower Pennsylvanian of Thailand (Fujikawa *et al*., 1999).

Occurrence. The Holikovs'ka-9 borehole (upper Visean).

Subclass AMMONOIDA Haeckel, 1866
Order GONIATITIDA Hyatt, 1884
Family ANTHRACOCERATIDAE Plummer & Scott, 1937

Anthracoceras Frech, 1899

Type species. *Nomismoceras* (*Anthracoceras*) *discus* Frech, 1899; by original designation.

Anthracoceras sp.
(Figure 5C)

Material. One fragment of a poorly preserved pyritized conch (IGS NASU-22/03; not described) and one fragment of a poorly preserved steinkern (IGS NASU-22/04) in a black carbonaceous mudstone.

Description. The specimen IGS NASU-22/04 (Figure 5C) consists of a fragment of a steinkern. The conch is probably thinly discoidal with a convex venter, broad and flattened flanks, rounded ventrolateral shoulder, angularly rounded umbilical margin and *c.* 12.0 mm whorl height. The umbilicus is narrow (uw = 5.0 mm, uw/dm = 0.17) at *c.* 30.0 mm conch diameter. The surface of the flanks is covered with frequent lamellar growth lines 0.3–0.4 mm thick in the middle of the flank height. These run in a biconvex course, forming a narrow, deep external sinus and a rather high and narrow projection on the ventrolateral shoulder. They form a shallow, broad sinus on the flank; the lines are almost invisible near the umbilical margin. On the midflank, the lines are spaced about 0.6 mm apart.

Remarks. The available material is represented by poorly preserved specimens, making it very difficult to compare these ammonoids with any known species of the genus *Anthracoceras*. *Anthracoceras* sp. described above is morphologically quite similar to the specimens of the type species of the genus (*Anthracoceras discus*) described from Poland (Miller & Furnish, 1954; Cząrniecki, 1959) and the USA (Bond & Saunders, 1989), but the surface ornamentation of the American conchs is somewhat less prominent than that of *Anthracoceras* sp. from the Dnipro-Donets Depression. *A*. sp. differs from the specimens of *A. glabrum* Bisat, 1924 figured by Bisat (1924: pl. 1, figs. 6, 7) by more prominent surface ornamentation, although it should be noted that the Bisat's specimens have much smaller diameters compared to *A*. sp. The specimens of *A. glabrum* figured by Currie (1954: pl. 4, figs. 11, 12), despite approximately equal conch diameters to those of *Anthracoceras* sp., have much narrower umbilicus.

Anthracoceras sp. is similar in surface ornamentation to the specimens of *A. paucilobatum* (Phillips, 1836), figured by Currie (1954, pl. 4, figs. 15–20), but the poor preservation of the studied material does not allow comparing *Anthracoceras*

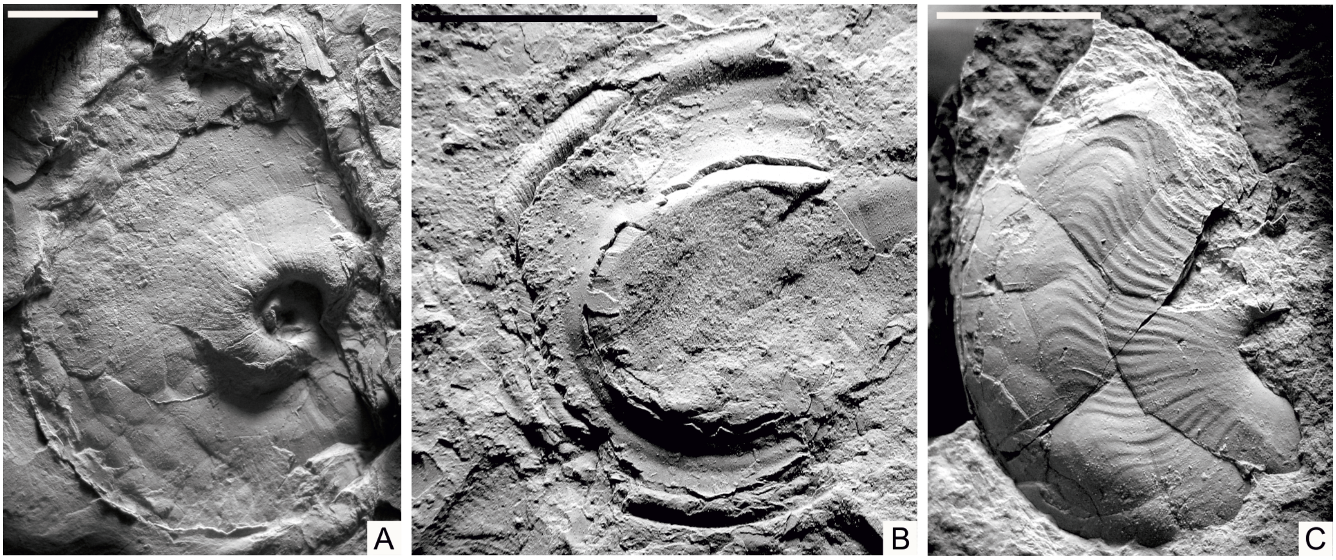

Figure 5. Visean coiled nautiloids and an ammonoid from the Dnipro-Donets Depression: **A**, ?*Phacoceras* sp. (lateral view, specimen IGS NASU-22/01, Holikovs'ka-9 well, upper Visean); **B**, *Catastroboceras* sp. (lateral view, specimen IGS NASU-22/02, Holikovs'ka-9 well, upper Visean); **C**, *Anthracoceras* sp. (lateral view, specimen IGS NASU-22/04, Vasylivka-14 borehole, upper Visean). Scale bars = 10 mm.

sp. from the Dnipro-Donets Depression with closely related species.

Range. *Anthracoceras* ranged from the upper Visean to Serpukhovian (Mississippian) (Bogoslovskaya *et al*., 1999).

Occurrence. The Voloshky-2, Voloshky-314 and Vasylivka-14 wells.

Trace fossils

Ichnofamily PLANOBOLIDAE Wisshak, Knaust & Bertling, 2019

Cyclopuncta Elias, 1958

Type ichnospecies. *Cyclopuncta girtyi* Elias, 1958; by original designation.

Cyclopuncta girtyi Elias, 1958
(Figure 6A–E, G)

1909 Little round spots or punctae: Girty, pl. 6, fig. 6.
1958 *Cyclopuncta girtyi* sp. nov.: Elias, p. 50, pl. 3, figs. 14–16.
1964 Pits made by ?boring organisms: Sturgeon, pl. 33, figs. 20–22.
1975 *Cyclopuncta girtyi*: Hantzschel, p. W184, fig. 108.5
2020 *Cyclopuncta girtyi*: Breton et al., p. 15, figs. 7B, C.
2022 *Cyclopuncta girtyi*: Dernov, text-figs. 4h, i.

Material. Three specimens of cephalopod conchs bearing bioerosions *Cyclopuncta girtyi* from the Visean of the Dnipro-Donets Depression: one fragment of the conch of the coiled nautiloid ?*Phacoceras* sp. (specimen IGS NASU-22/01), one fragment of an undetermined coiled nautiloid (specimen IGS NASU-22/08), and one conch fragment of the ammonoid *Anthracoceras* sp. (specimen IGS NASU-22/05). Four fragments of the cephalopod conchs (specimens IGS NASU-7/100 to IGS NASU-7/104) from the black shale of the upper Bashkirian Mospyne Formation, Donets Basin (see details in Dernov (2022: p. 492)).

Holotype. Not selected.

Type locality and stratigraphic level. Southern Oklahoma, USA (more detailed location of the type locality is unknown); Redoak Hollow Formation, Upper Mississippian.

Description. Bioerosion traces are represented by small, shallow, rounded pits 0.25–0.8 mm in diameter, concentrated in large groups on the outer and rarely inner surface of conchs of nautiloids and ammonoids. The shape of their intersection in the direction perpendicular to the conch surface is semicircular or almost conical. These trace fossils appear as hemispherical limonite (see Figure 6B, D) or mudstone (see Figure 6G) tubercles in the impressions of the surfaces of cephalopod conchs.

Remarks. Sharp rounded tubercles, which were formed as a result of filling the bioerosion pits with rock (Figure 6G), are present on the surface of the steinkern of the conch's body chamber (specimen IGS NASU 22/08), *i.e*., in this case, the traces of *Cyclopuncta girtyi* are probably post-mortem since it is rather difficult to assume their occurrence inside the body chamber during the mollusk's life.

Cyclopuncta girtyi from the Mississippian of the Dnipro-Donets Depression and the Bashkirian of the Donets Basin differ in shape and size: the pit fillings of *Cyclopuncta girtyi* from the Mississippian of the Dnipro-Donets Depression are conical and smaller (0.25 mm *vs*. 0.8 mm) than those of the trace fossils from the Donets Basin; in addition, the bioerosion fillings from the Donets Basin are semicircular in the perpendicular direction to a substrate surface. In my

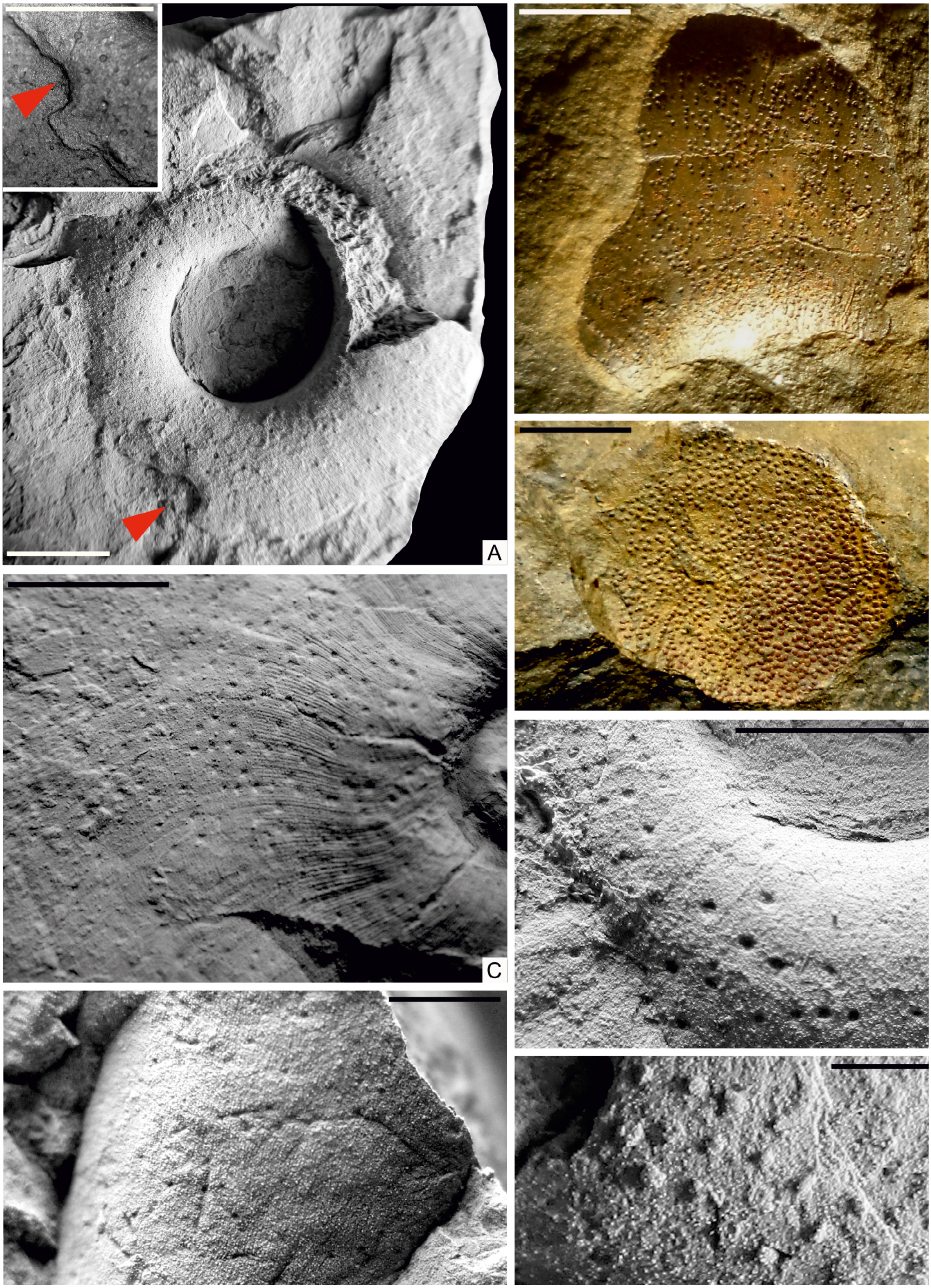

Figure 6. Bioerosion trace fossils *Cyclopuncta girtyi* Elias, 1958 (**A–E, G**) and *Talpina* isp. (**F**) on the Visean and Bashkirian cephalopod conchs from the Donets Basin and Dnipro-Donets Depression: **A, E, G**, specimen IGS NASU-22/08 (**A**, lateral view of the conch with a possible fish bite mark (enlarged in the box); **E**, *Cyclopuncta girtyi*; **G**, rock fillings of *Cyclopuncta girtyi*; unknown locality, Visean); **B**, specimen IGS NASU-7/100, lateral view of the conch (Donets Basin, Mospyne Formation, upper Bashkirian); **C**, flank of the shell of ?*Phacoceras* sp. with *Cyclopuncta girtyi* (specimen IGS NASU-22/01, Holikovs'ka-9 borehole, upper Visean); **D**, specimen IGS NASU-7/101, lateral view of the conch (Donets Basin, Mospyne Formation, upper Bashkirian); **F**, specimen IGS NASU-22/07, ventrolateral view of the conch (Zor'kovs'ka-170 well, lower Visean). Scale bars = 5 mm.

opinion, these differences are not significant for the division of these trace fossils into different ichnospecies.

The described borings *Cyclopuncta* differ from bioerosion traces in hard substrates belonging to the ichnogenera *Entobia* Bronn, 1837 and *Planobola* Schmidt, 1992 in several important morphological features. *Entobia* is represented by a network of tunnels inside the calcareous substrate (shells and rock) that open to the substrate surface with rounded holes (Bromley & D'Alessandro, 1984; Garilli *et al*., 2022), while *Cyclopuncta* are simple shallow borings. *Cyclopuncta* differs from *Planobola* by its much larger size. In addition, unlike *Cyclopuncta*, *Planobola* is represented by "spheroid or bulbous boring systems with latitudinal contact to the substrate surface" (Blissett & Pickerill, 2007: p. 90) rather than semicircular surface pits.

Localities. The Holikovs'ka-9 and Voloshky-2 wells and one unknown locality in the Dnipro-Donets Depression, as well as one outcrop of the upper Bashkirian Mospyne Formation, near the village of Makedonivka, Luhansk region, Ukraine (see details in Dernov, 2022: p. 492).

Occurrence. Mississippian of the USA, Westphalian (Lower and Middle Pennsylvanian) of the Netherlands, Visean and Bashkirian of Ukraine, and Bajocian (Jurassic) of France.

Ichnofamily TALPINIDAE
Wisshak, Knaust & Bertling, 2019

Talpina von Hagenow, 1840

Type ichnospecies. *Talpina ramosa* von Hagenow, 1840; by original designation.

Talpina isp.
(Figure 6F)

Material. One fragment of a cephalopod conch with borings *Talpina* isp. in a black carbonaceous shale (specimen IGS NASU-22/07).

Description. A network of thin (*c*. 0.2 mm in diameter), circular in cross-section, straight and zigzag, rarely branching tunnels with smooth walls, up to 2.0–3.5 mm long, located in a small cluster on a small area of the surface of the flank of a cephalopod conch.

Remarks. According to Wisshak *et al*. (2019), the ichnogenus *Talpina* includes 13 ichnospecies; some of these ichnospecies were originally described as representatives of the ichnogenera *Clionolithes* and *Conchotrema*. Unfortunately, the poor preservation and small quantity of the material do not allow us to attribute it to any particular ichnospecies.

The most likely producers of *Talpina* von Hagenow, 1840 are phoronids (Phoronida Hatscheck, 1888) (Voigt, 1972, 1975, 1978; Zonneveld & Bistran, 2013). For example, Voigt (1975, 1978) provided good evidence that species of the modern genus *Phoronis* Wright, 1856, constructed the tunnels of *Talpina*. Phoronids are vermiform organisms, known in the fossil record since at least the Devonian, that secrete chitinous dwelling tubes and commonly burrow or bore into various substrates (Emig, 2010; Zonneveld & Bistran, 2013). Phoronids are epibenthic (or infaunal) marine invertebrates closely related to brachiopods and represented by 11 modern cosmopolitan species and two genera, *Phoronis* Wright, 1856 and *Phoronopsis* Gilchrist, 1907 (Santagata, 2015). *Talpina* can be interpreted as domichnian borings (Bromley, 2005; Zonneveld & Bistran, 2013) or possible agrichnia traces (Wisshak et al., 2019). However, the problem of the systematic affiliation of the trace-maker(s) of *Talpina* is probably not yet clearly resolved, especially in relation to the Paleozoic ichnospecies of this ichnogenus.

Localities. See "Material and Methods".

Occurrence. Devonian to Recent; cosmopolitic.

DISCUSSION AND FINAL REMARKS

Taphonomy and paleoecology

The available Visean cephalopod remains from the Dnipro-Donets Depression are rather poorly preserved. They are usually represented by crushed fragments of natural rock cast of shells (Figure 7E–F) or laterally compressed shells (Figure 7A–D). Poor preservation of fossils greatly hinders the morphological description and taxonomic studies of cephalopods. However, as research by other authors have shown (*e.g.*, Lacchia *et al*., 2016), they do not significantly limit them.

It should be noted that in the Donets Basin, cephalopod remains are often found in black shales, and sometimes they have excellent preservation, for example, preserved color patterns on the shell surface (Dernov, 2023a), not only of adult shells but also of embryonic shells, as well as remains of ammonoid jaw apparatus (Dernov, 2022). In general, the faunistic assemblages of the Mississippian black shales of the Dnipro-Donets Depression are still very poorly understood. Still, their study is important for understanding the paleoecology of black shale-producing paleobasins.

The trace fossils *Cyclopuncta girtyi* has been recognized by various researchers on the conchs of Ordovician tarphycerids (Pohle *et al*., 2019), Devonian pseudorthocerids (Niko, 1996), Mississippian bactritoids (Girty, 1909), Mississippian and Pennsylvanian ammonoids (Delépine, 1937, author's interpretation; Elias, 1958), Pennsylvanian gastropods (Sturgeon, 1964; Hoare *et al*., 1980), as well as Pennsylvanian brachiopods and nautiloids (Hoare *et al*., 1980). Elias (1958) considered *Cyclopuncta* as traces of infusorians (Ciliophora) in the conch wall. Hoare *et al*. (1980) suggested an inorganic origin of these small pits and thought they were probably small deposits of an iron compound formed in the cavity between internal and external molds. This is incorrect since I have observed *Cyclopuncta* directly on the surface of calcite and pyritized cephalopod shells originating from both the Dnipro-Donets Depression and Donets Basin. It is possible that the epibionts on the ammonoid conch figured by the author (Dernov, 2022, text-fig. 4c) and in Figure 8 are the producers of these trace fossils, but this issue requires further investigation.

On the surface of the specimen IGS NASU-22/05 (Figure 7H), there are a large number of small bioerosion traces *Cyclopuncta girtyi* and a pyritized narrow curved ridge, 0.4 mm thick and 5 mm in length, which is supposedly a place where a possible sclerobiont was attached.

Diverse post-mortem and lifetime bioerosion traces were found on the bivalve and gastropod shells from the Pennsylvanian of the Donets Basin (author's unpublished data). Still, they were not found on cephalopod conchs, except for the above-mentioned *Cyclopuncta*. This fact is probably due to the design features of cephalopod conchs, the presence of an external organic layer on their surface, chemical

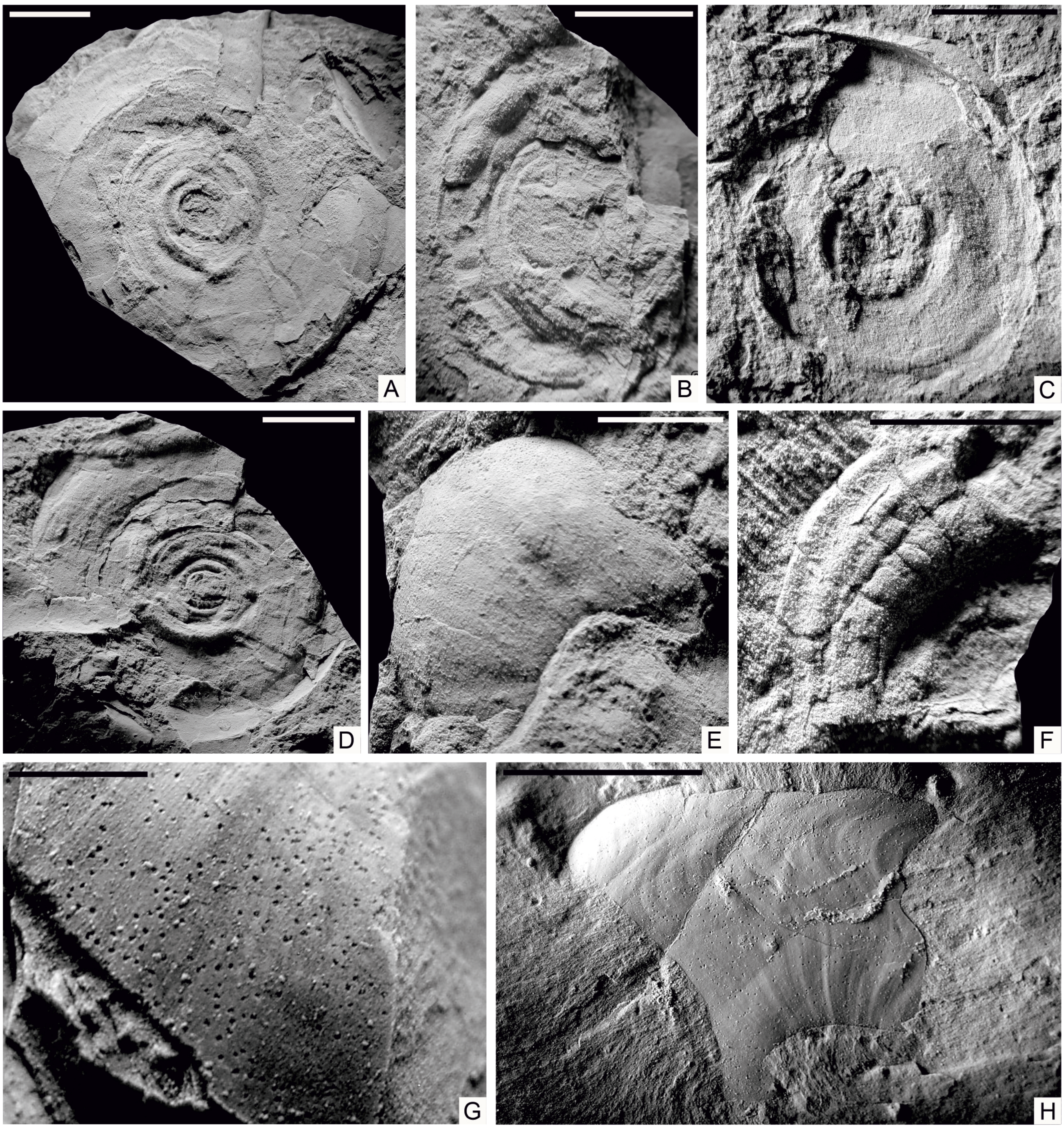

Figure 7. Taphonomic features of the studied cephalopod remains. **A–D**, flattened impressions of the cephalopod shells (**A**, specimen IGS NASU 22/13-1; **B**, specimen IGS NASU 22/15; **C**, specimen IGS NASU 22/14; **D**, specimen IGS NASU 22/13-2; lateral views; Gubs'ka-2 well, Solokhy Formation); **E–F**, deformed fragments of external molds (**E**, specimen IGS NASU 22/16; **F**, specimen IGS NASU 22/17; lateral views; Krasnozayars'ka well, Visean); **G**, ammonoid steikern fragment with bioerosion trace fossils cf. *Cyclopuncta* (specimen IGS NASU-22/05a, Voloshky-2 well, upper Visean); **H**, shell fragment of ?*Anthracoceras* sp. (lateral view) with trace fossils *Cyclopuncta girtyi* and a supposed mark of the pyritized sclerobiont (specimen IGS NASU-22/05, Voloshky-2 well, upper Visean). Scale bars = 10 mm.

protection mechanisms, cleaning of the conch surface by its host, and taphonomic reasons (Davis *et al*., 1999).

Many organisms settled on the surface of conchs of ancient cephalopods, *e.g*., algae, fungi, foraminifers, sponges, serpulids, brachiopods, bryozoans, gastropods, bivalves, echinoderms, and barnacles (Davis *et al*., 1999; Jackson *et al*., 2014). The most frequent Paleozoic organisms that settle on the surface of skeletal remains of living or dead cephalopods are foraminifers (Davis *et al*., 1999), microconchids (Rakociński, 2011), bryozoans (Kröger *et al*., 2009; Kröger

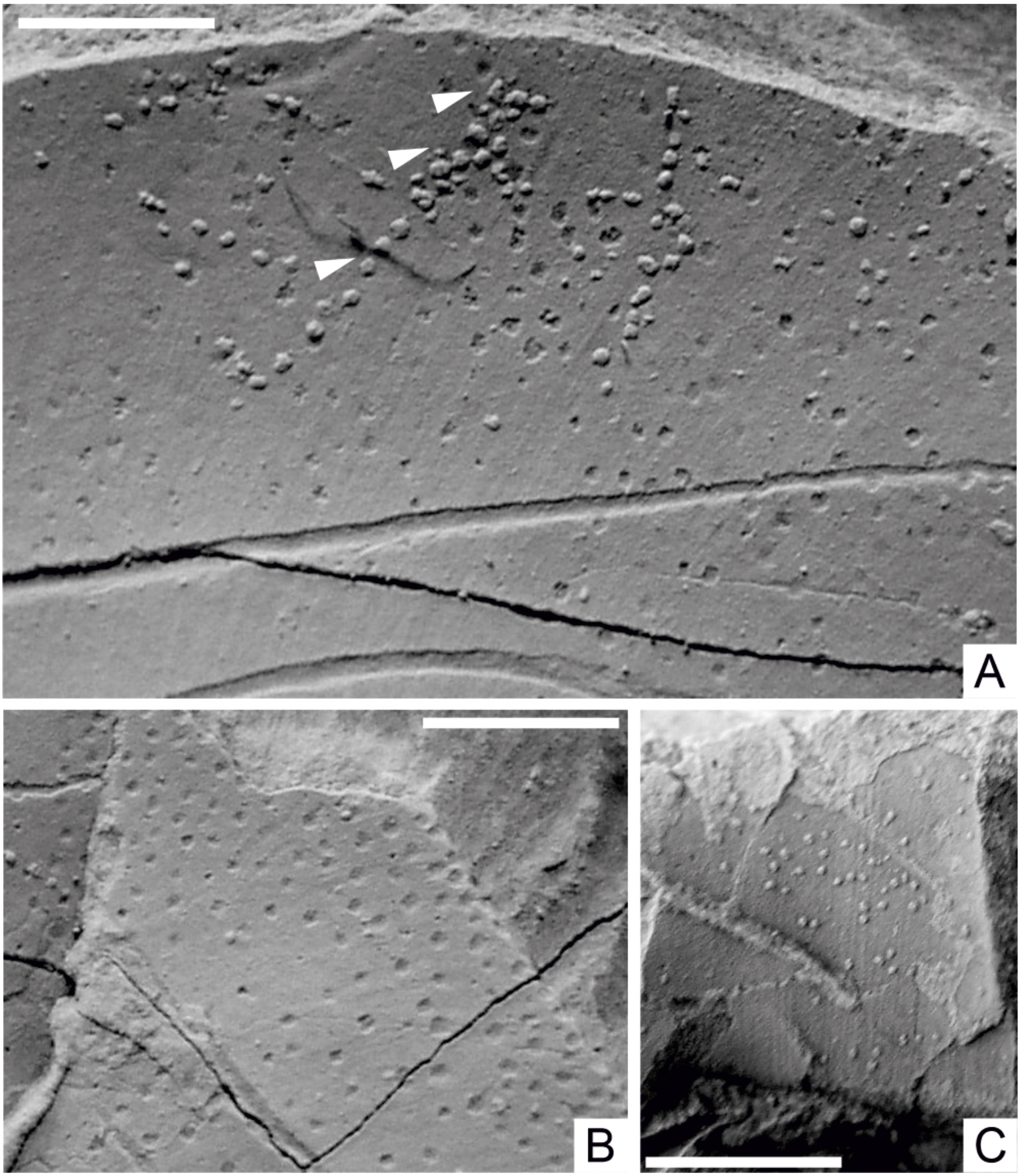

Figure 8. Fragments of cephalopod conchs bearing partly preserved enigmatic sclerobionts, possible producers of *Cyclopuncta*. **A–B**, specimen IGS NASU-9/08, impression of the outer surface of a conch with preserved ?sclerobionts (arrowed in Figure 8A) (western Ukraine, Lviv Paleozoic Trough, borehole No. 1653, depth 1544.0 m, Serpukhovian or lower Bashkirian); **C**, specimen IGS NASU-7/107, fragment of the umbilical wall of a coiled nautiloid conch with preserved ?sclerobionts (Donets Basin, black shale of the upper Bashkirian Mospyne Formation). Scale bars = 5 mm.

& Lefebvre, 2012; Jackson *et al*., 2014), cornulitides (Baird *et al*., 1989), corals (Davis *et al*., 1999), brachiopods (Davis *et al*., 1999), and crinoids (Rakociński, 2011).

The presence of the macroborings in the cephalopod conchs from the Donets Basin and Dnipro-Donets Depression and their absence on the skeletal remains of other co-occurred animals (*e.g*., brachiopods, bivalves, and gastropods) may indicate a prolonged postmortem exposure of cephalopod conchs on the seafloor surface as a hard substrate or, more likely, in a drifting (*i.e*., necroplanctonic) state. The overwhelming majority of *Cyclopuncta girtyi* studied by the author and other researchers (Girty, 1909; Délepine, 1937; Elias, 1958) comes from black shales formed under dysaerobic conditions, which are confirmed by the presence of framboidal pyrite, pseudoplanktonic bivalves and some other lithological and paleontological evidence in the rock (Machulina, 2015, 2016; Lukin, 2020). This may indicate that the producers of these trace fossils may be some microscopic chemosymbionts, but this issue requires more detailed study based on the more material.

The bioerosion traces in the Carboniferous skeletal remains of the marine fauna of the Donets Basin and Dnipro-Donets Depression are poorly understood. So far, the macroborings of barnacles *Rogerella* isp. in brachiopod shells and oncolites or limestone pebbles from the upper Bashkirian conglomerates and Moscovian bioclastic and microbial limestones have been described (Dernov, 2016). The real taxonomic diversity of the Carboniferous bioerosion trace fossils from the Donets Basin is much greater, as evidenced by the material available in the collections, but it has yet to be studied.

One studied nautiloid body chamber (specimen IGS NASU-22/08), bears a semicircular notch in the venter (arrowed in Figure 6A), very similar to ammonite conch damages, which are usually interpreted as predator bite marks ("ventral bite marks" *sensu* Klompmaker *et al*. (2009); for comparison see Andrew *et al*. (2010, 2015); Wright *et al*. (2014); Takeda & Tanabe (2015); Lukeneder & Lukeneder (2022). Donovan *et al*. (in Andrew *et al*., 2010) described these conch damages as the ichnogenus *Bicrescomanducator* Donovan *et al*. in Andrew *et al*., 2010, although usually such conch damages are described without the use of any parataxonomic names (*e.g*., Wright *et al*., 2014; Takeda & Tanabe, 2015; Lukeneder & Lukeneder, 2022). Ventral bite marks on ammonoid conchs are usually interpreted as evidence of predation of coleoids, marine reptiles, and fishes (Klompmaker *et al*., 2009; Andrew *et al*., 2010; Wright *et al*., 2014; Takeda & Tanabe, 2015).

The lithological features of the rock matrix with the studied conch fragment with the supposed ventral bite mark (black carbonaceous shale with remains of marine mollusks and brachiopods) indicate that this rock was formed in relatively low-energy dysaerobic marine environments, so it is difficult to assume an inorganic origin of this damage, *e.g*., during post-mortem drift of conchs or post-mortem transport after settling on the seafloor and perturbing of sunken shells by storm or turbidity currents that was suggested by Takeda & Tanabe (2015).

Among potential producers of the ventral bite mark on the specimen IGS NASU-22/08 listed above, the most likely are fishes since Carboniferous coleoid cephalopods are not known in Ukraine, although the Mississippian and Pennsylvanian biota (especially the one of the Donets Basin) has been studied in detail; marine reptiles are generally unknown in the Carboniferous. Probably, this is indeed the fish bite mark, but the Mississippian ichthyofauna of the Dnipro-Donets Depression has not been studied; there are only reports on indeterminate fish scales (Aizenverg,1958; Brazhnikova *et al*., 1969; Vakarchuk *et al*., 1969; Vinnichenko & Voloshyna, 1969).

BIOSTRATIGRAPHY

In summary, the Visean cephalopod fauna of the Dnipro-Donets Depression consists of nautiloids *Brachycycloceras scalare* (d'Archiac & Verneuil, 1842), *Br.* cf. *normale* Miller, Dunbar & Condra, 1933,?*Phacoceras* sp., *Catastroboceras* sp. (this study), *Lispoceras* sp. (Kuzina & Poletaev, 1991) and ammonoids *Dimorphoceras dnieperense* Kuzina in Kuzina & Poletaev, 1991, *Glyphiolobus pulcher* Kuzina in Kuzina & Poletaev, 1991, *Nomismoceras vittiger* (Phillips, 1836), *Girtyoceras* sp. 1, *G*. sp. 2, and *Anthracoceras* sp. (Kuzina & Poletaev, 1991).

Unfortunately, a relatively complete sequence of the Visean cephalopods has been established for only one section, namely, the Piskovs'ka-371 well, where ammonoids *Glyphiolobus pulcher* were found in the depth interval of 5006.0–5016.0 m, ammonoids *Nomismoceras vittiger* and *Girtyoceras* sp. were found in depth 4780.0–4800.0 m, and orthocerids *Brachycycloceras scalare* originate from a depth of 4400.0–4410.0 m (Kuzina & Poletaev, 1991; this study). According to Kuzina & Poletaev (1991), the above ammonoids originate from the Solokhy Formation; the orthocerid *Brachycycloceras scalare* is probably found in the Solokhy Formation or the Andriyashivka and Perekopivka formations which lie directly above the Solokhy Fm.

In the assemblage of ammonoids described by Kuzina (Kuzina & Poletaev, 1991), two species are new (*Dimorphoceras dnieperense* and *Glyphiolobus pulcher*), *Nomismoceras vittiger* is known from a significant number of upper Visean and lower Serpukhovian localities in Europe and North Africa (according to goniat.org). Two taxa are only identified in open nomenclature (*Girtyoceras* sp. 1, *G*. sp. 2). The Solokhy Formation probably corresponds to the *Goniatites* genozone, although all taxa described by Kuzina (Kuzina & Poletaev, 1991) co-occur in the upper Visean–lower Serpukhovian interval (goniat.org). *Brachycycloceras scalare* is not yet known from the lower Visean; therefore, this species may indicate late Visean age.

PALEOBIOGEOGRAPHY

In Ukraine, Visean cephalopods are also known in the Donets Basin (Aizenverg *et al*., 1979; Kuzina & Poletaev, 1991; Dernov, 2021b), which, together with the Dnipro-

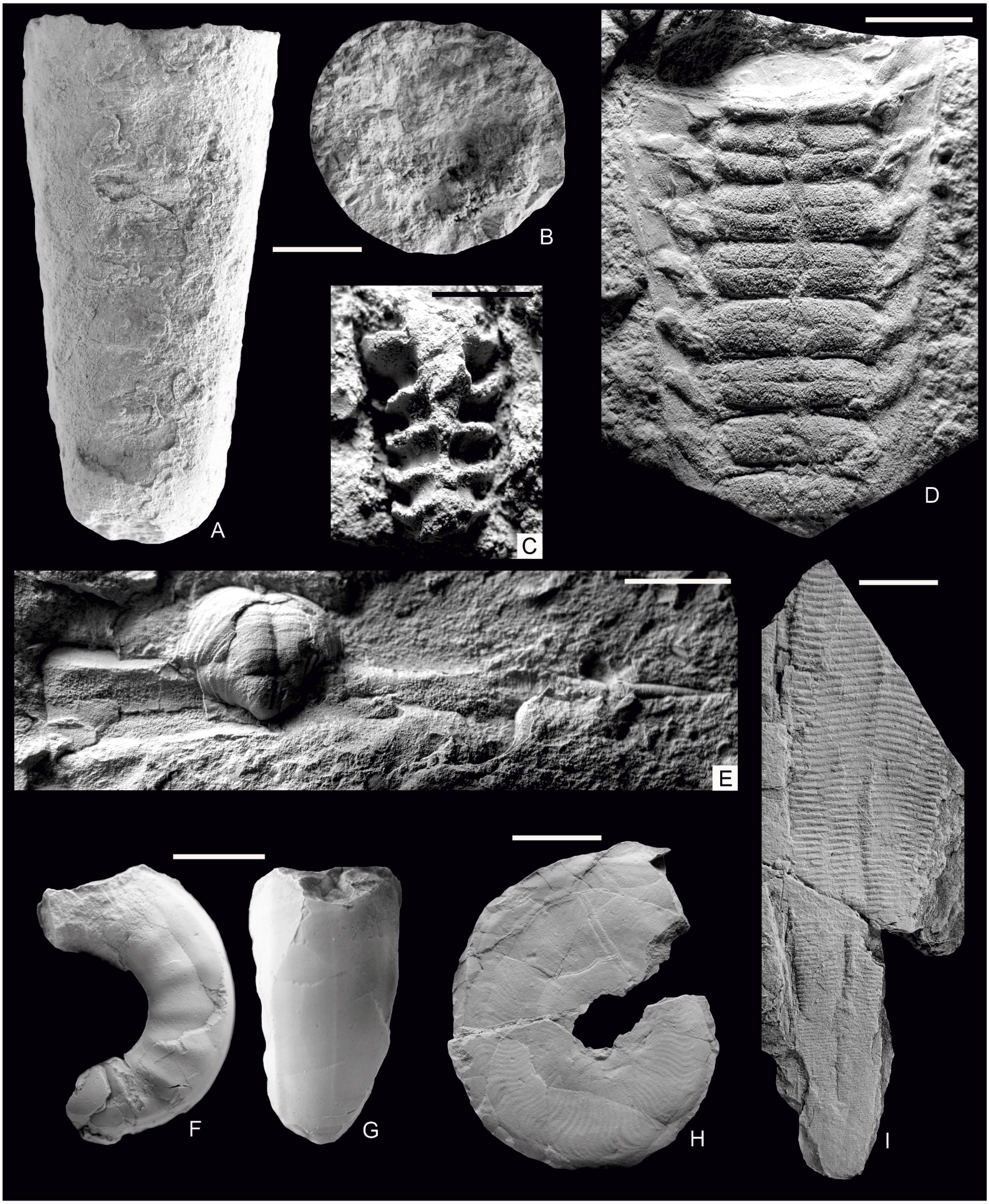

Figure 9. Some Mississippian cephalopods from the Donets Basin: **A–B**, actinocerid cephalopod *Rayonnoceras* sp. (**A**, ventral view, **B**, septal view; Mezhova Formation, upper Visean); C, unidentified actinocerid (ventral view; Styla Formation, Mokra Volnovakha Group, lower Visean); **D**, actinocerid cephalopod ?*Rayonnoceras* sp. (ventral view; Styla Formation, Mokra Volnovakha Group, lower Visean); **E**, unidentified poorly preserved orthocerid (?lateral view; unknown formation, Visean); **F–G**, coiled nautiloid *Gzheloceras aisenvergi* Dernov, 2021a (**F**, lateral view; **G**, ventral view; Samara Formation, lower Serpukhovian); **H**, unidentified ammonoid (lateral view; Styla Formation, Mokra Volnovakha Group, lower Visean); **I**, orthocerid nautiloid similar to *Mitorthoceras inaequiseptum* (Phillips, 1836) (specimen IGS NASU-7/108, Dokuchajevs'k Beds of the Karpivs'kyi Formation, Mokra Volnovakha Group, uppermost Tournaisian). Scale bars: A–B, D–H = 10 mm; C, I = 5 mm.

Donets Depression, forms a single Don-Dnipro Downwarp (Poletaev, 2013). Visean cephalopods in the Donets Basin are known from several stratigraphic levels: an actinocerid cephalopod ?*Rayonnoceras* sp. (Figure 9D) was identified from the Styla Formation (Mokra Volnovakha Group, upper Visean), *Rayonnoceras* sp. (Figure 9A–B) known from the B_8^1 limestone layer (Mezheva Formation, paralic coal-bearing part of the upper Visean succession) (Dernov, 2021b); unidentified poorly preserved orthocerids (Figure 9E) were found in the Visean dark gray crystalline limestones, uncovered by the borehole No. 51 at a depth of 88.0 m near the town of Dokuchaevs'k, Donetsk region (Dernov, 2021b). The only coiled nautiloid described from the Mississippian strata of the Donets Basin is *Gzheloceras aisenvergi* Dernov, 2021a (Figure 9F–G), found in the lower Serpukhovian Samara Formation (Dernov 2021a); no Visean coiled nautiloids have yet been found in the Donets Basin.

The Visean ammonoids of the Donets Basin have been studied in more detail. Aizenverg *et al*. (1979) described *Goniatites aisenvergi* Astakhova & Popov in Aizenverg *et al*., 1979 from the former C_1^vf Zone (modern Donets Formation of the Mokra Volnovakha Group, upper Visean (Poletaev & Vdovenko, 2013)) of the southern Donets Basin. Kuzina & Poletaev (1991) described *Bollandites donetzensis* Kuzina in Kuzina & Poletaev, 1991, *B. mediocris* Kuzina in Kuzina & Poletaev, 1991, *Bollandoceras stylense* Kuzina in Kuzina & Poletaev, 1991, and *Dimorphoceras* sp. from the former C_1^ve Zone (modern Styla Formation of the Mokra Volnovakha Group, upper Visean; Poletaev & Vdovenko, 2013).

As we can see, there is no common genus among the above assemblages of ammonoids from the Donets Basin and the Dnipro-Donets Basin, which can be explained by the difference in the age of these assemblages: the Visean ammonoids from the Dnipro-Donets Basin described by Kuzina (in Kuzina & Poletaev, 1991) probably originate from the *Goniatites* genozone, while the ammonoids described by the same researchers from the Donets Basin probably originate from the older *Bollandites-Bollandoceras* genozone. The species of the genus *Anthracoceras* (*A. discus* (Frech, 1899)) were described from the Serpukhovian part of the Kalmius Fm. of the Donets Basin by Astakhova (1983). Still, this genus is unknown in the Visean strata of the Donets Basin.

Other reasons for the differences in the systematic composition of the Visean cephalopod assemblages of the Donets Basin and the Dnipro-Donets Depression are the low taxonomic diversity of these assemblages, which complicate the comparison and significantly different environmental conditions: the Visean deposits of the Dnipro-Donets Depression are represented by the dysaerobic paleobasin facies with predominant terrigenous sedimentation (Lukin, 2020), while in the Donets Basin, the Visean rocks are represented by limestones and dolomites of the carbonate platform (lower and lower part of the upper Visean) and paralic coal-bearing strata (the highest part of the Visean) (Poletaev & Vdovenko, 2013).

Similar taxonomic composition of the studied small cephalopod assemblage and the data reported by Kuzina & Poletaev (1991) probably indicate a direct connection between the Visean paleobasin of the Dnipro-Donets Depression and the paleobasins of modern Western Europe (*e.g*., Ireland, England, and Germany).

ACKNOWLEDGEMENTS

I would like to thank V. Poletaev, V. Yefimenko, and T. Ryabokon (IGS NASU, Kyiv) for their help with old collections and numerous consultations. The reviewers, whose comments and suggestions improved the quality of the final version of the manuscript, are also acknowledged. The research was conducted within the framework of the programme "Strategic Mineral Resources for Economic Recovery of Ukraine: Analysis of Resources and Reserves, Development of Search Criteria for Increasing the Mineral Resource Base" (State Registration No. 0123U100855).

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Received: 22 October 2023. Accepted: 03 April 2024.

Associated editor: Sergio Martinez
Editor-in-chief: Matias do Nascimento Ritter