Turkish Journal of Earth Sciences

Manuscript 1923

Carboniferous graptolites (Hemichordata: Graptolithina) from the Dnipro-Donets Depression and Donets Basin, Ukraine

VITALY DERNOV

TÜBİTAK

Turkish Journal of Earth Sciences

http://journals.tubitak.gov.tr/earth/

Research Article

Turkish J Earth Sci
(2024) 33: 457-466

doi:10.55730/1300-0985.1923

Carboniferous graptolites (Hemichordata: Graptolithina) from the Dnipro-Donets Depression and Donets Basin, Ukraine

Vitaly DERNOV*

Department of Palaeontology and Stratigraphy of the Palaeozoic Sediments,
Institute of Geological Sciences of the NAS of Ukraine, Kyiv, Ukraine

Received: 06.12.2023 • **Accepted/Published Online:** 23.04.2024 • **Final Version:** 27.05.2024

Abstract: Remains of the Carboniferous graptolites ?*Ptiograptus* sp. and *Dictyonema* sp. are described from the Donets Basin and the border zone of the Dnipro-Donets Depression and Donets Basin (eastern Ukraine). These graptolites were found in the Mezhova (Visean, Mississippian) and Avilovka (Kasimovian, Pennsylvanian) formations. *Dictyonema* sp. from the Avilovka Formation is probably the youngest dendroid graptolite to date. The analysis of geological data allowed to make a reasonable assumption about the Late Devonian rather than the Carboniferous age of the graptolite fauna from the Englewood Formation of South Dakota (USA) and the Tournaisian rather than the Cisuralian age of graptolites from Hainan Island in China.

Key words: Mississippian, Pennsylvanian, *Ptiograptus*, *Dictyonema*, Ukraine

1. Introduction

In 1958, Ukrainian palaeontologist David Aisenverg published a short Ukrainian-language report on the discovery of graptolite remains in the upper Visean rocks of the western part of the Donets Basin (Dnipropetrovsk Region, eastern Ukraine). The assignment of the fossil, identified by him (Aisenverg, 1958a) as ?*Ptiograptus* sp. to dendroid graptolites is beyond doubt, but given that Aisenverg's work was published in Ukrainian in a little-known scientific journal (Reports of the Academy of Sciences of the Ukrainian SSR), this find remained unknown to the general palaeontological community, as demonstrated by subsequent works devoted to the study of Carboniferous graptolites (e.g., Erdtmann and Adams, 1975; Chapman et al., 1993; Maletz et al., 2020; Mottequin et al., 2023), which do not refer to Aisenverg's work.

The uncatalogued specimen of ?*Ptiograptus* sp. illustrated by Aisenverg (1958a: unnumbered text-figure) was considered lost, as the search for it in the collections of the Geological Department of the National Museum of Natural History, National Academy of Sciences of Ukraine, Kyiv (NMNH), which houses palaeontological materials studied by the researchers of the Institute of Geological Sciences, National Academy of Sciences of Ukraine, Kyiv (IGS NASU), yielded no results. However, in February 2023, the author found the specimen figured by Aisenverg (1958a) and one another unstudied Carboniferous graptolite fossil from the fossil site located in the border area of the Donets Basin and Dnipro-Donets Depression (eastern Ukraine), while working with the collection of Carboniferous productidine brachiopods from the Donets Basin stored in the IGS NASU.

Given that graptolites were a rather rare faunistic group in the Carboniferous and are currently known mainly from the United States, British Isles, Belgium and China, this paper describes the Carboniferous (Visean and Kasimovian) graptolites from eastern Ukraine. Previously, relatively diverse graptolite faunas had been identified in Ukraine only from the Ordovician, Silurian and Lower Devonian strata in the Volyn and Podillia (Krandievsky, 1963, 1968; Koren, 1968; Tsegelnyuk, 1974, 1976a, 1976b, 1988a, 1988b).

It should be noted that the findings of Carboniferous graptolites in Ukraine are unlikely to be repeated in the near future, and thus, the available poorly preserved sparse material is of great scientific importance. The data obtained expand our knowledge of the geographical distribution of the Carboniferous graptolites, detail the palaeontological characteristics of the Carboniferous succession of the Donets Basin and the Dnipro-Donets Depression, and supplement the fossil record of graptolites.

2. Material and methods

Two poorly preserved fragments of carbonized graptolite colonies (specimens IGS NASU-25/01 and IGS NASU-25/02) from two carbonaceous siltstone and mudstone

* Correspondence: vitalydernov@gmail.com

drill samples were studied. The studied collection (IGS NASU-25) is stored in the Department of Palaeontology and Stratigraphy of the Palaeozoic sediments of the IGS NASU, Kyiv, Ukraine. The sparce examined fossils do not allow investigation of the fine details of the graptolite morphology, as these fossils are poorly preserved. This poor preservation was further worsened by prolonged storage of the drill samples in inappropriate conditions in rooms with high humidity with other rock slabs rubbing against each other. It was therefore only possible to classify them at the genus level.

3. Geological setting

The available material comes from one Visean (Middle Mississippian) and one Kasimovian (Upper Pennsylvanian) stratigraphic level (Figure 1) in the western part of the Donets Basin and the border area between the Donets Basin and Dnipro-Donets Depression, respectively. These areas are located in Kharkiv and Dnipropetrovsk regions of Ukraine (Figure 2).

Single specimens come from the Visean Mezhova Formation (specimen IGS NASU-25/01) and Kasimovian Avilovka Formation (specimen IGS NASU-25/02).

Specimen IGS NASU-25/01. The drill sample of a carbonaceous siltstone with ?*Ptiograptus* sp. was taken at a depth of 341.95–342.80 m (former late Visean $C_1^v g_1$ zone (Poletaev et al., 2011; Poletaev and Vdovenko, 2013)) of the borehole No. 1341 drilled near the village of Petropavlivka (Dnipropetrovsk Region, eastern Ukraine; Novomoskovs'k-Petropavlivka zone of the Donets Basin according to Poletaev and Vdovenko (2013)). The collector is probably David Aisenverg.

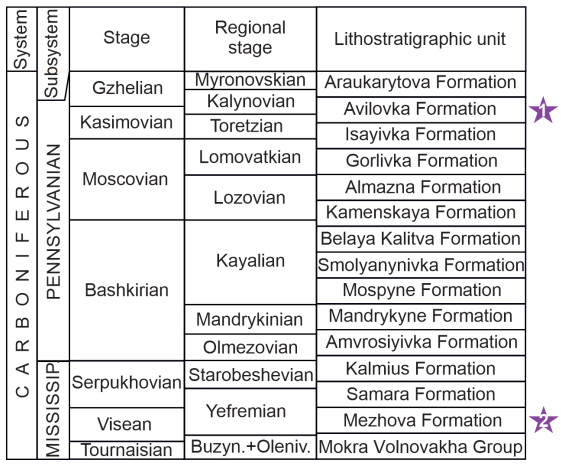

Figure 1. Stratigraphic position of the graptolite-bearing localities (numbered stars). Buzyn. + Oleniv. – Buzynivian and Olenivkian.

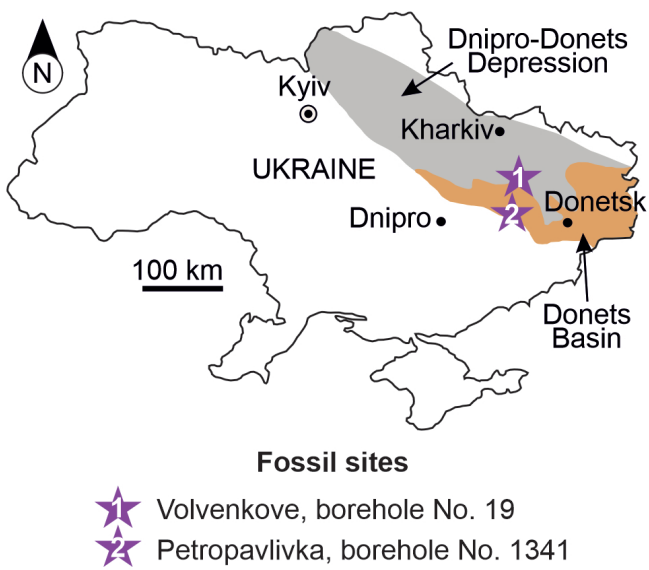

Figure 2. Geographical location of the graptolite-bearing localities (numbered stars).

Borehole No. 1341 uncovered a *c.* 320-m-thick succession of Visean (Mississippian) rocks (Aisenverg and Brazhnikova, 1955). The former late Visean $C_1^v g_1$ zone, which is now referred to the Mezhova Formation (Poletaev and Vdovenko, 2013: Figure 7.2), was exposed in the depth interval of 341.95–342.80 m in the borehole No. 1341 (Aisenverg and Brazhnikova, 1955). A gray, coarse-grained, slightly carbonaceous, horizontally bedded micaceous siltstone containing graptolite remains also contains spiriferid, chonetidine (Figure 3A) and productidine brachiopods, bivalves, crinoids, and trilobites (Aisenverg and Brazhnikova, 1955).

The Mezhova Formation consists of a 500-m-thick paralic succession of sandstones (22.2%), siltstones (65.4%), mudstones (11.0%), coals (*c.* 9 beds; 0.14%) and limestones (*c.* 18 layers; 1.2%). The marine rocks of the formation contain rich assemblages of fossil biota, including foraminifers, corals, brachiopods, bryozoans, bivalves, gastropods, trilobites and calcareous algae (Aisenverg, 1958b; Feofilova and Levenshtein, 1963; Aisenverg and Brazhnikova, 1969; Dunaeva, 1969). Well-preserved terrestrial plants also occur in the continental facies of the Mezhova Formation (Novik, 1968).

This formation corresponds to the upper half of the Yefremian Regional Stage (see Figure 1) of the regional stratigraphic scheme of the Dnipro-Donets Downwarp (Poletaev et al., 2011; Poletaev and Vdovenko, 2013). The Mezhova Formation lies on the top of the Mokra Volnovakha Group and is overlain by the Samara Formation (Poletaev and Vdovenko, 2013).

Specimen IGS NASU-25/02. The drill sample of a black shale with a graptolite *Dictyonema* sp. was taken at a depth of 263.3–267.5 m of the borehole No. 19 drilled near the village of Volvenkove (Kharkiv Region, Izyum District, Pivnichno-Volvenkove hydrocarbon deposit). *Dictyonema* sp. preserved in a gray slightly carbonaceous mudstone with bryozoans and marine bivalve *Phestia* (Figure 3B), as well as crinoid stems (Figure 3C). The rock with graptolite remains is a shale, which lies above the O_1 limestone layer of the Avilovka Formation (late Kasimovian–early Gzhelian, Late Pennsylvanian). The collector is unknown.

The O_1 limestone bed is a basal layer of the Avilovka Formation. This formation consists of a 300 to 1100-m-thick paralic succession of sandstones (38.0%), siltstones (30.0%), mudstones (30.0%), limestones (1.5%) and coals (0.5%) (Aisenverg et al., 1963; Dunaeva, 1969; Makarov and Kosenko, 1985; Stschegolev and Boyarina, 2013). This formation lies on the top of the Isayivka Formation (also called $C_{2\text{-}3}^1$ or N) and is overlain by the Araukarytova Formation (C_3^3 or P). A characteristic feature of the lower part of the Avilovka Formation is the presence of thick sandstone beds, as well as interlayers of brecciated limestones and mottled mudstones. In the upper part of the Avilovka Formation, the role of mottled mudstones increases considerably, and gravelites and coarse-grained sandstones occur (Dunaeva, 1969; Aisenverg et al., 1975; Makarov and Kosenko, 1985). The fauna of the Avilovka Fm. is represented by various foraminifers, rugose corals, ostracodes, brachiopods, bryozoans, bivalves, and conodonts (Stschegolev and Boyarina, 2013); a rich terrestrial plant assemblage is present in the Avilovka Fm. (Stschegolev, 1991; Boyarina, 2016).

The Avilovka Formation corresponds to the Torezian and Kalynovian regional stages of the Regional stratigraphic scheme of the Dnipro-Donets Downwarp (Poletaev et al., 2011; Stschegolev and Boyarina, 2013). The Kasimovian/Gzhelian boundary in the Donets Basin is at the base of the O_5 limestone layer in the upper part of the Avilovka Fm. (Stschegolev and Boyarina, 2013) or at the base of the O_7 limestone layer (Barrick et al., 2022; Ueno, 2022; Wang et al., 2023); Khodjanyazova et al. (2014: Figure 2) identified this boundary at the base of the O_6 limestone layer. Thus, the O_1 limestone layer is of late Kasimovian age.

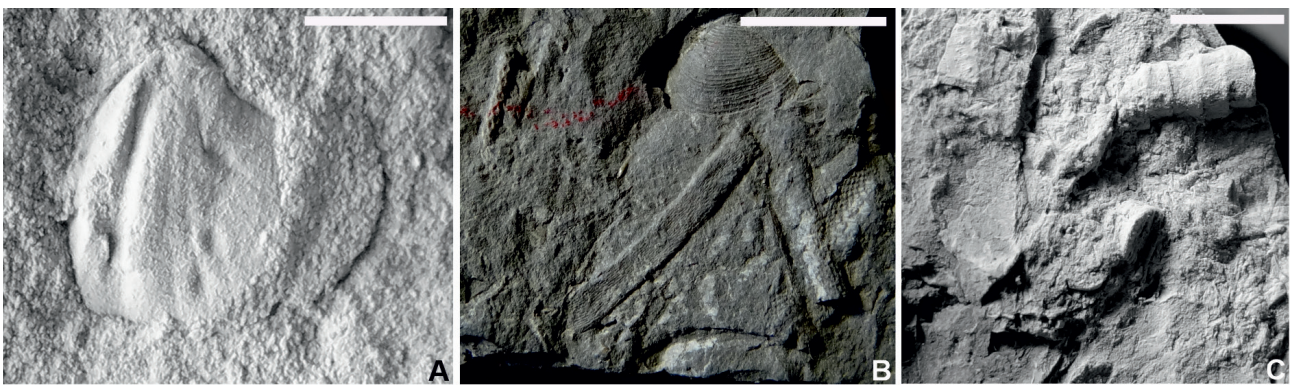

Figure 3. Fossils cooccurring with graptolites in the drill samples: **A** – brachiopod steinkern (borehole No. 1341, Petropavlivka; Visean); **B** – bivalve *Phestia* and bryozoans associated with *Dictyonema* sp. on the bedding plane (borehole No. 19, Volvenkove; Kasimovain); **C** – crinoid stem fragments (borehole No. 19, Volvenkove; Kasimovain). Scale bars = 5 mm.

4. Brief description of the graptolites

Phylum Hemichordata Bateson, 1885
Class Pterobranchia Lankester, 1877
Subclass Graptolithina Bronn, 1849
Order Dendroidea Nicholson, 1872
Family Acanthograptidae Bulman, 1938
Genus *Ptiograptus* Ruedemann, 1908

Type species. *Ptiograptus percorrugatus* Ruedemann, 1908; by original designation.

?*Ptiograptus* sp.
Figures 4A–4C
1958a ?*Ptiograptus* sp.: Aisenverg, pp. 562–563, unnumbered text-figure.

Material. One specimen (IGS NASU-25/01).

Description. Specimen IGS NASU-25/01 is represented by a single fragment, poorly preserved in lateral view, of a carbonized fan-like in the shape, relatively rapidly expanding tubarium with an expansion angle of *c*. 80–90°. The preserved part of the tubarium is *c*. 35 mm long and *c*. 30 mm wide at its widest part, with a stipe width of 0.5–0.7 mm, which remains constant along the entire fragment. The stipes are of medium width and demonstrate multiple dichotomous quickly reaching a parallel orientation. The stipe count ranges from 8 to 12 stipes per 10 mm; the lateral distance between stipes is 1.2–1.5 mm. The thecae are not visible, and anastomosis has not been observed in the specimen.

Genus *Dictyonema* Hall, 1851

Type species. ?*Gorgonia retiformis* Hall, 1843; subsequently designated by Miller (1889: p. 185).

Dictyonema sp.
Figures 4D–4G

Material. One specimen (IGS NASU-25/02).

Description. Specimen IGS NASU-25/02 is represented by a single poorly preserved in lateral aspect small fragment of the carbonized colony *c*. 10 mm wide and *c*. 20 mm long in a gray mudstone. The general shape of the colony is difficult to determine, but it appears to be fan-shaped. The specimen has a stipe width of *c*. 0.5 mm and is oriented nearly parallel to each other; a stipe count of *c*. 4 stipes in 5 mm. The connections between the stipes are *c*. 1.5–2.5 mm wide; the bridges of the thecal transfer are perpendicular to the stipes and obliques, but the number of sufficiently preserved bridges in the available material is small.

5. Discussion and concluding remarks

Carboniferous graptolites are known from few regions (Figure 5), but the age of some graptolite faunas is controversial, and it is likely that some of them (e.g., from the Englewood Formation (Ruedemann and Lochman, 1942; Ruedemann, 1947; Decker, 1954)) are actually of the Late Devonian age.

5.1. North America

In the United States, Carboniferous graptolites are known from several localities. Gurley (1896) was the foremost researcher to detect graptolites in Carboniferous deposits in North America and established a new species, *Dictyonema blairi* Gurley, 1896, from the Chouteau Limestone (Tournaisian) of Missouri. This species was later figured by Thomas (1965: pl. 11) from the Warsaw Formation (Visean) of Missouri.

Ruedemann and Lochman (1942) and Ruedemann (1947) described *Dictyonema dakotense* Ruedemann in Ruedemann & Lochman, 1942, *D. lochmannae* Ruedemann in Ruedemann & Lochman, 1942, and *D. mississippiense* Ruedemann in Ruedemann & Lochman, 1942 from the Englewood Formation (Late Devonian–early Tournaisian) of the Black Hills in South Dakota. Later, Decker (1954) described *Dictyonema aspidoides* Decker, 1954 from the same formation.

I think that the Carboniferous opinion that the Carboniferous age of the graptolite fauna from the Englewood Formation is open to question. The study of conodonts indicates that the Devonian/Carboniferous boundary in the Black Hills and Whitewood Canyon sections is located approximately 0.6–3.0 m below the top of the Englewood Formation (Klapper and Furnish, 1962; Klapper, 1966). The graptolites described by Ruedemann and Lochman (1942), Ruedemann (1947), and Decker (1954) from the Englewood Formation were found in its lower part, which, according to Klapper (1966), belongs to the Late Devonian lower *Spathognathodus costatus* Zone or to the Fammenian (Late Devonian) *Bispathodus aculeatus aculeatus*, *Bispathodus costatus*, and *Bispathodus ultimus* zones (Hogancamp, 2022). Thus, it is likely that the graptolites from the Englewood Formation are of the Famenian rather than the Early Mississippian age.

Erdtmann and Adams (1975) described *Dictyonema* cf. *dakotense* Ruedemann, 1942 and *Callograptus indianensis* Erdtmann & Adams, 1975 from the Harrodsburg Limestone (Visean) of Indiana.

5.2. China

There are different opinions about the age of the graptolite faunule consisting of *Dictyonema* ex gr. *fraiponti* Ubaghs, 1941, *D. hainanense* Mu et al., 1981, *D. shiluense* Mu et al., 1981, *D.* sp. and ?*D.* sp. from rocks of the Sanlingshan Formation outcropped near Sanlingshan of Shilu, Hainan Island in China (Mu et al., 1981; Deng, 1985). Mu et al. (1981) reported the Late Mississippian age for this formation and supported this conclusion by the terrestrial plants *Neuropteris* sp., ?*Pecopteris* sp., and ?*Rhodeopteridium* sp. However, Mu et al. (1981) did not provide images of the plant fossils, and thus, the definitions are somewhat questionable, especially concerning the genus *Pecopteris* Brongniart, 1828.

Deng (1985) reported that the Sanlingshan Formation is underlain by the Shilu Group, which, based on miospore studies, dates to the Carboniferous. However,

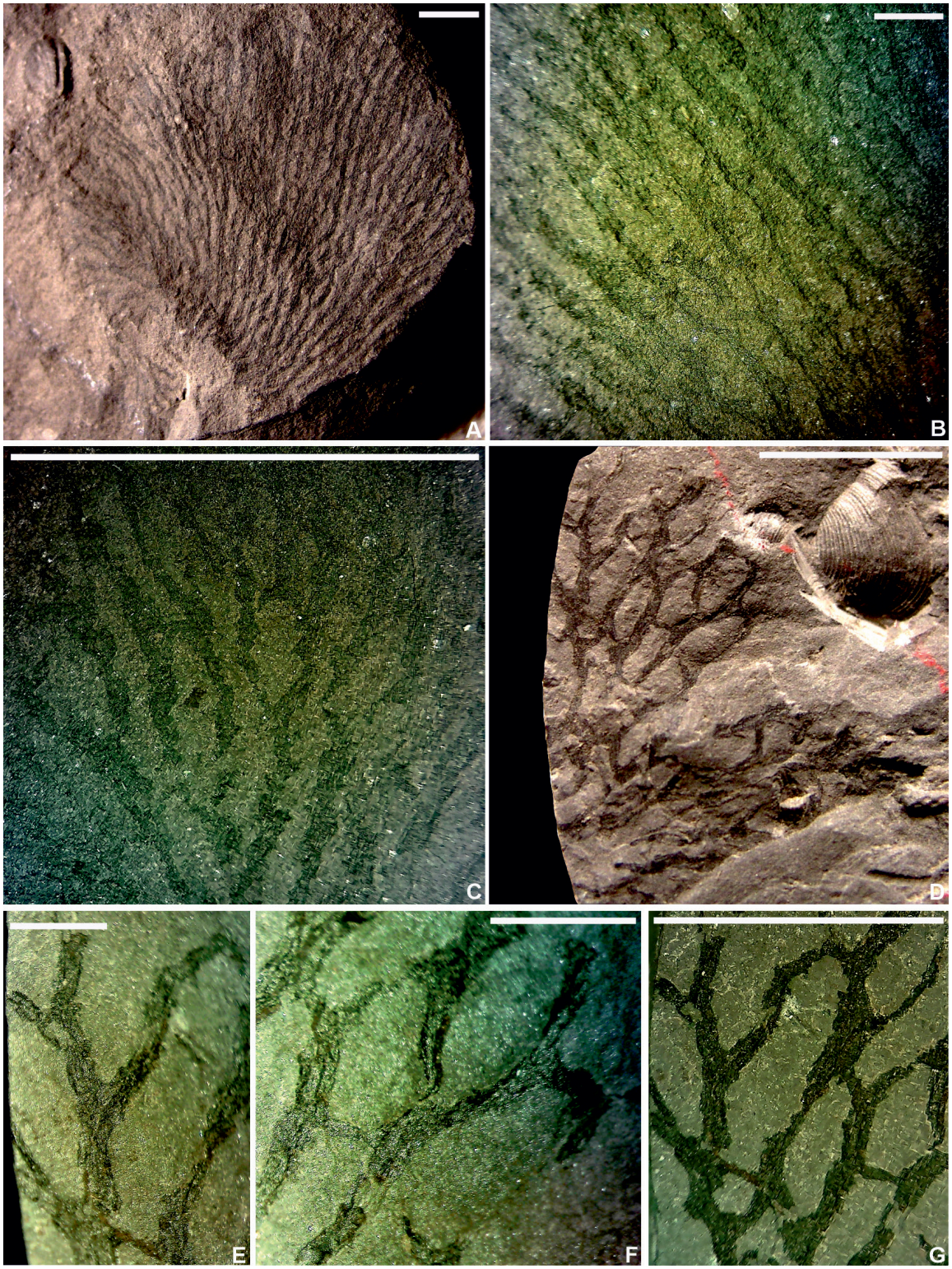

Figure 4. Carboniferous graptolites from Ukraine: **A–C** – ?*Ptiograptus* sp., general view of the tubarium (A) and some morphological details (B, C) (IGS NASU-25/01); **D–G** – *Dictyonema* sp., general view of the tubarium (D) and some morphological details (E–G) (IGS NASU-25/02). Scale bars = 5 mm.

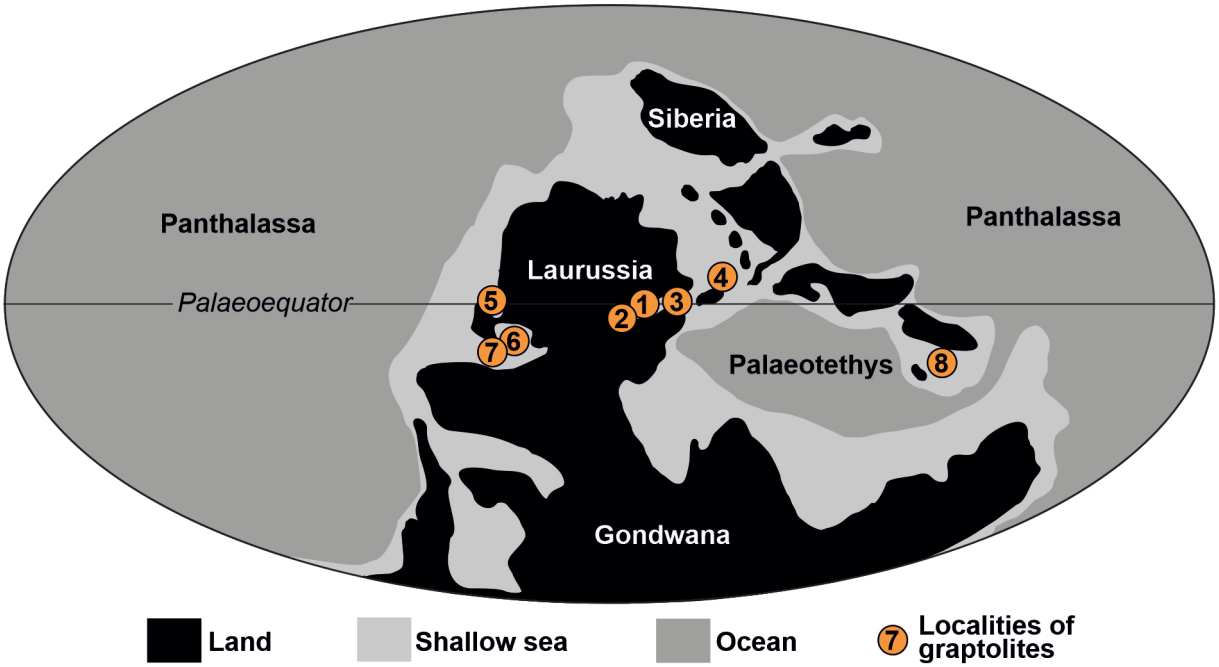

Figure 5. Geographical distribution of the Carboniferous graptolites. Locality numbers: 1 – England and Wales, 2 – Ireland and Isle of Man, 3 – Belgium, 4 – Ukraine, 5–7 – USA (5 – South Dakota, 6 – Indiana, 7 – Missouri), 8 – Hainan Island (China). Map modified from Scotese (2014).

according to new data (Xu et al., 2013, 2014), the Shilu Group is of the Meso-Neoproterozoic age and overlies the Sinian Shihuiding Formation. Deng (1985) also reported terrestrial plants such as *Linopteris* sp., *Mariopteris* sp., *Pecopteris* sp., *Neuropteris* sp., and *Cordaites* sp. in the layer below the graptolite-bearing rocks of the Sanlingshan Formation, which he attributed to the Pennsylvanian. Based on the results of terrestrial plant studies, Zhuangguang and Xiuhu (1981) determined the Visean–Namurian age of the Sanlingshan Formation, but Deng (1985) suggests an assumption about the Permian age of this formation that may require further substantiation.

According to the geological maps of Hainan Island (e.g., Xu et al., 2013: Figure 1; Xu et al., 2014: Figure 1a; Yao et al., 2021: Figure 1) and the Shilu outskirts in the northwestern part of the island (e.g., Xu et al., 2013: Figure 2; Zhang et al., 2013: Figure 2; Xu et al., 2014: Figure 1), Permian–Late Cretaceous granites, Early–Middle Permian mudstones, siltstones, sandstones and limestones (Echa, Eding, and Nanlong formations), and Mississippian–Early and Middle Pennsylvanian conglomerates, sandstones, mudstones and limestones (Nanhao and Qingtianxia formations) are exposed in the Shilu area.

However, it should be noted that the Nanhao Formation contains remains of Llandoverian (Silurian) brachiopods and trilobites (Zeng et al., 2004). In the Shilu area, this formation overlies the Early Silurian Kongliecun Formation; therefore, either these two formations form a single stratigraphic unit or Zeng et al. (2004) may have inaccurately assigned rocks of the Kongliecun Formation to the Nanhao Formation.

Yao et al. (2021) assigned the Nanhao Formation to the Early Silurian based on the Llandoverian fauna identified by Zeng et al. (2004), but slightly earlier Zhang et al. (2001) assigned different parts of the Nanhao Formation to the Silurian, as well as the Mississippian Jishi Formation, Late Devonian Changjiang Formation, and Pennsylvanian deposits. According to Yao et al. (2021), in the Shilu area, Mississippian deposits are represented by the Jishi Formation (Tournaisian); below it lies the Changjiang Formation (Famenian) and the Lanyang Formation (Frasnian) (Yao et al., 2021).

In summary, based on the Palaeozoic stratigraphy of the Shilu area, the graptolites may originate from the Early Silurian Nanhao Formation, Late Devonian Changjiang and Lanyang formations, Tournaisian Jishi Formation, and Pennsylvanian Qingtianxia Formation. However, this issue is resolved in favor of the Jishi Formation, as the images of fossil fauna given by Yao et al. (2021) include a graptolite (Figure 6.22) identified as the bryozoan *Fenestella* sp.

The origin of the misunderstanding regarding the age of the graptolite fauna is not entirely clear. Given that the Shilu area is located near the large Changjiang-Qionghai fault (Kong et al., 2022), it can be assumed that

the Tournaisian deposits are tectonically superimposed on the fossil plant-bearing Pennsylvanian rocks due to the presence of the fault, or that the geological section was misinterpreted due to the heavy dislocation of rocks and the extensive development of tropical vegetation, which hinders geological research, as pointed out by Zhang et al. (2013) and Yao et al. (2021).

5.3. Europe

In Europe, Carboniferous graptolites are known from Belgium, the British Isles and Ukraine. The Visean–early Serpukhovian age of the graptolite fauna, consisting of *Callograptus monensis* (Hind, 1907), *C. sevastopuloi* Chapman et al., 1993, *Dendrograptus whitewellensis* Chapman et al., 1993, *D. rileyi* Chapman et al., 1993, *D. oldhami* Chapman et al., 1993, *D. kittyae* Chapman & al., 1993, *Stelechocladia ubaghsis* Chapman et al., 1993, *Dictyonema carboniferus* (Hind, 1907), *D. crassum* (Girty, 1897), *D. fraiponti* Ubaghs, 1941, *D. heyi* Chapman et al., 1993, *D.* sp. A and *D.* sp. B from the British Isles described by Hind (1907) and Chapman et al. (1993) are well documented by ammonoid sequences.

The Belgian material originally described by Ubaghs (1941) have been revised recently by Maletz et al. (2020) and currently only two of the seven species (*Dictyonema ultimum* Ubaghs, 1941 and *D. fraiponti* Ubaghs, 1941) described by Ubaghs are valid. The Visean age (Molignée Formation) of the Belgian graptolites has been substantiated in detail (Mottequin, 2008; Mottequin et al., 2015), leaving no doubt about it.

In the Donets Basin, the shale above the O_1 limestone layer, in which the single specimen of *Dictyonema* sp. was found, belongs to the *Lobatopteris lamuriana* zone, which was defined by Boyarina (2016). This zone corresponds to the *Crenulopteris lamuriana* zone of Western Europe (Barruelian Substage, Kasimovian) (Knight et al., 2023). The stratigraphic interval with graptolite is located within the *Idiognathodus sagittalis–Id.* sp. A conodont zone, which correlates with the Khamovnichian Horizon of the stratotype of the Kasimovian Stage in the Moscow Syneclise (Russia) (Alekseev et al., 2022).

Dictyonema sp. from the Avilovka Formation is probably the youngest record of a dendroid graptolite to date. The closest findings in terms of age are *Dictyonema carboniferus* (Hind, 1907) and *D. heyi* Chapman et al., 1993 from England (Hind, 1907; Chapman et al., 1993). Thus, there exists a significant gap in the fossil record of Carboniferous graptolites, covering part of the Serpukhovian, Bashkirian, Moscovian, and part of the Kasimovian. It is possible that undescribed findings of graptolites from the Serpukhovian deposits of the Moscow Basin (Vinn and Mironenko, 2021; Van Iten et al., 2023) will assist in partially filling this gap.

Acknowledgments

I would like to thank Dr Jörg Maletz (Freie Universität Berlin) for his help with rare literature. I would also like to thank Dr Vladyslav Poletaev (Institute of Geological Sciences, NAS of Ukraine, Kyiv) for his help with the study of old collections. I sincerely acknowledge Dr Jörg Maletz and an anonymous reviewer whose comments and suggestions improved the quality of the final version of the manuscript.

References

Aisenverg DY (1958a). On a graptolite from the Lower Carboniferous of the Donets Basin. Reports of the Academy of Sciences of the Ukrainian SSR 5: 562-563 (in Ukrainian).

Aisenverg DY (1958b). Stratigraphy and Palaeogeography of the Lower Carboniferous of the Western Part of the Donets Basin. Kyiv, Ukraine: Publishing House of the Academy of Sciences of the Ukrainian SSR (in Russian).

Aisenverg DY, Belenko NG, Dedov VS, Levenshtein ML, Makarov IA et al. (1975). Stratigraphic excursion. In: Aisenverg DYe, Lagutina VV, Levenshtein ML, Popov VS (editors). Field Excursion Guidebook for the Donets Basin. Moscow, Russia: Nauka, pp. 201-245 (in Russian).

Aisenverg DY, Brazhnikova NE (1955). Materials on the stratigraphy of the Lower Carboniferous deposits of the western Donets Basin. Scientific Report. Institute of the Geological Sciences of the Academy of Sciences of the Ukrainian SSR, Kyiv, Ukraine (in Russian).

Aisenverg DY, Brazhnikova NE (1969). Northern slope of the Ukrainian Shield. In: Bondarchuk VG (editor). Stratigraphy of the Ukrainian SSR. Volume V. Carboniferous. Kyiv, Ukraine: Naukova Dumka, pp. 48-90 (in Ukrainian).

Aisenverg DY, Brazhnikova NE, Novik EO, Rotai AP, Shulga PL (1963). Carboniferous stratigraphy of the Donets Basin. Kyiv, Ukraine: Publishing House of the Academy of Sciences of the Ukrainian SSR (in Russian).

Alekseev AS, Nikolaeva SV, Goreva NV, Donova NB, Kossovaya OL et al. (2022). Russian regional Carboniferous stratigraphy. Geological Society, London, Special Publications 512: 49-117. https://doi.org/10.1144/SP512-2021-134

Barrick JE, Alekseev AS, Blanco-Ferrera S, Goreva NV, Hu K et al. (2022). Carboniferous conodont biostratigraphy. In: Lucas SG, Schneider JW, Wang X, Nikolaeva S (editors). The Carboniferous Timescale. Geological Society, London, Special Publications 512: 695-768. https://doi.org/10.1144/SP512-2020-38

Bateson W (1885). The later stages in the development of *Balanoglossus kowalevskii*, with a suggestion as to the affinities of the Enteropneusta. Quarterly Journal of Microscopical Science 25: 81-122.

Boyarina NI (2016). Middle and Upper Carboniferous (Pennsylvanian) megafloral zones of the Donets Basin. Geological Journal (Ukraine) 354: 21-35 (in Russian with an English abstract). https://doi.org/10.30836/igs.1025-6814.2016.1.97280

Brongniart AT (1828–1838). Historie des végétaux fossiles, ou recherches botaniques et geologiques sur les végétaux renfermés dans les diverses couches du globe. Volume 1. Paris, France: G. Dufour et D'Ocagne (in French). https://doi.org/10.5962/bhl.title.60992

Bronn HG (1849). Handbuch der Geschichte der Natur. Dritter Band, Zweite Abtheilung. II. Theil: Organisches Leben (Schluß). Index Palaeontologicus oder Ueberblick der bis jetzt bekannten fossilen Organismen. Stuttgart, Germany: Schweizerbart (in German).

Bulman OMB (1938). Graptolithina. In: Schindewolf OH (editor). Handbuch der Paläozoologie. Volume 2D (in German). Berlin, Germany: Borntraeger, pp. 1-92.

Chapman, AJ, Rickards RB, Grayson RF (1993). The Carboniferous dendroid graptolites of Britain and Ireland. Proceedings of the Yorkshire Geological Society 49: 295-319. https://doi.org/10.1144/pygs.49.4.295

Decker CE (1954). New graptolite from South Dakota. Journal of Paleontology 28 (2): 208-209.

Deng G (1985). *Dictyonema* finds in the Permian System of Hainan Island, Guangdong, China. Journal of Paleontology 59 (5): 1323-1324.

Dunaeva NM (1969). Open Donets Basin. In: Bondarchuk VG (editor). Stratigraphy of the Ukrainian SSR. Volume V. Carboniferous. Kyiv, Ukraine: Naukova Dumka, pp. 21-48 (in Ukrainian).

Erdtmann BD, Adams RL (1975). *Callograptus indianensis* n. sp.; the latest North American graptolite from the Mississippian (late Osagean) of Indiana. Journal of Paleontology 49 (2): 340-345.

Feofilova AP, Levenshtein ML (1963). Features of sedimentation and coal accumulation in the Lower and Middle Carboniferous of the Donets Basin. Moscow, Russia: Publishing House the Academy of Sciences the USSR (in Russian).

Girty GH (1897). A revision of the sponges and coelenterates of the Lower Helderberg group of New York. New York State Geologist Annual Report 14: 261-309.

Gurley RR (1896). North American graptolites. The Journal of Geology 4 (3): 291-311. https://doi.org/10.1086/607500

Hall J (1851). New genera of fossil corals from the report by James Hall, on the Palaeontology of New York. The American Journal of Science and Arts, 2nd Series 11: 398-401.

Hind W (1907). On the occurrence of dendroid graptolites in British Carboniferous rocks. Proceedings of the Yorkshire Geological Society 16: 155-157. https://doi.org/10.1144/pygs.16.2.155

Hogancamp NJ (2022). Taxonomy and biostratigraphy of Devonian and Carboniferous conodonts and their applications in geologic studies of timescale revision, correlations, and depositional environments. PhD, University of Houston, Houston, USA.

Khodjanyazova RR, Davydov VI, Montanez IP, Schmitz MD (2014). Climate- and eustasy-driven cyclicity in Pennsylvanian fusulinid assemblages, Donets Basin (Ukraine). Palaeogeography, Palaeoclimatology, Palaeoecology 396: 41-61. https://doi.org/10.1016/j.palaeo.2013.12.038

Klapper G (1966). Upper Devonian and lower Mississippian conodont zones in Montana, Wyoming, and South Dakota. The University of Kansas Paleontological Contributions 3: 1-49.

Klapper G, Furnish WM (1962). Devonian-Mississippian Englewood Formation in Black Hills, South Dakota. American Association of Petroleum Geologists Bulletin 46: 2071-2078.

Knight JA, Cleal CJ, Álvarez-Vázquez C (2023). The challenge of relating the Kasimovian to west European chronostratigraphy: a critical review of the Cantabrian and Barruelian substages of the Stephanian Stage. In: Lucas SG, DiMichele WA, Opluštil S, Wang X (editors). Ice Ages, Climate Dynamics and Biotic Events: the Late Pennsylvanian World. Geological Society, London, Special Publications 535: 31-71. https://doi.org/10.1144/SP535-2022-189

Kong J, Xu Z, Cheng R (2022). Detrital zircon geochronology of middle Paleozoic to lower Mesozoic strata from Hainan: implications for sedimentary provenance and tectonic evolution of Hainan. International Journal of Earth Sciences 111: 2053-2077. https://doi.org/10.1007/s00531-022-02221-1

Koren TN (1968). First records of Early Devonian monograptids in the Borschovian Horizon of the Podillya. Reports of the Academy of Sciences of the USSR 182 (4): 938-940 (in Russian).

Krandievsky VS (1963). First mass finds of Silurian graptolites in the western Volyn, and their stratigraphic significance. Geological Journal (Ukraine) 23 (5): 34-39 (in Ukrainian).

Krandievsky VS (1968). Silurian graptolites of the Volyn and Podillia. In: Shulga PL (editor). Palaeontology and Stratigraphy of the Lower Paleozoic of the Volyn and Podillya. Kyiv, Ukraine: Naukova Dumka, pp. 26-62 (in Russian).

Lankester ER (1877). Notes on the embryology and classification of the animal kingdom; comprising a revision of speculations relative to the origin and significance of the germlayers. Quarterly Journal of Microscopical Science, New Series 17: 339-454.

Makarov IA, Kosenko ZA (1985). Avilovka Formation. In: Unpublished technical report "Complex study of stratotypes of the Carboniferous formations (Moscovian and Late Carboniferous) of the Donets Basin". Volume 1. Institute of Geological Sciences, NAS of Ukraine, Kyiv (in Russian).

Maletz J, Mottequin B, Olive S, Gueriau P, Pernègre V et al. (2020). Devonian and Carboniferous dendroid graptolites from Belgium and their significance for the taxonomy of the Dendroidea. Geobios 59: 47-59. https://doi.org/10.1016/j.geobios.2020.03.003

Miller SA (1889). North American Geology and Paleontology. Cincinnati, USA: Western Methodist Book Concern.

Mottequin B (2008). The "black marble" of Denée, a fossil conservation deposit from the Lower Carboniferous (Viséan) of southern Belgium. Geological Journal 43 (2–3): 197-208. https://doi.org/10.1002/gj.1102

Mottequin B, Maletz J, Goolaerts S (2023). New data on the Devonian and Carboniferous Graptolithina (Dendroidea) from Belgium with notes on possible occurrences of Rhabdopleuridae in the Belgian Carboniferous. Annales de Paléontologie 109 (2): 102612. https://doi.org/10.1016/j.annpal.2023.102612

Mottequin B, Poty E, Prestianni C (2015). Catalogue of the types and illustrated specimens recovered from the "black marble" of Denée, a marine conservation-Lagerstätte from the Mississippian of southern Belgium. Geologica Belgica 18 (1): 1-14.

Mu EZ, Ge MY, Chen X (1981). Lower Carboniferous graptolites of Shilu, Hainan Island. Acta Palaeontologica Sinica 20: 185-187 (in Chinese with English abstract).

Nicholson HA (1872). A Monograph of the British Graptolitidae. Edinburgh and London, Scotland and England: Blackwood & Sons.

Novik EO (1968). Early Carboniferous Flora of the Donets Basin and Its Western Extension. Kiyv, Ukraine: Naukova Dumka (in Russian).

Poletaev VI, Vdovenko MV (2013). Lower Carboniferous (Mississippian). In: Gozhik PF (editor). Stratigraphy of the Upper Proterozoic and Phanerozoic of Ukraine. Volume 1. Stratigraphy of the Upper Proterozoic, Paleozoic and Mesozoic. Kyiv, Ukraine: Logos, pp. 250-283 (in Ukraine).

Poletaev VI, Vdovenko MV, Stschegolev AK, Boyarina NI, Makarov IA (2011). Stratotypes of the Carboniferous and Lower Permian Regional Stratigraphic Units of the Don-Dnipro Downwarp. Kyiv, Ukraine: Logos (in Ukrainian).

Ruedemann R (1908). Graptolites of New York. Part 2. New York State Museum Memoir 11: 1-583.

Ruedemann R (1947). Graptolites of North America. Geological Society of America, Memoirs 19: 1-652. https://doi.org/10.1130/mem19-p1

Ruedemann R, Lochman C (1942). Graptolites from the Englewood Formation (Mississippian) of the Black Hills, South Dakota. Journal of Paleontology 16 (5): 657-659.

Scotese CR (2014). Atlas of Permo-Carboniferous paleogeographic maps (Mollweide Projection). Maps 53-64. The Late Paleozoic. Evanston, USA.

Stschegolev AK (1991). Late Carboniferous Lycopsids and Sphenophytes. Kyiv, Ukraine: Naukova Dumka (in Russian).

Stschegolev AK, Boyarina NI (2013). Upper Carboniferous (Upper Pennsylvanian). In: Gozhyk PF (editor). Stratigraphy of the Upper Proterozoic and Phanerozoic of Ukraine. Volume 1. Stratigraphy of the Upper Proterozoic, Paleozoic and Mesozoic. Kyiv, Ukraine: Logos, pp. 303-316 (in Ukrainian).

Thomas JN (1965). The geology of the interstate highway 244 and 44 exchange, Kirkwood, Missouri. Master Thesis, University of Missouri, Rolla, USA.

Tsegelnyuk PD (1974). Stage subdivision of the Silurian deposits of the Volyn and Podillia based on graptolites. In: Bondarchuk VG (editor). Stratigraphy of the Ukrainian SSR. Volume 4, part 1. Silurian. Kyiv, Ukraine: Naukova Dumka, pp. 47-63 (in Ukrainian).

Tsegelnyuk PD (1976a). Some Ordovician and Early Silurian graptolites of the Podillia. In: Graptolites and stratigraphy. Tallin, Estonia: Publishing House of the Institute of Geology of the Academy of Sciences of the Estonian SSR, pp. 234-244 (in Russian).

Tsegelnyuk PD (1976b). Late Silurian and Early Devonian monograptids of the SW part of Eastern European Platform. In: Palaeontology and Stratigraphy of the Upper Precambrian and Lower Paleozoic of the SW Part of Eastern European Platform. Kyiv, Ukraine: Naukova Dumka, pp. 91-133.

Tsegelnyuk PD (1988a). Graptolites of the group *Monograptus ludensis* (Murchison, 1839) from the Silurian of the Volyn and Podillia. In: Graptolites in the Earth History. Vilnius, Lithuania: Publishing House of the Vilnius University, pp. 81-83 (in Russian).

Tsegelnyuk PD (1988b). Graptolites of the group *Monograptus ultimus* Perner, 1899 and some not related monograptids. In: Graptolites in the Earth History. Vilnius, Lithuania: Publishing House of the Vilnius University, pp. 84-87 (in Russian).

Ubaghs G (1941). Les Graptolithes dendroïdes du Marbre noir de Denée (Viséen inférieur). Bulletin de l'Institut Royal des Sciences Naturelles de Belgique 17 (2): 1-30 (in French).

Ueno K (2022). Carboniferous fusuline Foraminifera: taxonomy, regional biostratigraphy, and palaeobiogeographic faunal development. In: Lucas SG, Schneider JW, Wang X, Nikolaeva S (editors). The Carboniferous Timescale. Geological Society, London, Special Publications 512: 327-496. https://doi.org/10.1144/sp512-2021-107

Van Iten H, Mironenko A, Vinn O (2023). A new conulariid from the Upper Mississippian (early Serpukhovian) of Central Russia (Moscow Basin): systematics, microstructure, and growth abnormalities. Paläontologische Zeitschrift 97: 311-322. https://doi.org/10.1007/s12542-022-00636-4

Vinn O, Mironenko A (2021). Discovery of plywood structure in *Sphenothallus* from Gurovo Formation (Mississippian), Central Russia. Annales Societatis Geologorum Poloniae 91: 67-74. https://doi.org/10.14241/asgp.2021.01

Wang X, Hu K, Li Y (2023). Timescale for the Kasimovian Stage. In: Lucas SG, DiMichele WA, Opluštil S, Wang X (editors). Ice Ages, Climate Dynamics and Biotic Events: the Late Pennsylvanian World. Geological Society, London, Special Publications 535: 17-30. https://doi.org/10.1144/SP535-2022-260

Xu D, Wang Z, Cai J, Wu C, Bakun-Czubarow N et al. (2013). Geological characteristics and metallogenesis of the Shilu Fe-ore deposit in Hainan Province, South China. Ore Geology Reviews 53: 318-342. https://doi.org/10.1016/j.oregeorev.2013.01.015

Xu DR, Wang ZL, Chena HY, Hollings P, Jansen NH et al. (2014). Petrography and geochemistry of the Shilu Fe–Co–Cu ore district, South China: implications for the origin of a Neoproterozoic BIF system. Ore Geology Reviews 57: 322-350. https://doi.org/10.1016/j.oregeorev.2013.08.011

Yao HZ, Zhang RJ, Niu ZJ, Tu B, Wang ZH et al. (2021). Frasnian–Tournaisian (Late Devonian to Earliest Carboniferous) lithostratigraphy and biostratigraphy of Hainan Island, South China. Geological Journal 56 (12): 5987-5999. https://doi.org/10.1002/gj.4112

Zeng QL, Li ZH, Xie CF, Fu TA, Zhang S (2004). Discovery of late Llandoverian brachiopod *Xinanospirifer* from Hainan Island area, China with comments on the Nanhao Formation. Acta Palaeontologica Sinica 43: 86-93 (in Chinese with English abstract).

Zhang RJ, Wang CY, Hu N, Feng S (2001). Biostratigraphy of Famennian in Hainan Island, South China. Science in China (Series D): Earth Sciences 44: 1057-1064. https://doi.org/10.1007/BF02906862

Zhang R, Yao H, Wang J, Tu B (2013). Middle Devonian–Tournaisian rocks and biota on Hainan Island, South China. Science China: Earth Sciences 56: 1934-1941. https://doi.org/10.1007/s11430-013-4650-1

Zhuangguang M, Xiuhu Z (1981). Palaeobotanical evidence of the age of the Sanlingshan Formation of Shilu, Guangdong. Annual Conference of the Paleontological Society of China (1979): 132-136 (in Chinese).