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Diversity of the Vendian fossils of Podillia (Western Ukraine)

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Diversity of the Vendian fossils of Podillia (Western Ukraine). — V. Grytsenko. — Diversity of Vendian fossil associations is a common feature. The diversity depends on many factors: firstly, physical conditions in the basin, in which animals lived (i.e. depth of the sea, its oxygenation state, temperature, salinity, hard or soft bottom, wave activity, and currents); secondly, biological conditions (members of the association, nutrition, bioturbation, presence of enemies, laws of evolution, etc.). Fossils represent remains of different soft-body animals (with radial, bilateral, and triradial symmetry) as well as algae, microfossils, bacteria and fungi. Bacteria (cyanobacteria) and micro-algae formed mats, which served as food resource for animals. Only some of the animals had special organs for eating bacterial mats. The eating tracks were discovered in the White Sea and Australian Ediacaran sections. Facies changes determined the sequence of fossil associations. The lithological succession reflects changing water depth and oxygenation conditions. Different conditions favored different fossil associations (communities). Fifteen species of imprints and animal tracks are described. The diversity of imprints, tracks, and sedimentary rocks is illustrated on photos. In previous articles, new species of vendobionts from the Vendian of Ukraine were described and imaged. More than two thousand samples are stored in the Geological Department of the National Museum of Natural History NAS of Ukraine. The samples need more detailed study including statistic treatment and description. There are some species, which are similar with those from the Ediacaran of Russia and Ediacaran species from the ancient sea basins (paleobasins) of others continents (Gondwana and Laurasia), but there are dozens of species, which are different. Among the reasons of the differences, in our opinion, are paleogeographical controls, which were linked with climate and in accordance with facies distribution. The Cryogenian (Snowball Earth) period (720–635 millions of years ago) was followed by Ediacaran (635–542 millions of years ago). Predominantly carbonate sedimentary rocks (limestones and dolostones) are typical for the Ediacaran successions of East Siberia and some regions of China. The carbonate accumulations are associated with warm or even tropical climates. The almost entire absence of carbonate sedimentary rocks in the Ediacaran sequence of Podillia is a possible testimony of temperate climate, which established after glaciations of the Cryogenian age in Baltica. The food resource for the Ediacaran animal communities were likely bacterial mats and plankton. Attention should be paid to animal remains and bacterial mats found in a large quarry on the left bank of the Dniester River near Novodniestrovsk, which has potential for discoveries of new species of Ediacaran animals.

Key words: fossils, diversity, Vendian, Podillia, lagerstätte.

Introduction

The Ediacaran sections around the world has been critical for scientists since the first discovery of imprints of animals with radial, bilateral, and triradial symmetry, which at first were considered to be of Cambrian age. Then it turned out that life on Earth appeared even earlier in the Proterozoic Era. The fossils found in the Australian Pound sandstones turned out to be much older than it was considered before. This conclusion was confirmed by geochronological data.

Our predecessors and we have been collecting samples of Vendian fossils (imprints of soft body animals and tracks of ichnofossils) for many years starting from the beginning of twentieth century. The Ukrainian Ediacaran collection contains thousands of samples mainly from the Mohyliv-Podilsky Series outcrops and from cores of boreholes. The majority of outcrops occurs along the banks of the Dniester River and its tributaries.

The collection consists mainly of fossils with radial symmetry. The remains of bilateral and triradial fossils are very rare. The former curator of the geological collection, Yuriy Shevela, has recently found a large disc with the tree-beam structure in the center.

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Alla Ischenko, a famous researcher of ancient algae, presented a collection of Vendotaenian algae from the Podillia sections to our museum. The collection comprises thousands of samples of petrified algae on thick sections of mainly aleurolites and fine-grained, bedded sandstones from many Ediacaran outcrops of Podillia.

The review of a part of the collections by Valery Zaika-Novatsky, Volodymyr Palij, Mikhail Fedonlin, Yuriy Gureev, and Angelina Menasova was published in the Atlas (Ivantsov *et al*. 2015). The collections are stored in state and private museums of Kyiv and in the Paleontological Museum of the Russian Academy of Sciences.

We had an opportunity to collect new samples from outcrops and open pits thanks to funding of several expeditions by the Foundation for Fundamental Studies of the Ministry of Education and Science and support provided by the National Museum of the Natural History of the National Academy of Sciences of Ukraine. Results were partially published in scientific journals and reported on a conference (Grytsenko, 2009). The studies of the Ediacaran succession of Podillia were continued with the representatives of M. P. Semenenko Institute of Mineralogy, Geochemistry, and Ore Formation with participation and financial support of researchers from the USA (Andrey Bekker and Gordon Love) and Canada (Murray Gingras). The construction of a water dam in 1986 caused a rise of groundwater level and resulted in forestation along the banks of the Dniester River. On the other hand, intense abrasion caused the development of new outcrops along the river.

Material

This paper deals with new fossil findings that mostly came from the Bernashivka open pit. It is located on the left bank of the Dniester River. The collection consists of more than two thousand plates of sandstone and aleurolites with Ediacaran imprints and ichnofossils either or both on the upper and lower surface of the bedding. The size of the plates varies from several cm^2 up to 0.5–0.6 m^2. Most of the fossils were excavated from the Lomoziv, Yampil, lower Liadova, Bernashivka, and Bronnitsa members of the Mohyliv-Podilsky Series and from the Komariv Member of the Studenitsa Formation of the Kanylivka Series.

Samples that were collected in the Bernashivka open pit are so-called lagerstëtte. The term means concentration of fossils having unique scientific value. Other two locations occur on both banks of the Dniester River near the flooded Bakota village, where ichnofossils and petrified imprints of Ediacaran algae and other fossils are well-preserved. These locations can also be classified as the lagerstëtte category.

Another unique outcrop is located on the bank of the Ternava River near Kytaihorod village, where the boundary parastratotype of the Precambrian and Lower Cambrian forms an outcrop. The location represents a continuous transition from the Vendian (Ediacaran) to Cambrian, i.e. from the Vendian Studenitsa Formation to the Cambrian Khmelnitsky Formation of the Baltic Series (before the trilobite appearance). Ichnofossils and Pogonofora are common in this Lagershtëtte locality. *Phycodes* (=*Trichophycus*) *pedum* that marks the boundary between the Ediacaran and Cambrian is found in this location.

Geological setting

The Podillia region and the Vendian sequence were studied in detail as these studies were related to the geological prospecting of fluorite deposit in the Dniester area. The research was conducted by scientists who represented universities and institutions of the Academy of Sciences of Ukraine (researchers V. Ya. Velikanov, O. O. Aseeva, V. M. Palij, Yu. O. Gureev, L. I. Konstantinenko, V. P. Grytsenko and others led by professor Valeriy Zaika-Novatsky). A. Sh. Menasova, A. I. Martyshin, Yu. Soldatenko with colleagues joined the investigation a few decades later.

Russian academicians B. S. Sokolov, M. A. Fedonkin and D. M. Grazhdankin, A. Yu. Ivantsov, who represented the Paleontological Institute of the Russian Academy of Sciences, conducted investigations here many times.

As a result of all these studies, a detailed stratigraphic chart was compiled (Fig. 1). The chart is based on lithological, paleontological, geochemical, and new geochronological data.

The Vendian succession in Western Ukraine is composed of two groups of rocks with different origin. The Lower Vendian occurs in the Volyn region, where the thickness of volcanic rocks reaches 450 m. The complex is mostly composed of basalt flows, which alternate with tuffs and tuff-agglomerates of the Volyn Series (Shumlyanskyy *et al.* 2007; 2012). The basalt flows poured out in continental conditions. No fossils were found in this succession. The age was determined as ca. 570 Ma by geochronological and geological methods (Shumlyanskyy *et al.* 2016).

Volcanic rocks (basalts) are mined in open pits for construction purpose (crushed stone, paving stone, mineral wool), and stone casting. A few outcrops of Upper Vendian sandstones and argillites with phosphorite concretions are known in the southern part of Volyn region and in the northern part of Khmelnitsky region. The Upper Vendian sections were studied there in outcrops and boreholes.

Two basalt flows were recovered from boreholes near fifty years ago in the southern part of Podillia and near the Dniester region of the Republic of Moldova, where the volcanic rocks belong to the Kamyanka Formation. The Hrushka Formation, which is considered as a stratigraphic analogue of the Kamyanka Formation, crop out near Hrushka village on the right bank of the Murafa River. The formation is represented by grey and brown poorly laminated sediments of continental origin, which are considered by some investigators as diluvium (rubble of granite), but as glacial deposits (ancient moraine) by others. A single boulder with flat facets of granite was found in the outcrop. The Hrushka Formation filled out depressions in the paleorelief. The Mohyliv-Podilsky Series covers the Hrushka Formation or rests on positive forms of the paleorelief. The Series constitutes the lower part of the Upper Vendian. It consists of three formations: Mohyliv, Yaryshiv, and Nahoryany. The upper part of the Upper Vendian, the Kanylivka Series overlies the Mohyliv-Podilsky Series with a stratigraphic hiatus, which is indicated by a half-meter-thick weathering crust.

Each of the Vendian series has a different appearance and consists of formations and members with their own names. The Mohyliv Formation is subdivided according to the lithological composition into the following members: the Olchedaiv Member (coarse-grained polymineral sandstone) has a thickness up to 40 m; the Lomoziv Member (mostly fine-grained sandstones, alternating with aleurolites, and, rarely, with coarse-grained sandstones and gravelites) has a thickness up to 30 m in the fully exposed sections; Yampil Member (thin-bedded near the base and in the upper part, and thick-bedded, massive, and cross-bedded sandstones in the middle part), the thickness of the member is ca. 30 m; and the Lyadova Member (in the lower part it has a gradual transition to the Yampil Member sandstones, from which they differ by the presence of green-colored, clay material). The Lyadova Member is mainly made of brown and greenish argillites and has the thickness of up to 25 m. The Liadova Member contains two layers of bentonites with the thickness of near 30 cm. The bentonites contain zircon, which was used for the age determination by the U-Pb TIMs method (557 Ma, (Soldatenko *et al.* 2019)). The Lyadova Member contains remains of algal films and complex microfossils typical for the Mohyliv Formation (Velikanov *et al.* 1983). The Mohyliv and Yaryshiv formations are divided by a clear erosional boundary with unusual, multi-directional, 5 cm deep furrows.

The overlying Yaryshiv Formation is composed of the Bernashivka Member, which consists of two sandstone beds and a bed of dark-grey and green argillites between them. In the lower sandstone bed some of the bedding surfaces are marked by *Arumberia banksi* fossils. A layer of orange-colored bentonite occurs in the central part of the bed and has a thickness of ca. 30 cm. The total thickness of the middle part is ca. 7 m. It hosts remains of ichnofossils and algae *Serebrina crustacea* Istch. and *Eoholynia* Gnil. In the argillite layers, A.A. Ischenko found flat disks with concentric wrinkles on the periphery — *Bentanelloides podolicus* Ischenko (Gnilovskaya *et al.* 1988). The upper part of the member is ca. 5 m thick and represented by arkosic, coarse-grained sandstones, in which V. S. Zaika-Novatsky and V. M. Palij for the first time in Ukraine found samples of Ediacaran fossils of *Cyclomedusa plana* Glessner et Wade and a complex of macrofossils (Zaika-Novatsky & Palij 1968; Palij 1976).

The next member is the Bronitsa Member, which comprises fine-grained, green tuff-argilites with a complex of ichnofossils (Grytsenko 2009). From the upper part of the member represented by brown argillites, Zaika-Novatsky described small fossil, *Bronicella* Zaika-Novatsky (Zaika-Novatsky 1965). The thickness of the member is ca. 25 m. Thin layers of the bentonite clays occur in the uppermost part of the Bronitsa Member. The boundary with the Zinkiv Member is marked by the change in sediment color to green.

The Zinkiv Member is represented by green-grey, thin-bedded argillites and aleurolites with interbeds of clayey and calcareous sandstones. The Zinkiv Member includes a rich complex of microfossils (Velikanov *et al.* 1983; Riabenko *et al.* 1976). The thickness of the member is ca. 30 m.

The Nagoriany Formation overlies the Yaryshiv Formation with a sharp boundary. The formation consists of two members: Dzhurzhivka and Kallyus. The lower member is mainly represented by coarse-grained, glauconitic sandstones (up to 20 m in thickness). The upper member is represented by dark-grey to black argillites. The Kallyus Member is characterized by the presence of variably sized phosphorite concretions, which occur on 16-20 levels in the argillites. Remains of the Vendotaenidae algae occurs at two levels within the member. The lower level sits near the base of the member, while the upper level occurs near the member's upper boundary. The complex of microfossils of the Nagoriany Formation differs from that of the Mohyliv Formation (Aseeva 1988; Sokolov & Ivanovsky 1985 *a–b*). The thickness of the member is up to 50 m (Fig. 1).

The Mohyliv-Podilsky Series and the overlying Kanylivka Series are separated by a weathering crust with a thickness of 0.5 to 1.5 m. The Kanylivka Series, based on sediment cycles, is subdivided into four formations: Danylivka, Zharnivka, Krushanivka, and Studenitsa. Each of the formations consists of two members that have their own names (Fig. 1). The lower one consists of coarser-grained beds with predominantly grey sandstones, while the upper member comprises predominantly green-grey and red, fine-grained beds of argillites and aleurolites. Remains of algae are represented by different species of Vendotaenidae (Gnilovskaya *et al.* 1988) are common in the Kanylivka Series; in the Krushanivka Formation, remains of *Cochleatina canilovica* (small carbonaceous fossil) rarely occur and were redescribed recently (Slater *et al.* 2020). Due to shallow-water depositional conditions, small wave ripples are very common, whereas animal remains are almost entirely absent except ichnofossils and fossil algae (Gureev, 1985, 1988; Fedonkin, 1987).

The Danylivka Formation is subdivided into the Pylypy Member represented by greenish-grey, fine-grained sandstones (the thickness is ca. 30 m) and the Shebutyntsy Member composed of thin-bedded alternation of green, grey, and brown argillites and grey aleurolites (the thickness is ca. 25 m).

The Zharnivka Formation is subdivided into the Kulishivka Member, which is represented by coarse- and fine-grained sandstones often crossbeded (2-3 m in thickness), which is overlain by alternation of sandstones, aleurolites, and greenish-grey argillites (ca. 25 m in thickness), and the Stara Ushytsya Member composed of red and brown argillites and grey aleurolites with a thickness of ca. 15 m.

The Krushanivka Formation comprises the Kryvchany Member and the Durniakivtsy Member. The Kryvchany Member is represented in the lower part by fine- to medium-grained sandstones (up to 3–4 m in thickness) and in the upper part by thick beds of alternating green and grey sandstones, aleurolites, and argillites with a total thickness of ca. 30 m. There were found enigmatic fossil *Cochleatina canilovica* Aseeva, 1974 (Slater *et al.* 2020). The Durniakivtsy Member is made of alternation of brown aleurolites, argillites, and grey sandstones, rarely with lenses of limestones and phosphoritic argillites, with a total thickness of ca. 15 m. The total thickness of the Krushanivka Formation is ca. 45 m.

The Studenitsa Formation comprises the Polivaniv Member made of alternating grey sandstones, aleurolites and argillites, with a bed of fine- and coarse-grained sandstones of ca. 2-3 m thick at the base of the member; and the Komariv Member represented by a thin alternation of grey argillites and aleurolites. The thickness of the Studenitsa Formation is ca. 60 m.

Remains of Vendotaenidae, diverse ichnofossils, and, rarely, body imprints are known from all formations of the Kanylivka Series (Velikanov *et al*. 1983; Fedonkin 1987; Gureev 1988; Menasova 2006). Two lower formations of the Kanylivka Series host a complex of microfossils different from those in the two upper formations. The complexes are suitable for geological correlation with other regions (Aseeva 1988 *a*).

The Kanylivka Series has a gradual contact with the Baltic Series. The base of the Baltic Series is accepted as the boundary between the Ediacaran (Vendian) and Cambrian, which is defined by the ichnofossil zone *Phycodes* (=*Trichophycus*) *pedum*; an international standard for the Precambrian-Cambrian boundary (Landing 1994). In the Podillia region, the Baltic Series includes the Okunets, Khmelnitsky, and Zbuch formations (Fig. 1).

The lowermost Okunets Formation is represented by grey and greenish-grey argillites with interbeds and lenses of aleurolites and fine-grained sandstones. The lower boundary of the formation is gradual with the Studenitsa Formation, whereas the upper boundary corresponds to the basal layer of glauconitic quartz sandstone, which belongs to the Khmelnitsky Formation. Microphitofossils — acritarchs and macroalgae (*Tirasotaenia* and *Vendotaenia*) — dominate in the Okunets Formation. Yuriy Gureev described the macrofossil species *Kamenecia stella* Gur. and *Ternavellus vialovi* Gur. Ichnofossils such as *Planolites* sp. and *Curvolithus* sp. are also present in the Okunets Formation, as well as skeletal fossils (Sabellidites): *Sokoloviina* sp. and *Parasabellidites* sp. (Velikanov *et al*. 1983; Kirjanov 1993). The thickness of the formation is up to ca. 15–17 m.

The Khmelnitsky Formation is composed of thin-bedded, dark-grey and greenish-grey argillites with interbeds of aleurolites and glauconitic quartz sandstones (ca. 5–6 m in thickness). In some places, the formation includes interbeds of conglomerate and breccia (up to 0.3 m thick).

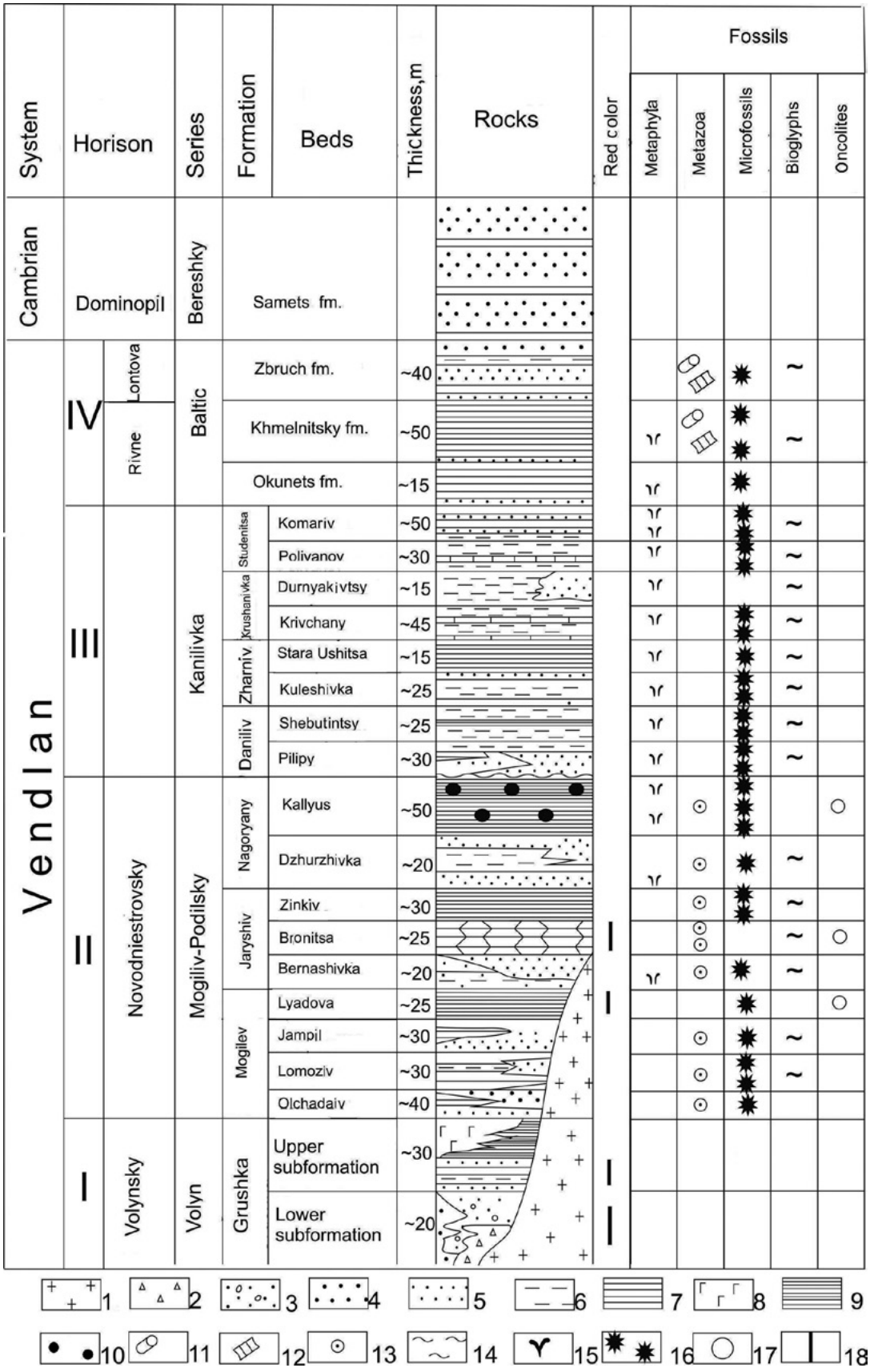
In the northern part of the area, three beds were identified in boreholes that recovered the Khmelnitsky Formation: 1) the basal beds represented by sandstones having a thickness of 6.5–14.0 m; 2) the middle beds represented by argillites with thin (up to 0.1 m thick) interlayers of limestone; the total thickness of beds is ca. 21–31 m; 3) the upper beds are made mainly of aleurolites with interlayers of sandstone up to ca. 18–24 m. In the outcrops along the Ternava River near Kitayhorod village only the lower part of the basal beds can be observed.

The fossils found in the Khmelnitsky Formation are more diverse compared to the Okunets Formation: *Nemiana simplex* Palij, *Cyclomedusa minuta* Fedonkin, *Elassenia zhuravleva* Gur., *Kullingia concentrica* Glaessn. There are also many ichnofossils: *Bergaueria major* Palij, *Didymaulichnus tirasensis* Palij, *Treptichnus bifurcus* Miller, *T. triplex* Palij, *Planolites* sp. and others. The Rivne complex of acritarchs is typical for the Khmelnitsky and Okunets formations (Aseeva 1985 *b*; Velikanov *et al.* 1990).

Methods

The Bernshivka open pit is the best locality to search for imprints and tracks of ichnofossils in the Podillia region. The explosive work in the open pit caused the formation of microcracks, which are parallel to or coincide with the bedding surfaces. These cracks help to open rock along the bedding where fossils are located. We use chisels with acute ends, geological hammers and sledgehammers for breaking flat blocks of the rocks. Then technical knifes and surgery chisels with thin long blades are used to cut blocks into thin plates.

It is important to mark the orientation of plates and blocks. We usually use "+" to indicate the upper surface of the bedding and "–" to define the basal surface. The packing is a very important issue, because samples can be destroyed during transportation. We use thin foam rubber and synthetic plastic films with vesicles to wrap samples. The wrapped samples must be separated one from another by corrugated cardboard. Then we join cardboards with the samples into packs by adhesive tape to save during transportation. We densely put the packs into cardboard boxes and wrap them tightly with adhesive tape again. Finally, we put the boxes densely into a trunk. When samples are delivered to the laboratory, they are inspected, inventorized and photographed with oblique lighting and scale bar. The oblique lighting adds a contrast and a relief to the pictures, making more details visible.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Microfossils
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Cambrian
Vendlan
Dominopil
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← **Fig. 1.** Stratigraphic chart of the Ediacaran and Lover Cambrian of Ukraine: 1 — bedrocks of the Ukrainian Shield; 2 — breccia; 3 — conglomerates, gravelites; 4 — coarse-grained sandstones; 5 — middle-, and fine-grained sandstones; 6 — aleurolites; 7 — argillites; 8 — basalts; 9 — tuff-argillites; 10 — phosphorite concretions; 11 — platisolenites; 12 — sabelliditides; 13 — imprints of soft-bodied animals; 14 — ichnofossils; 15 — remains of algae; 16 — microfossils; 17 — oncolites; 18 — red and brown color (after Velikanov, 2011 with modifications).

Рис.1. Стратиграфічна схема венду та нижнього кембрію України: 1 — кристалічні породи Українського щита; 2 — брекчії; 3 — конгломерати та гравеліти; 4 — грубозернисті пісковики; 5 — середньо- та тонкозернисті пісковики; 6 — алевроліти; 7 — аргиліти; 8 — базальти; 9 — туфоаргиліти; 10 — конкреції фосфоритів; 11 — платісоленітиси; 12 — сабеллідітиси; 13 — відбитки м'якотілих організмів; 14 — іхнофосилії; 15 — рештки водоростей; 16 — мікрофосилії; 17 — онколіти; 18 — червоні та бурі кольори порід (Великанов, 2011), з деякими змінами автора.

Description of new species

All specimens are stored in the monographic collection hall of the Department of Geology of the National Museum of Natural History NAS of Ukraine.

Aspidella (Charniodiscus) podolica Grytsenko sp. nov. (Fig. 2. *1*)

Description. The attached discs could be from *Charnia* or other petellonams. The diameter of the discs in the collection of the museum varies from 120 mm to 160 mm and to 315 mm. The lower surface of the discs is covered by thin, nearly concentric wrinkles. The outlines of the discs differ from ideal circles. The thin concentric wrinkles change twice to thicker wrinkles, which could be caused by seasonal changes. The peripheral edge ends with the negative wrinkle. There is a short remain of the holdfast about 20 mm in diameter at the center of the disk.

Remarks. The finding of the samples was unusual. The late Leonid Konstantinenko and I cut a big block of sandstone and inside we found three big discs on the same bedding surface. The name *Aspidella* was proposed many years ago and now some paleontologists use it for almost all discs, but I think the approach must be revised.

The main locality of the species is the Bernashivka open pit near the dam of the Dniester Hydroelectric Power Plant. The stratigraphical position is the upper level of the Yampil Member of the Mohyliv Formation. It is supposedly the same level where D. Pylypenko found two samples of *Charnia ivantsovi* Grytsenko, 2016. Derivation of name is from Podillia.

Holotype. Coll. No. 2525/3 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Kaisalia yurii Grytsenko sp. nov. (Fig. 2. *2*)

Description. A big imprint of the animal with radial symmetry having three levels of umbrella ornamented by concentric lines. The external diameter is ca. 140 mm, the second wrinkle diameter is ca. 100 mm, and the central is about 40 mm. The upper part of the central disc of the sample is broken off.

Location. The Bernashivka open pit, the Yampil Member of the Mohyliv Formation.

Remarks. The species differs from *Kaisalia levis* Gureev by the well-developed narrow central disc. Derivation of the species name is from the name of Yuri Gureev.

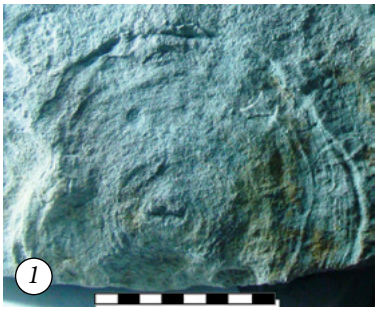
Holotype. Coll. No. 2525/12 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Hiemalora stellaris Fedonkin, 1984 (Fig. 2. *3*)

Diagnosis. "Bowl-shaped body with smooth or concentrically rugate aboral part and numerous tentacles, radiating from the outer margin of the body. Preserved in a negative epirelief, less frequently, in positive hyporelief." [Fedonkin, 1980b].

Description. The tentacles are located at some wrinkles and deepen to the surrounding rock. The diameter of body with tentacles is ca. 60 mm. The thickness of tentacles is ca. 3 mm. The imprint is split at the middle level, what's why two or three sets of of tentacles can be seen.

Remarks. The imprints are mostly found within sediments of the Lomoziv Member. The imprint can be split at different levels within thin bedded rocks. The stratigraphic position is the upper part of the Lomoziv Member of the Mohyliv Formation.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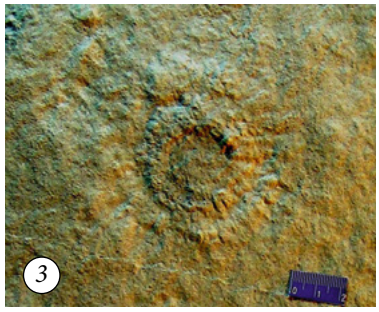
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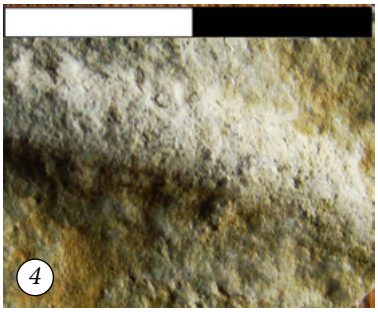
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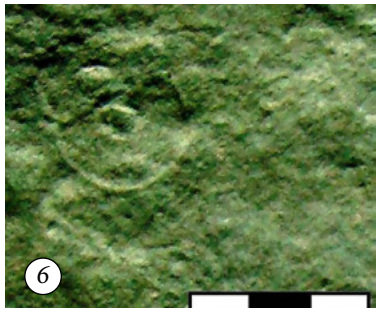
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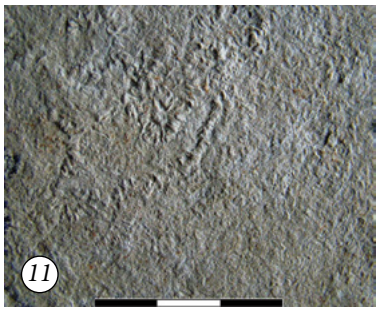
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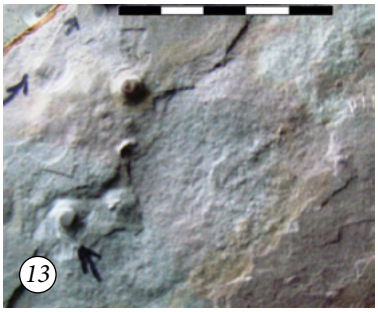
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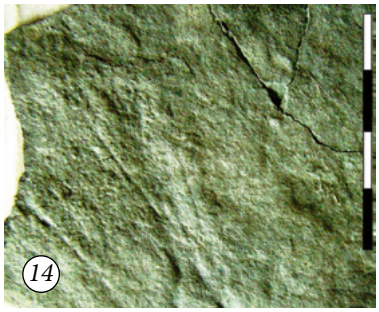
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Holotype. Coll. No. 2525/3 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Cucumber bacotaensis Grytsenko gen. et sp. nov. (Fig. 2. *4*)

Description. The tube-like body-cast has small tubercular appendixes, which cover the visible surface of the specimen. The appendixes are arranged in a chess-like order 3 mm apart. The cast size is over 35 mm long and from 5 to 6 mm in diameter. It is a positive hyporelief.

Remarks. Derivation of the genus name is from the cucumber-like shape. The species name is from the place of finding near the former Bakota village, which was flooded by the power plant's reservoir 33 years ago. The cast is on the lower part of the bedding surface (positive hyporelief).

Holotype. Coll. No. 2525/787 was found in the upper part of the Komariv Member of the Studenitsa Formation on the right bank Bacota bay under cave monastery.

← **Fig. 2.** The diversity of Vendian fossils of the Ukraine. Explanation, scale bar 1 cm:
1 — ***Aspidella (Charniodiscus) podolica*** Grytsenko sp. nov. Coll. No. 2525/1276 was found in the upper part of the Yampil Member of the Mohiliv Formation; *2* — ***Kaisalia yurii*** Grytsenko sp. nov. Coll. No. 2525/12 was found in the upper part of Yampil Member of the Mohiliv Formation; *3* — ***Hiemalora stellaris*** Fedonkin, 1984. Coll. No. 2525/1136 was found in the upper part of Yampil Member of the Mohiliv Formation; *4* — ***Cucumber bacotaensis*** Grytsenko gen. et sp. nov. Coll. No. 2525/787 was found in the upper part of the Komariv Member of the Studenitsa Formation; *5* — ***Paleopascihnus sinuosus*** Fedonkin, 1981. Coll. No. 2525/200 was found in the upper part of the Yampil Member of the Mohiliv Formation; *6* — ***Paliella petaliformis*** Fedonkin. Coll. No. 2525/219 was found in the upper part of the Yampil Member of the Mohiliv Formation; *7* — ***Scratchichnus dniestery*** Grytsenko ichnogen. et ichnosp. nov. Coll. No. 2525/1609 was found in the upper part of the Yampil Member of the Mohiliv Formation; *8* — ***Nemiana minima*** Grytsenko sp. nov. Coll. No. 2515/26 was found in the upper part of the Yampil Member of the Mohiliv Formation; *9* — ***Tirasiana disciformis*** Palij. Coll. No. 2525/1113 was found in the upper part of the Yampil Member of the Mohiliv Formation; *10* — ***Spearella bernasheviensis*** Grytsenko gen. et sp. nov. Coll. No. 2525/2024 was found in the upper part of the Yampil Member of the Mohiliv Formation; *11* — ***Pseudohiemaloraichnus podolica*** Grytsenko, 2009. No. 2480/193(10) was found in the Bronnitsa Member of the Bernashivka Formation near Mohyliv-Podilskiy in the locality Borschiv Jar; *12* — ***Didymaulichnus nerodenkoi*** Grytsenko, 2016. Coll. No. 2525/1860 was found in the upper part of the Yampil Member of the Mohiliv Formation; *13* — ***Capephyllum podolicum*** Grytsenko gen. et sp. nov. Coll No. 2514/27 was found in the upper part of the Lomoziv Member of the Mohiliv Formation; *14* — ***Velicanovia faniformis*** Grytsenko gen. et sp. nov. Coll. No. 2525/152 was found in the upper part of the Yampil Member of the Mohiliv Formation; *15* — ***Cyclomedusa dniestriensis*** Grytsenko sp. nov. Coll. No. 2514/12 was found in the upper part of the Lomoziv Member of the Mohiliv Formation.

Рис. 2. Різноманітність викопних організмів венду України (поділки масштабної лінійки 1 см):
1 — ***Aspidella (Charniodiscus) podolica*** Grytsenko sp. nov., колекційний № 2525/1276, знайдений у верхній частині ямпільських могилівської світи, Бернашівський кар'єр; *2* — ***Kaisalia yurii*** Grytsenko sp. nov., колекційний № 2525/12, зразок походить з ямпільських верств могилівської світи, Бернашівський кар'єр; *3* — ***Hiemalora stellaris*** Fedonkin, 1984, колекційний № 2525/1136, зразок походить з ямпільських верств могилівської світи, Бернашівський кар'єр; *4* — ***Cucumber bacotaensis*** Grytsenko gen. et sp. nov. колекційний №. 2525/787, зразок походить з комаріських верств соколецької світи нижче Бакотського печерного монастиря; *5* — ***Paleopascihnus sinuosus*** Fedonkin, 1981, колекційний № 2525/200, зразок походить з ямпільських верств могилівської світи, Бернашівський кар'єр; *6* — ***Paliella petaliformis*** Fedonkin., колекційний № 2525/219, зразок походить з ломозівських верств могилівської світи, Бернашівський кар'єр; *7* — ***Scratchichnus dniestery*** Grytsenko ichnogen. et ichnosp. nov. колекційний № 2525/1609, зразок походить з ломозівських верств могилівської світи, Бернашівський кар'єр; *8* — ***Nemiana minima*** Grytsenko sp. nov., колекційний № 2515/26 зразок походить з ямпільських верств могилівської світи, Бернашівський кар'єр; *9* — ***Tirasiana disciformis*** Palij, колекційний №. 2525/1113, зразок походить з ямпільських верств могилівської світи, Бернашівський кар'єр; *10* — ***Spearella bernasheviensis*** Grytsenko gen. et sp. nov., колекційний № 2525/2024, зразок походить з ломозвівських верств могилівської світи, Бернашівський кар'єр; *11* — ***Pseudohiemaloraichnus podolica*** Grytsenko, 2009, колекційний № 2480/193(10), бронницькі верстви яришівської світи, Борщів яр біля м. Могилів-Подільський; *12* — ***Didymaulichnus nerodenkoi*** Grytsenko, 2016, колекційний № 2525/1860 зразок походить з ломозівських верств могилівської світи; *13* — ***Capephyllum podolicum*** Grytsenko gen. et sp. nov., колекційний № 2514/27 зразок походить з верхньої частини ломозівських могилівської світи, Бернашівський кар'єр; *14* — ***Velicanovia faniformis*** Grytsenko gen. et sp. nov., колекційний № 2525/152 зразок походить верхньої частини ямпільських верств могилівської світи, Бернашівський кар'єр; *15* — ***Cyclomedusa dniestriensis*** Grytsenko sp. nov., колекційний № 2514/12 зразок походить з ломозівських верств могилівської світи, Бернашівський кар'єр.

Paleopascihnus sinuosus Fedonkin, 1981 (Fig. 2. *5*)

Description. The specimen shows chains of special tracks, which are interpreted as ichnofossils of agglutinated foraminifera or other organisms. The width of tracks is ca. 12 mm. The tracks (of the animals) look like a more or less well-preserved chain. Each link has a shape similar to the narrow distorted oval.

Remarks. The species is common for the Yampil Member of the Mohyliv Formation.

Coll. No. 2525/1860 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Paliella petaliformis Fedonkin (Fig. 2. *6*)

Description. The disc-like imprints, which are very common in deposits of the Lomoziv Member of the Mohyliv Formation in the Bernashivka open pit. The central raising is surrounded by much broader flat umbrella with the uplifted edge. The size varies over a wide range. The largest one can reach ca. 20-30 mm.

Remarks. The interesting fact about this form is its mode of reproduction by dividing. The central part of the animal (specimen No 1862) is stored in the collection.

Coll. No. 1844 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Scratchichnus dniestery Grytsenko ichnogen. et ichnosp. nov. (Fig. 2. *7*)

Description. Scratch lines left by unknown animal. The scratch lines spread like a fan from the wrinkle structure. The sector of scratching lines occupied near 130° on a surface of the sample. The wrinkle structure has interruption on the opposite (back?) side of the animal imprint.

Remarks. The mechanism of eating is unclear as we can see only scratch lines. The type locality is the Lomoziv Member of the Mohyliv Formation in the Bernashivka open pit. Similar structures are described from the Ediacaran of Australia and the Vendian of the Winter Shore of the White Sea, sometimes with imprints of scratchings of animals.

Holotype. Coll. No. 2525/1609 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Nemiana minima Grytsenko sp. nov. (Fig. 2. *8*)

Description. We found for the first time the occurrence of *Nemiana* in the Yampil Member of the Mohyliv Formation in the Bernashivka open pit. The specific feature of the colony is the very small size of "meduzoids" casts, reaching max. 5–6 mm in diameter. Therefore, it is considered a new species.

Remarks. Most of the imprints are smaller than 6 mm in diameter and no overlap between imprints was observed. Larger forms are absent. The given name emphasizes the very small size of the casts.

Holotype. Coll. No. 2515/26 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Tirasiana disciformis Palij (Fig. 2. *9*)

Description: "Moderately convex cast (3-4 mm) in the form of medium-size discs on the lower bedding planes. The main, slightly flattened disc is superposed by the second, smaller and relatively more convex disc with a small, round tubercle in the center. The margin of the main disc surface, extending into the rock, is curved abruptly inward. The casts are separated from the underlying bed by thin interlayer of the bluish-green mudstone. Unlike the rest of surface, which is easily separated from the rock, the central tubercle is often cemented in the underlying layer. The casts more often are arranged in small groups (3-4 specimens) or isolated. The casts of adherent specimens are very typical" (Palij 1976).

Remarks. The casts of *T. disciformis* differ from *T. coniformis* Palij by flatter shape and simpler structure with only two superimposed discs (Palij, 1976). Both species are typical for the Yampil Member of the Mohyliv Formation.

Coll. No. 2525/1113 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Speariella bernasheviensis Grytsenko gen. et sp. nov. (Fig. 2. *10*)

Description. The cast is a simple spear-like structure. It is ca. 30 mm long and less than 5 mm wide in the lower part, which is destroyed by near oval-shaped mechanoglyph (the size is ca. 30×35 mm). The upper end of the "spear" is acute. The "spear" was formed by two straight low combs, which converge at the upper end. There are also two shorter lines between combs. Some unclear lines are located outside of spear.

Remarks. The cast is located on the upper side of the bedding surface (negative epirelief). Bad taphonomic conditions destroyed some features of the primary structure. It hypothetically might be a fragment of rangeamorph petallonama. Derivation of the name is from spear-like form. The specimen was found in the Bernashivka open pit.

Holotype. Coll. No. 2525/2024 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Pseudohiemaloraichnus podolica Grytsenko, 2009 (Fig. 2. *11*)

Description. "There is an oval projection (3×5 mm) at the central part of a trace, from which thin traces of eating of the substrate radially spread. The trace, 2 mm in width, moves along the coil; the trace has a composite path, resembling sinusoid. The trace intersects the furrows-hatches, directed obliquely towards the animal's movement." (Grytsenko 2009).

Remarks. The ichnofossil occurs in green argillites of the Bronnitsa Member of the Bernashivka Formation near the city of Mohyliv-Podilsky in the Borschiv Yar locality.

Holotype. Coll. No. 2480/193(10) was found in the upper part of the Yampil Member of the Mohyliv Formation.

Didymaulichnus nerodenkoi Grytsenko, 2016 (Fig. 2. *12*)

Description. These are moderately elongated tracks with close to straight trajectories. Maximum width in the middle part is ca. 5-6 mm. The length of some of them reaches from 12 to 40 mm. They appear on the bedding surface and disappear again. The tracks are divided by negative line (grove) up to 2 mm in width. Poorly distinct structures like ticks oriented in one direction are seen in the groves.

Comparison. The new species differs from *D. tirasensis* Palij and *D.* cf. *miettensis* Young by smaller size and stratigraphic position. The first form was found in the Lower Cambrian, and the second one in the Lomoziv Member of the Mohyliv Formation.

Remarks. The name of species is given in honer of my teacher V. M. Nerodenko. Some of species samples in Yu. Gureev collection 2088/6 after death of the researcher was lost in the Geological Department.

Holotype. Coll. No. 2525/1860 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Capephyllum podolicum Grytsenko gen. et sp. nov. (Fig. 2. *13*)

Description. A population of new species and new genus was discovered in the sandy facies of the Lomoziv Member of the Mohyliv Formation. The colony embraces several forms at the same level. The shape of the form is very simple: it is a small cylinder with convex ends and a narrow collar on one side.

Remarks. Sometimes due to weathering the fossils can be easily separated from the sediment. Derivation of the name is from the cap-like shape. The specimen was found in the Bernashivka open pit.

Holotype. Coll No. 2514/27 was found in the upper part of the Lomoziv Member of the Mohyliv Formation.

Velicanovia faniformis Grytsenko gen. et sp. nov. (Fig. 2. *14*)

Description. The imprint resembles the branch of thin fibrils, which diverge dichotomically. Such structure can look like a fan. It forms a positive epyrelief.

Remarks. The genus name is given in honor of the late V. Velikanov, who was the best expert in the Vendian stratigraphy of Podillia. The species name was choosen due to its remote similarity to a fan.

Holotype. Coll. No. 2525/152 was found in the upper part of the Yampil Member of the Mohyliv Formation.

Cyclomedusa dniestriensis Grytsenko sp. nov. (Fig. 2. *15*)

Description. The cast consists of a central disc and an outer wrinkle. The diameter of the central disc is 15 mm. It is surrounded by an outer wrinkle of 25 mm in diameter. The central disc is separated from the outer wrinkle by a narrow grove. The outer wrinkle is limited by a poorly developed concentric convexity with short obliquely orienteering "eyelashes".

Remarks. The reason for the given name is related to the location near the Dniester River.

Holotype. Coll. No. 2514/12 was found in the upper part of the Lomoziv Member of the Mohyliv Formation.

Discussion

The Vendian succession in Podillia has been studied for about a century, but it is still less known than the Ediacaran successions in Australia, Canada, Namibia, Great Britain, northwest Russia, and China. Many publications dealing with the Ediacaran period appeared in the last few decades describing the results of investigation of this section, including the study of fossils and imprints of animals, ichnofossils, geochemical investigation, determination of age by various methods and facies generalizations.

Information regarding many traditional and new localities is now available. Comparing successions and fossils from the Mistaken Point (Newfoundland, Canada) and Charnwood (Great Britain), the following conclusions can be made: (1) it is apparent that depths of the basins were different; (2) there are some similarities in fossil assemblages; (3) these assemblages existed at different times in different places. Thicker section in Australia is characterized by significant diversity of fossils and lithologies in the section. There are mainly siliciclastics there ranging from fine-grained to coarse-grained sandstones.

A special set of sedimentary rocks and fossil associations was found on the southern bank of the White Sea (Arkhangelsk region of Russia). Many species were discovered in that area, some of which are similar to Ediacaran fossils, but many of them are different from those found in Australia. A poor association was found in the Southern Urals, where ichnofossils dominate (Bekker 1996, 2010, 2013). Some locations were discovered and studied in eastern Siberia and China. We have to emphasize that successions there contain carbonate rocks (limestones and dolostones) and differ significantly from contemporary siliciclastics-dominated successions in other places. Some species in these areas are characterized by excellent conservations and even presence of embryos in south China.

New locations of Ediacaran successions and fossils were recently found in Brasil and Argentina, in the Arabian Peninsula, in India and Iran.

The facies model of the Vendian paleobasin in Podillia

The Vendian succession of the Podillia paleobasin has remained unknown to the international community for many years because of its location close to the Soviet Union border due to which studies were complicated by the regime of security. Now the area near the Dniester River is easily accessible, has good exposure, excellent level of study, and facies diversity of sedimentary rocks and fossils, which reflect changes in relative sealevel and basin extent. The location of the sections within the south-western slope of the Ukrainian Shield and the Eastern European platform defines proximity to tectonically active areas. A tectonically active zone was located on the place of the modern Carpathians, which is reflected in the development of the Vendian paleobasin of Podillia.

The formation of the basin in the Volyn-Podillia pericraton and intensive volcanic activity from the beginning of the Vendian resulted in accumulation of a sequence of volcanic rocks. In the Late

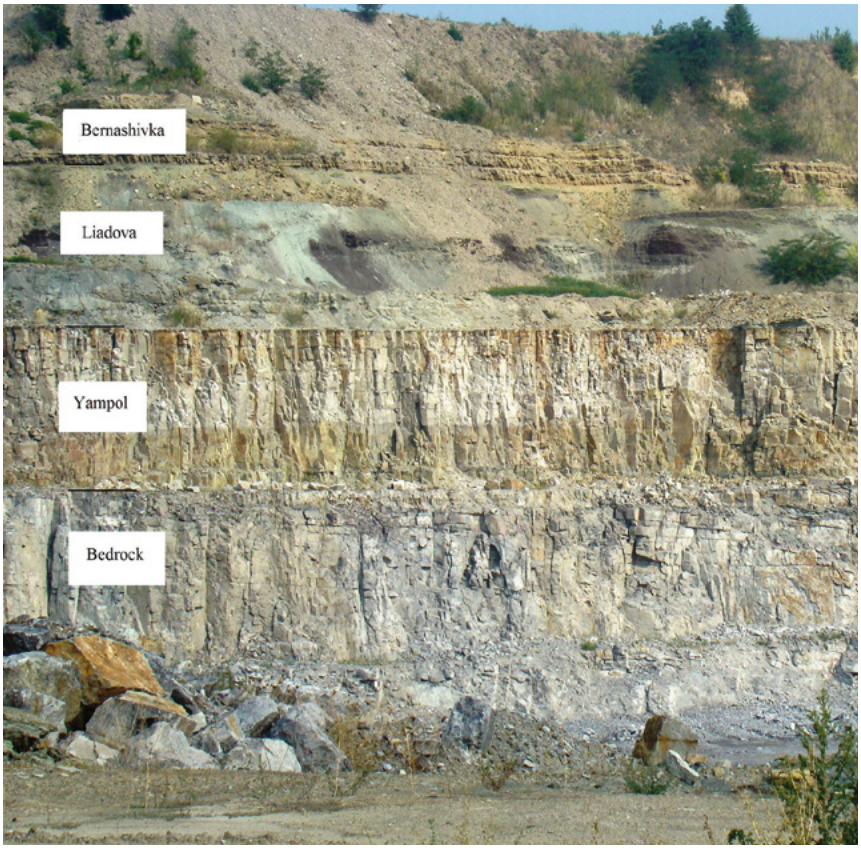

Fig. 3. The view on the central part of the Bernashivka open pit: crystalline basement (bedrock), Yampil, Lyadova, and Bernashivka members. The Lomoziv Member is absent in this part of the open pit, but it crops out in its southern part reaching in thickness ca. 10 m.

Рис. 3. Розріз східної стінки кар'єру: кристалічні породи (фундаменту) Українського щита, редуковані розріз могилівської світи за рахунок Бернашівського виступу фундаменту та яришівської світи через розмив сеноманською трансгресією. Ломозівські шари відсутні в цій частині кар'єру, але вони збереглися у південній частині, де їхня потужність досягає 10 м.

Vendian, the gradual immersion of the pericraton basin led to the transgression of the sea and sedimentation in the negative landforms on the slope of the Ukrainian Shield. During the Olchedaiv time, polymictic gravelites were accumulated in the shallow basin due to the erosion of positive landforms that were represented by crystalline rocks of the Ukrainian Shield (Fig. 3).

During the Lomoziv time, the sea was deeper and accumulation of very fine-grained material (clays and very fine-grained sand) dominated. However, denudation of positive landform continued near the shoreline, which can be seen in the Bernashivka open pit where beds of coarse-grained sandstones and gravelstones among siltstones are present. In the deeper parts of the basin, algal-bacterial mats and associations of Vendobionts, which possibly ate that substrate (Fig. 2.*7*), were abundant.

During the Yampil time, the basin shallowed. The shallowing is indicated by crossbedding and tidal sigmoidal structures in quartz sandstones. It is interesting that population (colony) of *Nemiana simplex* Palij settled on the flat sandy bottom of shallow-water sea, on coarse-grained sand (Fig. 3) and even on ripple marks.

On the sandy bottom, in the beginning of the Lyadova time colonies of *Nemiana simplex* continued to develop. At the same time and same stratigraphical level, imprints of *Charnia* sp. and *Aspidella* sp. (Fig. 1) are found. Then the basin became deeper and poisoned by hydrogen sulfide, which is evident from frequent finding of pyrite concretions in argillites of the Lyadova Formation.

During the Bernashivka time, due to regression the shallow-water settings expanded and resulted in favorable conditions for the development of algal-bacterial mats and *Arumberia cf. banksi* structures. In the Bernashivka time, the basin experienced two cycles of shallowing, which are divided by a phase of deepening. The relatively short-lasted phase of deepening was accompanied by volcanic activity and accumulation of a bed of volcanic ash, which is now represented by the bentonite clay layer that has a thickness of 30 cm and more.

During the Bronnitsa time, the volcanic activity continued and a bed of volcanic ash (tuff-argillites) was deposited in the deep basin. Ichnofossils (Fig. 2. *11*) were found in the lower part of the member. During the Zinkiv time the intensity of volcanic erruptions has weakened, and only thin beds of bentonites within the deep-water green clays (argillites of the Zinkiv Member) were accumulated. No macrofossils were found in these sediments, but a large amount of microfossils was discovered in argillites.

During the Dzhurzhivka time, the basin returned to shallow-water oxygenated conditions and the favorable conditions has renewed, but only remains of *Vendotaenia* were found.

During the Kallus time, the basin became deeper and relatively narrow with anoxic conditions (Francovschi *et al.* 2020). Clays (argillites) bearing phosphate concretions are distinguished as a separate member. At the end of the Kallus time, the sea-level dropped in the basin and weathering crust was formed under continental conditions. During the Kanylivka time, sedimentation in the basin was cyclic and sea-level rise was partially compensated by sedimentation. Intensive sediment accumulation and bioturbation at that time have destroyed all imprints and only ichnofossiles and remains of Vendotaenia are preserved. During the Khmelnitsky time, the basin was oxygenated as indicated by the presence of glauconite. The sedimentary cycles during that time maintained favorable conditions for animal expansion.

Diversify of Vendian and Lower Cambrian fossil remains in Podillia

Forms with radial symmetry dominate among Vendian fossils in Podillia. The findings of bilateral remains are very rare. Tracks of ichnofossils were developed only under favorable conditions in the Mohyliv-Podilsky, Kanylivka, and Baltic Series. A colony of tubes of *Propaleolina vendiensis* Menasova, 2003 was found in Borschiv Yar near the city of Mohyliv-Podilsky in the Bronitsa Member of the Yaryshiv Formation. The lower Cambrian Khmelnitsky Formation is very rich in ichnofossils. Tubes of Sabelliditids occur among skeletal forms at some levels.

The diversity of fossil remains is shown in Fig. 2, which represent only a small number of collected samples; others are yet to be described. The study of the thousands of radial forms requires statistic approach. Bilateral animals in the sedimentary sequence and in the collection require additional search taking into account taphonomical features of the fossil remains. In connection to the possible re-cultivation of the open pit, it is expedient to create the paleontological lagerstëtte in the Bernashivka Quarry near the Dniester Hydroelectric Power Plant, which would consist of three components: (1) declared before as a Geological monument "Bernashivka sandstones" in the gully near Bernashivka village; (2) an addition, it should also include the open pit, (3) and outcrops of the Nagoriany Formation along the Dniester River. All three components should be declared as Geological Park with the goal of further study of these localities and conservation of unique geological heritage of the lower part of the Podillian Vendian as the upper part of the Ediacaran, which was addopted as the last period of the Proterozoic.

The possibility of the geological correlation

In general, the facies diversity complicates correlation of the Vendian and Ediacaran sedimentary rocks on different continents. Recently, such correlation was made possible on the basis of precise geochronological data (Walter *et al.* 2000; Condon *et al.* 2005; Shumlyanskyy *et al.* 2016).

The paleontological method continues to play a major role in comparison of sequences in different regions. For example, the boundary between the Ediacaran and Cambrian is agreed to be placed at the first appearance of the ichnofossil *Phycodes* (=*Trichophycus*) *pedum.* Recently, the geochemical approach for correlation has been applied in many countries (e.g. Pehr *et al.* 2018).

Conclusions

The Vendian succession of Podillia shows cyclicity. It is observed in open pits and natural outcrops along rivers.

Tectonic movements and fluctuations of basin levels resulted in facies variations from shallow-water to deep sea with anoxic environmental conditions.

The evolution of Vendobionts and the change of sea level and facies conditions led to the diversity of fossil forms.

The construction of the water reservoir caused the rise of groundwater level and led to the forestation along the banks of the reservoir. However, it also resulted in enhanced erosion, which produced new outcrops near the water reservoir. Hence, that area is suitable for detailed paleontological studies aiming to search for new fossil remains in order to improve the understanding of the Vendian succession of Podillia.

We should emphasize the unsettled statigraphical nomenclature at the time the paper is written, which was noted by one of the reviewers. For example, the same stratigraphic element has several names: bed, unit, member, etc.

The paleontological lagerstëtte of the Bernashivka open pit near the Dniester Hydroelectric Power Station has to be declared as a Geological monument and a part of the Geological Park "Bernashivka Sandstones" that will include the open pit, outcrops in the gully near Bernashivka village, and outcrops of the Nagoriany Formation along the Dniester River.

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