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Новые данные литолого-палеонтологического изучения биогенных силицитов среднего эоцена центральной части Украинского щита

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Аннотация. Приведены новые результаты комплексных исследований геологического строения, литологии и фауны опоковидных пород среднего эоцена Ингульского мегаблока Украинского щита (разрезы сел Цыбулево, Верблюжка, Первозвановка Кировоградской области, с. Вороновка Николаевской области). На основании новых находок и анализа

малакофауны обоснован среднеэоценовый возраст опоковидных песчаников села Верблюжка. Впервые в силицитах данного региона обнаружены многочисленные и разнообразные остатки породообразующих организмов: губок (lithistid Demospongiae), кораллиновых (Corallinaceae) и зеленых водорослей (Dasycladales, Halimedaceae). В силицитах Первозвановского месторождения впервые доказано присутствие биогенных построек, сформированных организмами с карбонатным (кораллиновые и зеленые водоросли, крупные фораминиферы, моллюски, кораллы) и силикатным (литистидные губки) скелетами. Наличие в силицитах биогенных леписфер предполагает активное участие в формировании изученных пород кремнеобразующих, бактериальных сообществ. На основании первых находок цеолитов, а также следов монтмориллонита в опоковидных песчаниках с. Вороновка прогнозируется наличие «камуфлированной» пирокластике. Анализ литологических особенностей, минерального и фаунистического состава пород позволяет сделать вывод о многостадийном характере генезиса силицитов среднего эоцена центральной части Украинского щита и влияния на их формирование палеогенового вулканизма. Вулканическая деятельность и денудация продуктов вулканизма обусловили массовое поступление в воды среднеэоценового палеобассейна необходимого количества SiO₂, что способствовало широкому развитию кремнистых организмов и, в частности, кремнеобразующих бактериальных сообществ, активно участвующих в процессах образования силицитов.

Ключевые слова: силициты, цеолиты, вулканизм, моллюски, фораминиферы, зеленые водоросли, красные водоросли, кораллы, средний эоцен, биостратиграфия, литология, Украинский щит, Украина

New results of the lithological and paleontological study of the Middle Eocene biogenic siliceous rocks of the central part of the Ukrainian Shield

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Abstract. The present paper contains new results of complex studies on the geological structure, lithology, and fauna of the Middle Eocene siliceous rocks of the Ukrainian Shield Ingul megablock located in the vicinity of the villages of Tsybulevo, Verblyuzhka and Pervozvanovka of Kirovograd Oblast and Voronovka village of Mykolayiv Oblast. Based on new findings and analysis of malacofauna, the Middle Eocene age of the gaize-like sandstones of Verblyuzhka village was confirmed. For the first time, numerous remains of rock-forming organisms such as sponges (lithistid Demospongiae), coralline (Corallinaceae) and green algae (Dasycladales, Halimedaceae) have been found in the siliceous deposits of this region. In addition, biogenic buildups formed by organisms with carbonate (coralline and green algae, large foraminifera) and silicate (lithistid sponges) skeletons were found for the first time in the siliceous rocks of the Pervozvanovka deposit. The observed biogenic lepispheres in the studied rocks suggests that the latter have been formed with active participation of silica-producing bacterial communities. Based on the first finds of zeolites, as well as montmorillonite traces, it is forecast that "disguised" pyroclastic material is present in the gaize-like sandstones of Voronovka village. Analysis of the lithological features and the mineral and faunal composition of the studied rocks allow us to draw a conclusion about the multi-stage genesis of the Middle Eocene siliceous deposits in the central part of the Ukrainian Shield and the influence of

Paleogene volcanism on their formation. It appears that volcanic activity and denudation of volcanic products caused a massive flow of SiO_2 into the waters of the Middle Eocene paleobasin. This contributed to the widespread development of siliceous-skeleton organisms (in particular, silica-producing bacterial communities) that actively participated in the formation of siliceous rocks.

Key words: siliceous rocks, zeolites, volcanism, mollusks, foraminifera, green algae, red algae, corals, Middle Eocene, biostratigraphy, lithology, Ukrainian Shield, Ukraine

Introduction. Siliceous rocks of the Eocene age are widely distributed in the Ingul megablock territory of the Ukrainian Shield and along both banks of the Southern Bug River in the lower reaches. Here they outcrop to the surface and are opened by many boreholes and mine workings (Faas, 1904; Slodkevich, 1932; Kljushnikov, 1951a, 1951b, 1953, 1958; Makarenko et al., 1987; Stefanskyi, 1992; Berezovsky, 2004, 2009; Zosimovich and Shevchenko, 2015; Shekhunova et al., 2015a, 2015b, 2016). These rocks have a great industrial and economic importance. Thus, the tripoli of the Pervozvanovka deposit (south of Kropyvnytsky city, formerly Kirovograd) are being developed as cristobalite-opal raw materials. Gaize and gaize-like rocks of the Bug River region are currently being mined for local needs as building materials (sawn stone, aggregate for concrete) and carbonate raw materials for lime calcining (Vynogradov et al., 2003).

From the perspective of industrial value, the material composition of the siliceous rocks has been studied rather well (Vynogradov et al., 2003). However, despite the long history of the study of Paleogene of the central part of the Ukrainian Shield, there are still a number of unresolved issues of stratigraphy, patterns of distribution, and genesis of Eocene siliceous rocks.

For example, the age of some tripoli and gaize-like rock mass of the Ingul megablock of the Ukrainian Shield has not yet been clearly identified. In particular, the attribution of a significant part of the siliceous rocks to the Upper Eocene (Nechajenko et al., 2007) is questionable. The latest lithological and facial maps of the Bug River region Eocene with information on the distribution of mineral resources were made more than 50 years ago (the production report of B.U. Mastystyi, 1963) and have not yet been updated. For some siliceous Eocene rocks of the Southern Bug River basin, some questions of their formation have not yet been clarified; some important paleontological groups of organisms have not been characterized, especially the fauna with a siliceous skeleton, which has a rock-forming significance. Also the questions about the ways of siliceous rocks formation on the studied territory as well as the possible sources of SiO_2 intake which was enough for the siliceous rocks origin within the Ingul megablock are left open.

In the light of the above, the authors carried out lithological and mineralogical as well as paleo-

ntological studies of siliceous rocks (gaize-like sandstones of the villages of Verblyuzhka, Tsybulevo, Voronovka, tripoli and gaize-like marls of the Pervozvanovka quarry) in order to obtain new data for improving geological maps and correcting the search for cristobalite-opal raw materials.

Materials and methods

Location. The research area partially covers the territories of the Kirovograd and Mykolaiv oblasts of Ukraine. Geologically, the studied sections are confined to the tectonically active Ingul megablock of the central part of the Ukrainian Shield and its slopes, as well as to the Golovanevskaya suture zone in the region of the South Bug River basin (Fig. 1). The tectonic activity of these structures is described in a number of works (Kruhlov et al., 2007; Antsiferov, 2008; Isakov, 2017).

Materials. The authors used some materials of the field research in the vicinity of the Pervozvanovka and Verblyuzhka villages, conducted by V.L. Stefanskyi, T.A. Stefanska, and I.P. Tupchij in 2017 for the purpose of geological and paleontological study of Paleogene siliceous rocks of the Ingul megablock (about 300 samples from natural and artificial outcrops). We also studied the collections of A.A. Veselov (specimens gathered in the 1960-80s from the area of the Voronovka, Tsybulyovo, and Pervozvanovka villages), in particular about 200 samples of gaize-like rocks with a lot of faunal remains.

Methods of laboratory and analytical studies. Paleontological, lithological, and mineralogical studies were performed using a scanning electron microscope-microanalyzer REMMA 102-02 (operator S.I. Ovechko, Dniepropetrovsk Department of the Ukrainian State Geological Prospecting Institute, Dnipro city), as well as a binocular microscope MBS-1 and a polarizing petrographic microscope MIN-8. X-ray diffraction (XRD) analysis was performed using a DRON-210 X-ray diffractometer (operator A.S. Baskevich, Ukrainian State Chemical and Technological Institute, Dnipro city). Interpretation of diffractograms was performed by M.L. Kutsevol. The identification of fossils was performed by V.L. Stefanskyi and T.A. Stefanska by observing thin sections, rock specimens, and polished rock samples. Lithological studies were performed by V.L. Stefanskyi, M.L. Kutsevol, and T.A. Stefanska.



Fig. 1. Location of studied geological sections.

I – Ukrainian Shield: *a* – Ingul megablock; *b* – the rest of the Shield;

II – suture zones: circled letter *A* – Golovanevskaya suture zone. The numbers on the map are the studied sections: 1 – Tsubulevo village; 2 – Pervozvanovka village; 3 – Verblyuzhka village; 4 – Voronovka village

The paleontological and biostratigraphic researches focused on the study of orthostratigraphic and characteristic groups of fauna (mollusks, foraminifera, sponges), as well as the remnants of marine flora which were first discovered in this area.

Mollusks. In addition to the well-known general works on mollusks taxonomy (Moore, 1969; Korobkov, 1971), some new data on the bivalves and gastropods systematic were used in the identification of mollusks (for example, Berezovsky, 2004, 2010; Pacaud, 2016).

Fauna analysis was carried out taking into account that the systematic composition of malacoenoses is significantly influenced by lithological and facial features that complicate the correlation and stratification of the Paleogene by means of malacofauna (Zhizhchenko, 1969, 1974). When comparing paleontological objects, both similarities and differences in the fauna and its complexes were analyzed. During the gaize-like rocks stratification, the differences of mollusk complexes in similar facies, having a firmly established age by plankton groups of archistatigraphic organisms, were taken into account, first of all.

Previously, in many works of Ukrainian paleontologists (Kljushnikov, 1958; Stefanskyi, 1992; Berezovsky, 2004), the "Latdorfian Stage" of Northern Germany (Koenen, 1893, 1894) was mistakenly regarded as a single Upper Eocene stratum, and this negatively affected the results of biostratigraphic correlation. We take into account the data of the nannoplankton studies (Martini and Ritzkowski, 1968), according to which the "Latdorfian Stage" includes deposits of different ages from the Middle Eocene (the Annenberg Layers) to the Oligocene (Silberberg Layers, characterized by the

zone NP 21 *Ericsonia subdistica* of E. Martini's standard scale).

Foraminifera. Significant diagenetic and post-diagenetic transformation of the studied rocks, as well as low level of preservation of foraminifera tests connected with these processes exerted an influence on the choice of methods for studying of this group of organisms. The siliceous rocks developed here are represented by strong, ringing, gaize-like sandstones (the villages of Verblyuzhka and Tsubulevo) or loose mealy tripoli (Pervozvanovka village), almost entirely consisting of lepispheres. In both cases, the extraction of foraminifera from the rock by standard methods is not productive. As noted by L.A. Digas (1982), who studied the foraminifera of the Paleocene in pieces of rocks, thin sections, and washed fractions, the use of conventional disintegration and washing for these deposits artificially impoverishes microfauna complexes (by 20-50%), since many tests remain in the rock only as prints, which will be destroyed during the laboratory treatment. In the making of thin sections, up to 30-40% of the tests are also destroyed.

The above-described experience of study was taken into account in our research of the siliceous rocks. The microfauna has been examined in the rock fragments and their polished surfaces with the binocular as well as in thin sections using an optical microscope. The last method proved to be more effective for strong gaize-like sandstones, while for tripoli the study of foraminifera in thin sections was not sufficiently informative.

For taxonomic definitions, the classification of E.M. Bugrova (Bugrova et al., 2005) has been used, and also the extensive literature on the Paleogene foraminifera has been taken into account (in particular, Kaptarenko-Chernousova, 1951, 1956;

Zernetsky, 1962; Murray and Wright, 1974; Pozaryska, 1977; Machaniec et al., 2011).

Sponges. Skeletal remains of sponges are known to be a characteristic paleontological component for the Middle Eocene siliceous rocks of the Ukrainian Shield (Kaptarenko-Chernousova, 1951; Makarenko et al., 1987). All studied localities contain a significant number of sponge fossils dominating in orichthocoenoses. Most often these fossils are represented by numerous spicule prints resulting from the dissolution of the primary skeletal substance of the sponges during diagenetic and post-diagenetic processes. Accordingly, the definition of the spicules morphotypes and the taxonomic composition of the sponges in such rocks are rather hard. Spicules analysis, which is successfully used in the study of Paleogene sponges of Ukraine in clayey silts, marls, and sandy-argillaceous facies (Ivanik, 2003), here has a subordinate significance. Therefore, the main role was given to a thorough examination of the rocks in the field for the detection of silicification spots, as well as to research the rock samples with a binocular during laboratory studies to reveal the structure of the sponge skeleton network.

During the identification of individual spicules and fragments of sponge skeletons, the systematics of "Systema Porifera ..." (Hooper and van Soest, 2002) has been used, as well as a number of basic literature sources (in particular, Hurcewicz, 1966; Boury-Esnault and Rützler, 1997; Pisera, 2002; Pisera and Lévi, 2002; Kaesler, 2003; Ivanik, 2003).

Seaweeds. This group of organisms was found in thin sections and pieces of rocks. When studying and diagnosing the material, well-known reference works were involved (Maslov, 1962; Flügel, 2004; Riding, 2012), as well as publications on the marine flora of the Paleogene (Barattolo, 1998; Dragastan and Herbig, 2007; Génot, 2009; Radoičić and Özgen-Erdem, 2014).

Mineralogical and petrographic research. In the petrographic studies, the general literature was consulted (Mikheev, 1957; Naumov, 1989; Deer et al, 2004; Flügel, 2004). Additionally, some works including information on the petrography of the Eocene, Paleocene and Cretaceous siliceous rocks of Ukrainian Shield, Dnieper-Donets Depression, and adjacent territories (Bushinsky, 1954; Murav'ev, 1973; Ivanova, 2006; Zorina et al., 2012a, 2012b; Zorina and Afanasjeva, 2013; Shekhunova et al., 2015a; 2015b; 2016), as well as literature on the Dniester River basin (Sen'kovsky, 1977), were also consulted.

The conclusions were made on the basis of the data from a set of studies that supplemented each other and included a study of rock samples

and their polished surfaces using the binocular microscope, a study of thin sections, X-ray diffraction analysis, electron microscopy, and geomorphological analysis of geological sections.

Geological and stratigraphic position of the siliceous rocks of the research area. Siliceous rocks occupy a significant place in the Paleocene-Eocene section of the central part of the Ukrainian Shield and its slopes (Faas, 1904; Slodkevich, 1932; Kaptarenko-Chernousova, 1951; Kljushnikov, 1951a, 1951b, 1953, 1958; Makarenko et al., 1987; Stefanskyi, 1992; Nechajenko et al., 2007; Berezovsky, 2004, 2009; Zosimovich and Shevchenko, 2015; Shekhunova et al., 2015a, 2015b, 2016). Among these rocks, special attention of stratigraphers is attracted by the gaize-like calcareous deposits of the Southern Bug River basin, in particular, the so-called "Voronovka sandstone" near the village of Voronovka, where the gaize-like rocks are outcropped in many places on both river banks. Besides, interest is generated by "Kalinovka marl", which has been opened by some quarries for cristobalite opal raw materials south of Kropyvnytsky city. First of all, this interest was due to the findings of numerous Middle Eocene mollusk fauna (Kljushnikov, 1951a, 1951b, 1953, 1958; Nechajenko et al., 2007). Their study has played an important role in the making of geological maps. Later, the microfauna and nanoflora finds have allowed us to reliably establish that the age of the "Voronovka" and "Kalinovka" deposits is Middle Eocene (Krajeva and Luljeva, 1977; Berezovsky and Vaga, 2003).

A rather detailed geological description of these deposits can be found in the works of M.N. Kljushnikov (1951a, 1951b, 1953, 1958), as well as the production geological report of B.U. Mastystyi (1963) with indications on the lithological variations of the gaize-like rocks (from siliceous marls to gaize), and content of numerous fauna with both siliceous and calcareous skeleton in those rocks. Among this fauna there are spicules of sponges, radiolarians, mollusks, sea urchins, small and large foraminifera. "Gaize-like sandstones" were also noted in the glauconitic sands of the central part of the Ukrainian Shield and the South Bug River basin in the form of inclusions (Slodkevich, 1932; Kljushnikov, 1951b, 1953, etc.).

The results of the paleontological study of mollusks and foraminifera (respectively by M.N. Kljushnikov and O.K. Kaptarenko-Chernousova) formed the basis for the conclusion about the correspondence of the "Voronovka sandstone" to the lower part of the Upper Eocene (not higher than the Barton Stage) and to the lower horizon of the Kiev marl (Kljushnikov, 1951b, 1953). Later, according to the data of the nannoplankton study (Krajeva and

Luljeva, 1977), the age of the gaize-like rocks in the vicinity of Voronovka village was determined in the volume of the NP15 *Nannotetrina fulgens* – NP 16 *Discoaster tani nodifer* zones of E. Martini's standard scale.

Discussion questions of the investigated strata stratigraphic position. Stratigraphically, the position of glauconitic sands of the central part of the Ukrainian Shield and the South Bug River basin is problematic. In some places, these sands contain spicules of sponges, gaize-like nodules, and remains of mollusks of bad preservation. Thus, the gaize, tripoli, and gaize-like rocks mass are entirely referred to the Middle Eocene in the work on the geology of the "Voznesensk" survey sheet (Schwartz et al., 2004). Also here the glauconitic stratum with the subordinate layers of the gaize-like rocks is considered to be the Upper Eocene. At the same time, this conclusion has not been received either paleontological or any other substantiation.

On the lithological and facial maps of the Eocene (production report by B.U. Mastystyi, 1963) it is shown that the glauconitic formations fringe the gaize-like and marl facies from the north, occupying the areas with the highest marks of the crystalline basement of the Ukrainian Shield. In our opinion, these constructions have been made in accordance with the outdated stratigraphic scheme of 1963 and only partially reflect the real distribution of glauconitic sands, which are a background facies for the Paleogene, and typical for the Middle and Upper Eocene of the Ukrainian Shield depressions in particular.

The next question is connected with the position of the Middle-Upper Eocene boundary in the regions of gaize-like rocks development, as well as the reliability of paleontological evidence of the Late Eocene age of a part of the siliceous rocks strata.

Thus, in the collective work (Makarenko et al., 1987, p. 49) a geological section of the Kamennaya gully (Konoplyanka village, south of Kropyvnytsky city) is given. Herewith it is positioned as a typical section for the Kiev Suite of this region. Here, gaize-like calcareous sandstones with mollusks and nummulitides, as well as tripoli-like rocks of top part of the section, are attributed to the Obukhov Horizon of the Upper Eocene without any explanation, and the lower part of the section ("sandy white marls") – to the Kiev Horizon. The lack of validity of stratigraphic conclusions, in our opinion, devalues the section description and reduces its informativeness. Therefore, this section cannot be considered as typical for the Kiev Horizon of the central part of the Ukrainian Shield without additional paleontological studies.

A number of published paleontological materials complicate the problem of the dating of the siliceous rocks in the studied region. For example, lists of Middle Eocene mollusks from the gaize-like rocks, given in the works of M.N. Kljushnikov (1953, 1958), demonstrate some fossils which were collected in different places, in different deposits, and include inhabitants of various ecological niches. According to the authors, the conclusion about the younger age of coarse-grained sandstones near the village of Tsybulevo concerning siltstones of the vicinity of Voronovka village (Kljushnikov, 1953) is not sufficiently substantiated. The difference in the systematic composition of mollusks for both locations is probably due not to the stratigraphic placement of different fauna, but to the difference in paleoecological conditions.

In some publications, various shallow-water facies of the Upper Eocene, including sharply different paleontological complexes, are erroneously and unjustifiably attributed to the unique Mandrykovka Layers of Dnipro city. This also leads to an erroneous conclusion about the Upper Eocene age of the gaize-like rocks of the Verblyuzhka and Tsybulevo villages (Zosimovich and Shevchenko, 2015), which are compared to the Mandrykovka Layers.

In some works (Berezovsky, 2004; Zosimovich and Shevchenko, 2015), the gaize-like sandstones ("siltstones") of the Verblyuzhka village were erroneously assigned to the Obukhov Suite of the Upper Eocene of the central part of the Ukrainian Shield. This negatively affected the construction of geological maps of the Kirovograd sheet, where the rocks of the Middle Eocene are depicted as formations of the regressive stage of the Paleogene paleobasin (Nechajenko et al., 2007). This contradicts the history of geological development of the Northern Ukraine, and does not agree with data on adjacent survey areas. Thus, in the neighboring territory of the Kaniv Dnieper Region, the Upper Eocene rocks are clearly regressive in relation to the Middle Eocene (Zosimovich et al., 2015).

The upper part of the tripoli stratum in quarries near the Pervozvanovka village is also referred to the Upper Eocene (Shekhunova et al., 2015b). Such a conclusion, unfortunately, does not have a biostratigraphic justification.

Thus, an analysis of the available literature sources on the biostratigraphy of the studied region showed the lack of the convincing paleontological data which are necessary for the correct detailing of the gaize-like rocks profile and their dating.

Lithological and paleontological studies. In the Paleogene siliceous rocks of the researched area, previously studies have been made of mollusks (Slodkevich, 1932; Kljushnikov, 1951b, 1953;

Stefanskyi, 1992; Berezovsky, 2004), large and small foraminifera (Zernetsky, 1962; Krajeva and Luljeva, 1977), and calcareous nannoplankton (Krajeva and Luljeva, 1977; Berezovsky and Vaga, 2003). Recently, so-called "figured sandstones" have been established. Two points of view exist about their formation. According to the first, they are considered as ichnofossils (Shekhunova et al., 2015b), according to the second – by fossil corals of the genus *Acropora* (Zernetsky, 2016).

We have improved the knowledge on the paleontological content of the siliceous rocks of the studied territory. Based on the new paleontological results, the age of these rocks and the paleoenvironmental conditions of this section of the Middle Eocene basin are established. Below, we give some new information on the geological sections, lithological and paleontological features of the studied locations, which are important for our conclusions.

Geological section of the Verblyuzhka vil-lage. In view of the absence in the literature of any geological and lithological information about the siliceous deposits of the Verblyuzhka village, as well as the stratigraphic importance of the local fauna complex for rock dating and mapping, below a brief description of them is given.

Siliceous rocks of the Verblyuzhka village are usually covered by vegetation or flooded with the waters of the river of the same name. A series of their indigenous outcrops of modest thickness (1.0-1.5 m) has been found along the road (in a roadside ditch) near a dam in the southwestern part of the village next to an abandoned rock quarry (500 m from the T-12-10 route). Siliceous rocks lie on the weathering crust of the Precambrian rocks, have a thickness of about two meters, overlap with greenish-gray glauconitic sands with numerous brown and yellow spots of ferruginization.

Siliceous rocks are greenish-gray, with spotty texture, non-carbonate, tripoli-sandy-silty, locally with a coarse gravel material admixture (up to 0.5 mm), and with widespread flints and silicification zones, as well as numerous stains and flow marks of iron hydroxides. When the samples are split, the unclear, rough, and irregularly-tuberculate surfaces of the break are observed. The distribution of the component material in the rock, as a rule, is unsystematic, nest-shaped. The variations of clast content in the rock are observed in thin sections as well. These vary from 5 to 55% in different areas. The majority of the clasts are from 0.3 to 0.7 mm, and a small amount has size of 0.06-0.1 mm. Most of the clasts are medium-rounded.

The terrigenous material of the rock is composed predominantly of quartz, microcline is less common. Almandine, glauconite, and muscovite are rarely found. Cement is composed of mi-

crocrystalline opal-CT. Aggregations of opal globules are observed in some places (Tab. II, Fig. E).

Paleontological remains are diverse: mollusks, sponges, echinoderms (Tab. I, Fig. C-F), balanuses, corals, bryozoans. The biogenic component occupies not less than 60-70% in thin sections: there are cross sections of foraminifera tests, sponge spicules, green algae (Tab. II), needles of sea urchins, etc.

Preservation of mesofossils of siliceous rocks of the Verblyuzhka village greatly varies and is largely conditioned by silicification. There are external and internal cores of invertebrates, their imprints, detritus of shells. Often, thanks to silicification, small details of the sculpture remain on the shells and even on their small fragments (Tab. I, Fig. E). This facilitates making correct paleontological determinations. On the other hand, the presence of fossils of poor preservation makes it possible to determine the fauna only with the sign "cf." or up to the level of higher taxa.

Mollusks. The paleontological study of the Verblyuzhka malacofauna complex confirms and supplements the previously published lists of species (Berezovsky, 2004). We have established the bivalve complex which includes 28 forms (the taxa first established here are marked in bold type): *Arca cf. sandbergeri* Desh., *Barbatia scabrosa* Nyst, *Barbatia jekaterinoslavica* Sok., *Cuccularia sp.*, *Glycymeris cf. lunulatus* (Nyst), ***Lentipecten corneus*** (Sow.), *Chlamys gigantea* Slodk., ***Chlamys ex gr. subimbricata*** (Münst.), ***Chl. refa Berez.***, ***Chl. orientalis*** Sok., *Chl. biarritzensis* (Arch.), ***Ctenoides explanatus*** Koen., *Spondilus tenuispina* Sandb., *S. buchi* Phill., *S. bifrons* (Münst.), *Cubitostrea prona* Wood, *Venericardia praeminata* Slodk., *V. enitestita* Slodk., *Chattonia raricostata* (Klush.), *Crassatella duplex* Berez., ***C. aff. fuchsi*** Slodk., ***Eomiltha contorta*** (Defr.), *Chama calcarata* Lamck., *Vepricardium praepitatum* (Slodk.), *Pitar sokolovi* Slodk., ***Solena (Eosolen) plagiulax*** Cossm., *Tellina cf. longiuscula* Beyr.

Gastropods occur quite often, although in systematic diversity they are much inferior to bivalves. In total, we have established 10 forms: ***Tectus aff. margaritaceus*** Desh., ***Cirsotrema rotula*** Koen., ***Haustator sp.***, ***Tomyris ukrainae*** Mich., *Motyris ukrainae* (Mich.), ***Motyris fasciata*** Lamck., ***Hadriana flandrica*** Koen., ***Mithra sp.***, ***Pachicrommium sp.***, ***Volutidae (Athleta sp.?)***. Shells of herbivorous gastropods *Motyris* are found most often. Representatives of other genera are established in single specimens.

In addition to our list of mollusks, A.A. Berezovsky (2004) has named such forms: *Chlamys subtripartita* (d'Archiac), *Cuccularia heterodonta*

Deshaes, *Tellina* aff. *concellata* Koenen, *Pycnodonta callifera* (Lamarck), *Pholadomia weissii* Phillipi, *Chama* cf. *monstrosa* Phillipi, *Miocardiopsis praelonga* (Giebel), *Devaricardium depressum* (Koenen), *Crassatella manifeste* Berezovsky, *Crassatella* aff. *parisiensis* d'Orbigny.

To define the age of the siliceous rocks of Verblyuzhka village by malacofauna, the following should be taken into account. A significant number of mollusk species from the Verblyuzhka siliceous facies are known from the reliably stratified gaize-like rocks of Voronovka village ("Voronovka sandstones"), the gaize-like marls of Pervozvanovka and Kalinovka villages ("Kalinovka marl"), and Middle Eocene marly and sandy facies of the Ingul River basin. There are common species for these all locations: *Barbatia scabrosa* Nyst, *Barbatia jekaterinoslavica* Sok., *Cuccularia heterodonta* Deshaes, *Lentipecten corneus* (Sow.), *Chlamys gigantea* Slodk., *Chl. refa* Berez., *Chl. biarrizensis* (d'Arch.), *Chl. subtripartita* (d'Archiac), *Chl. orientalis* Sok., *Spondilus tenuispina* Sandb., *S. buchi* Phill., *S. bifrons* (Münst.), *Cubitostrea prona* Wood, *Cyclocardia praeminenta* Slodk., *C. enitestita* Slodk., *Crassatella duplex* Berez., *Crassatella* aff. *fushi* Slodk., *Eomiltha contorta* (Defr.), *Chama calcarata* Lamck., *Chama* cf. *monstrosa* Phillipi, *Vepricardium praepitatum* (Slodk.), *Nemocardium* cf. *parile* Desh., *Pitar sokolovi* Slodk., *Solena (Eosolen) plagiulax* Cossm., *Motyris ukrainae* (Mich.), *Motyris fasciata* Lamck. The malacofauna complex of Verblyuzhka contains some species found exclusively in the Middle Eocene deposits of Ukraine and Western Europe: *Chlamys gigantea* Slodk., *Chama calcarata* Lamck., *Crassatella duplex* Berez., *Crassatella* aff. *fushi* Slodk., *Vepricardium praepitatum* (Slodk.), *Pitar sokolovi* Slodk. Species *Chlamys gigantea* Slodk., *Vepricardium praepitatum* (Slodk.) are pointed out as the Upper Eocene taxa (Berezovsky, 2004). But they are known only from the Middle Eocene of Ukraine (Slodkevich, 1932; Kljushnikov, 1951, 1953, 1958). Some species such as *Ctenoides explanatus* Koen., *Miocardiopsis praelonga* (Giebel) were found in the Upper Eocene Mandrykovka Layers of Ukraine (Stefanskyi, 1992), as well as in the Oligocene Zilberberg Strata of Germany (Koenen, 1893); we consider them as transit. Only two bivalves *Crassatella manifeste* Berezovsky, *Chattonia raricostata* (Klush.), and one gastropod *Motyris fasciata* Lamck. are known only from Verblyuzhka siliceous rocks and from the Mandrykovka Layers.

It must be particularly underlined that it is not methodologically correct to use unique Mandrykovka mollusks as a standard Late Eocene complex of malacofauna of Platform Ukraine as was

done previously (Berezovsky, 2004). The Upper Eocene of the Ukrainian Shield and its surroundings has a variegated facies composition with sharply different faunal complexes (Stefanskyi, 1992). Mandrykovka coral sands include fauna complexes unique to the Ukrainian Shield and characteristic of the coral biocenosis and the littoral zone (Stefanskyi, 2015a, 2015b). Malakofauna of Mandrykovka sharply differs from that of the gaize-like rocks of Verblyuzhka village; only a few forms that dwell in similar environment have stratigraphic significance. For example, the *Chama* bivalves living on the rocky biotopes of the littoral zone have different species composition in the Mandrykovka and Verblyuzhka rocks. Therefore, the Middle Eocene *Chama calcarata* Lamck., found in the Verblyuzhka sandstones is of paramount importance for determining geological age.

Thus, the examined mollusk complex includes typically Middle Eocene species of bivalves; this complex has significant similarities and small differences with the Middle Eocene malacofauna of the gaize-like rocks of Tsybulevo, Voronovka, Kalinovka and Pervozvanovka villages, as well as the marls of the Kiev Regiostage of the Ingulets river basin; the malacofauna of Verblyuzhka is sharply distinguished from the Upper Eocene complex of the Mandrykovka Layers and proves the Middle Eocene age of the host siliceous rocks.

Foraminifera. In thin sections there are numerous random profiles of spiral-convoluted tests, mainly belonging to the foraminifera of the families Anomalinidae, Discorbidae, Cibicididae. The larger of the cross sections (200-350 µm) are presumably related to *Lobatula* cf. *lobatula* (Walker et Jacob) (Tab. II, Fig. A), *Heterolepa* sp. (similar to *H. eocaena* (Guemb.) or *H. dutemplei* (d'Orb.)). Small rotaloid specimens (120 µm) probably belong to the genera *Heterolepa*, *Cibicidoides*, *Discorbis* (*Discorbis* cf. *propinqua* (Terquem)). Small Bolivinitidae (genus *Bolivina*), Reussellidae (*Reussella* cf. *limbata* (Terquem)) are less common. The above taxa are widely developed in Eocene sediments.

From an ecological point of view, the microfauuna complex is shallow-water – representatives of these genera live mainly within the shelf; in mode of life they are clinging or attached epifauna, herbivores or suspension feeders (excepting *Bolivina*, which refers to detritivores, infauna / epifauna) (Murray, 2006). Most of the foraminifera found were epiphytes. According to their grouping by life model (Langer, 1993; Mateu-Vicens et al., 2014), anomalinids and discorbids belong to a group of temporarily mobile, not permanently attached forms with a short life span of up to 2-5 months. Representatives of this group often form the core of

epiphytic foraminiferous complexes, and reach 25-85% of the total assemblage (Langer, 1993). As pointed in the cited works, species of this group live on seagrass and algae, and the most convenient for attaching is the surface of seagrass flat leaves; foraminifera with small tests equally occupy both groups of marine flora. Representatives of the genus *Bolivina* are tolerant to the gas regime deterioration; therefore, environments in rhizomes of marine plants with lower oxygenation caused by organic decay are fit for them. The adduced microfauna association is not sufficient for a confident assumption about the actual seagrass presence in the Middle Eocene phytocoenosis of Verblyuzhka village. However, this speculation becomes more probable if we take into account the fact of finding such vegetation, in particular *Zostera kiewensis* Schmalh., *Posidonia rogowiczi* Schmalh., as well as seaweeds *Chondrites grandis* Schmalh., *Ch. kiewensis* Schmalh. in the same-aged Middle Eocene sands in the Kiev region (Schmalhgausen, 1884, in Kaptarenko-Chernousova, 1951).

Algae. Together with the foraminifera, numerous green algae were established in the samples (Tab. II, Fig. A-D). Preliminary study suggested their belonging to the orders Dasycladales (*Clypeina* sp., *Uteria* (?), *Cymopolia* (?)), and Bryopsidales (family Halimedaceae, *Halimeda* (?)). It is the first record of such flora for the Middle Eocene of this territory. Such flora is typical for tropical and subtropical areas, where, thanks to the ability to quickly calcify, it participates in the bioherms formation, accompanies reef building (Genot, 2012; Mu, 2012); it is also characteristic of coastal lagoons, coastal bays; limited to shallow depths (Dasycladales are common for depths less than 5 m (Genot, 2012)). It should be noted that "islands" of Middle Eocene siliceous sandstones with flora imprints are observed on the northern board of the Ukrainian Shield (Kaptarenko-Chernousova, 1951). Thus, the findings of the shallow foraminifera association and algae are in good agreement with the general paleogeographic situation of the region.

Sponges. In thin sections, the remains of the fauna with a siliceous skeleton are represented by corroded spicules of soft and lithistid sponges (rhabds, diaenes, triaenes, rhizoclonas, tetraclonas), and fragments of skeletal gratings (Tab. II, Fig. D, F). When studying the pieces of rock, numerous fragments of the lithistid sponge skeletons have been found, completely or partially converted to flint.

There are three main forms of preservation of sponges. The first is fragments of skeletons, sometimes quite distinctly shaped (Tab. I, Fig. C); their network consists of desmas, which are modified in varying degrees. Only for rare specimens, it

can be assumed with caution that some desmas are tetraclonas or rhizoclonas (in some single cases – heloclonas); more often the desmas' substance is dissolved so much that spicules resemble a fine mealy powder. The skeletal network is white or stained with iron hydroxides, in whole or in part; in the latter case, iron hydroxides emphasize the sponge outlines or its pores and channels. The silicon cores – are the second form of sponge preservation; sometimes there are flints in the form of a cup up to 20 cm long. When wetting with water, the lithistid skeletal network sometimes shines through in the flints. The third form is combined: the central part of the sponge is turned into a flint core, the outer part is preserved as a skeletal network. Among the sponges found, the presence of representatives of the suborders Tetracladina (possibly the genus *Siphonia*), Rhizomorina, and Helomorina is assumed.

Usually, the abundance of siliceous fauna in rocks is considered to be an indicator of the deep-water situation of sedimentation and low temperatures, since many modern organisms with non-calcareous skeleton live in deep-water conditions, in particular, this is typical for most of the lithistid sponges and hexactinellids (Hooper and van Soest, 2002). By considering the ecology of the studied sponges, it is necessary to take into account the results of research into Paleogene sponges in New Zealand (Buckeridge and Kelly, 2006) and South-West Australia (Gammon et al., 2000), which showed the presence of a diverse fauna of lithistids and hexactinellids in rocks formed in the warm waters of the shelf; the latest does not correspond to ecology of many modern sponges. A. Pisera believes that Eocene lithistids and hexactinellids communities of South-West Australia dwelt at the depths of no more than 10-15 m, and describes the shallow water habitat of the fossil sponges with a higher content of silica in the paleobasins than in modern seas and oceans (Pisera, 2003(2004)). O.K. Kaptarenko-Chernousova (1951), who observed the numerous sponge remnants in the Middle Eocene sediments of the Kirovograd region (present Kropivnitsky) and Dniepropetrovsk (present Dnipro) also considered these sponges to be shallow water fauna.

Tsybulevo village. The samples of gaize-like sandstones studied from the quarry near the village of Tsybulevo were collected by A.A. Veselov in the 1960-80s. Lithologically, they are very similar to gaize-like sandstones of Verblyuzhka village. In contrast to the latter, they are less silicified, as indicated by the better preservation of the small sculptural elements of the sponge skeletons in them. In addition, Tsybulev sandstones are

much more saturated with glauconite than their analogues in the village of Verblyuzhka.

The faunal remains are represented by mollusks, lithistid sponges, and foraminifera. The malacofauna complex is basically similar to that described in M.N. Kljushnikov's works (Kljushnikov, 1951a, 1951b, 1953).

Among the foraminifera remains, single axial sections of lenticular nummulites tests (*Nummulites* sp.), some undeterminable spiral-convoluted forms, and small *Bolivina* sp. are found.

The sponges were preserved in the form of large fragments of the lithistid skeletal network (Tab. I, Fig. A) randomly located in the rock. Often the cylindrical and cup-shaped form of the skeletons is emphasized by the strong ferruginization of the sponges' contours. The network is formed by

desmas, the pore space is completely replaced by silica (Tab. I, Fig. B). Taxonomic affiliation can be specified further in the study of skeleton structure with an electron microscope. Preliminarily, some sponges found can be attributed to the suborder Tetracladina.

Pervozvanovka village. Detailed studies carried out by the authors in 2017 made it possible to obtain new data on the lithological and paleontological features of the Paleogene sediments of the Pervozvanovka village vicinity, in particular to specify the previously published description of the tripoli-like rocks profile in this area (Shekhunova et al., 2015b). Below there is some preliminary information about lithology and fossils of Pervozvanovka tripoli and gaize-like "Kalinovka marls" of quarries near the village of Pervozvanovka (Fig. 2, 3).

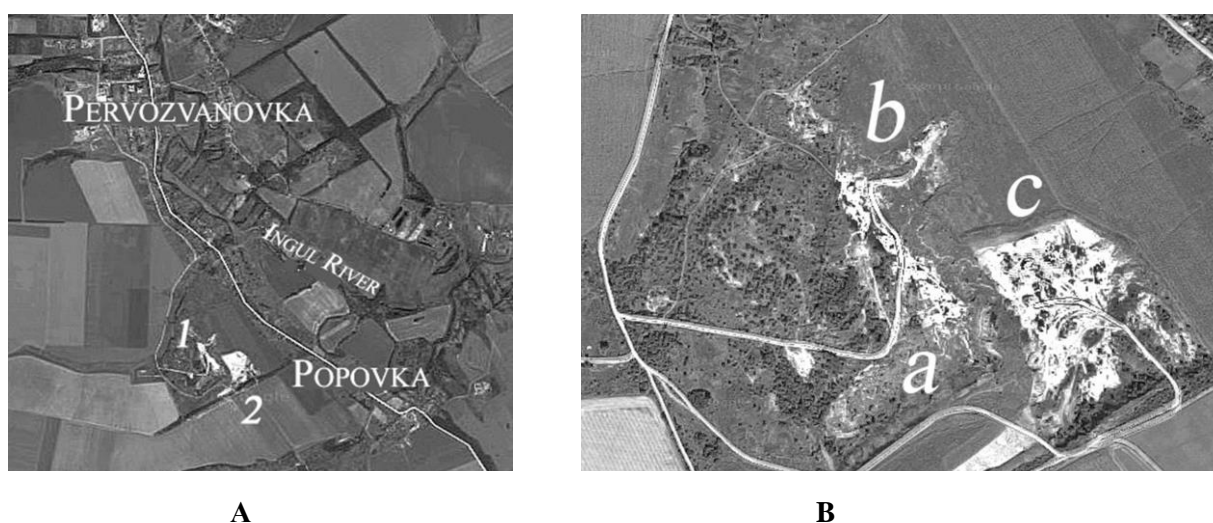


Fig. 2. Scheme of location of the investigated sections in the vicinity of the Pervozvanovka and Popovka villages (south of Kropivnitsky city).

A – quarries, which opened Eocene rocks: 1 – for extraction of cristobalite-opal raw materials; 2 – for extraction of Quaternary clays; **B** – position of the main Eocene sections in quarries: a – gaize-like "Kalinovka marls"; b – rocks of the tripoli stratum; c – sections of glauconitic sands.

In this quarry (Fig. 2, B, b, Tab. III), the gaize-like rocks stratum has a complex geological structure (interruptions in sedimentation, and different lithologic composition) which indicates to heterogeneous paleosedimentological conditions of its formation. Below is its description (from the bottom up).

Packet 1. "Kalinovka marls", light gray to white, carbonate, siliceous, gaize-like. Includes a rich complex of the Middle Eocene fossils: mollusks, sponges, calcareous algae, foraminifera, corals. Visible thickness is about 4 m.

Packet 2. Tripoli, light gray to white, with the clear pronounced lumpy-tuberculate structure (Tab. III, Fig. A, C). Visible thickness is 2.0-2.5 m. It has primary sponge-algal origin, includes the remnants of green and red rock-forming algae (Tab. IV, Fig. A-E), foraminifera (large and small), and a depleted monotonous mollusks complex with a

predominance of herbivorous gastropods, spondiluses and pectenids. The stratum is completed by a thin weathering crust (up to 0.5-0.7 m). The latter sharply stands out in the profile thanks to the bright coloration of iron hydroxides (Tab. III, Fig. A, C); includes remnants of discocyclines (?) and ferruginate incrusting coralline algae.

Packet 3. Rare interbedding of tripoli of various structures with greenish-light gray siliceous clays of low thickness (0.4-1.0 m). The latter have a sheeting structure, an unclear subhorizontal lamination, and in places are stained with iron hydroxides (Tab. III, Fig. D). There are remnants of fauna (rare mollusks, as well as prints of probably sponges, sea urchins, large foraminifera). Visible thickness is 4.0 m.

Packet 4. Tripoli, light gray, with cloddy structure, with silicified remains of colonial scleractinian corals (Tab. III, Fig. E), dasycladalean algae,

large foraminifera, and finger-like fossils of algal and obscure systematic affiliation. Visible thickness is up to 2.0 m. At the top of the packet there is a weathering crust which is determined by a sharp change in the lithological composition, secondary opalization, and enrichment of the rock with the rounded fauna remnants.

Packet 5. Sands, gray-green, quartzoglaucitic, with ocher spots of iron hydroxides. In base they include numerous redeposited ferruginate and rounded fragments of siliceous fauna from the underlying rocks. Visible thickness is 3-4 m.

We traditionally consider the deposits of "Kalinovka marl" (packet 1) to be the lower part of the Kiev Regiostage (Middle Eocene) of Northern

Ukraine and correlate them with the Lutetian of Western Europe. Based on the mollusks fauna and the general transgressive bedding character, packets 2-4 are considered to the Kiev Regiostage and somewhat cautiously correlated with the Bartonian of Western Europe. The packet 5, which does not contain any visible paleontological remnants, presumably belongs to the Kharkov Series (Lower Oligocene ?) on the basis of general geological data (Makarenko et al., 1987). Packets 2-4 belong to the productive formation and are operated.

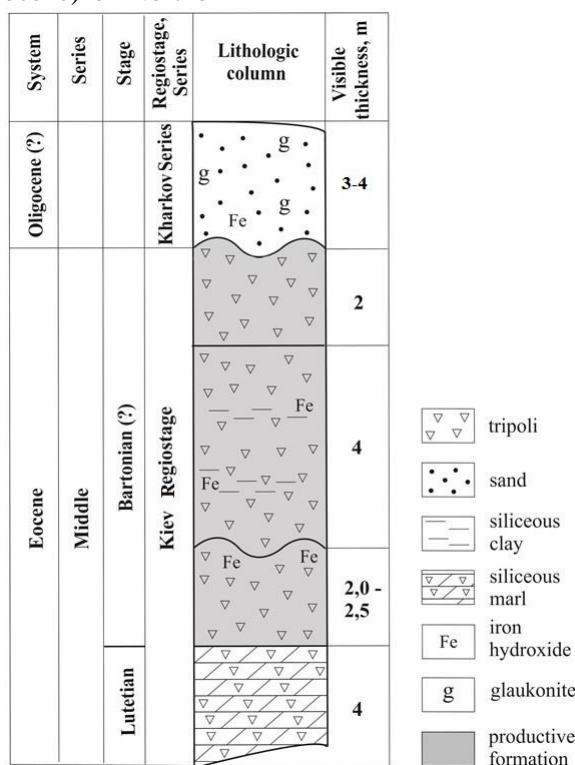


Fig. 3. Stratigraphic column of Paleogene deposits of the Pervozvanovka quarry

Lithological and mineralogical data. The studied rock is dominated by opal-CT (97%), with an admixture of terrigenous clastic material (3%) and goethite (single grains). Opal-CT (cristobalite and tridymite opal) has an amorphous-grained structure, with grain size less than 0.01 mm. Weak anisotropy is observed in cross-polarized light. The clastic grains are mainly composed of quartz; glauconite is found less often. The clasts are of silt size (0.05 mm); sand size grains (up to 0.5 mm) are present in small numbers. Glauconite forms brownish-green aggregates of irregular shape. It displays green interference colour in crossed polars. According to X-ray diffraction analysis results, the main mineral phases in the studied sample are α -cristobalite and α -tridymite. There are X-ray maxi-

mums of admixture minerals in the diffractogram as well: quartz (0.332 nm and others), microcline (0.322 nm) and weak peaks of kaolinite (0.714 nm, 3.58 nm). Only the most intense diffraction peaks of glauconite are present: 0.260 nm, 0.333 nm, 0.473 and 0.942 nm. The last two reflections indicate alteration of crystal structure of the mineral due to oxidation considering that one of the strongest maxima of unchanged glauconite corresponds to an interplanar spacing of 1.01 nm.

The tripoli of the Pervozvanovka quarry have a quite diverse paleontological composition. In the lower part of the productive stratum, siliceous remains of numerous sponges are observed, in places – coralline algae, mollusks imprints and cores (Tab. I, Fig. F).

Mollusks. The following bivalves are found: *Spondilus tenuispina* Sandb., *S. bushi* Philippi, *Lentipecten (Lentipecten) corneus* (Sow), *Chl. refa* Berez., *Chl. (Aquapecten) sp.* Among the gastropods are herbivorous species: *Motyris ukrainae* Mich, *Motyris fasciata* Lamck.

The upper part of the tripoli section, separated from the lower part by a distinct ferruginous weathering crust (Tab. III, Fig. C), includes only sparse remains of mollusks. Among them, attaching *Spondilus* sp. and herbivorous *Motyris* have been identified. Almost all forms found are of a wide stratigraphic distribution or observed exclusively in the Middle and Upper Eocene of Ukraine and Western Europe. However, *Chlamys refa* Berez. finding, which is known from the marls of the Kiev Regiostage of the Ingulets River basin (Berezovsky, 2009), and also found by us in the siliceous rocks of Verblyuzhka village, suggests the Middle Eocene age of the Pervozvanovka tripoli.

Foraminifera, sponges, algae. The most interesting fossils have been found in thin sections and polished pieces of rocks. When studying tripoli in thin sections, a depleted orictocoenosis have been found. Due to silicification, only single tests sections of the genera *Nodosaria*, *Subbotina*, *Bolivina* can be found. Besides foraminifera, some random sections of sponge spicules are observed, as well as the remains of green algae supposedly of the order Dasycladales. An unclear algal structure is often traced in thin sections.

Silicification has played an important role in preserving foraminifera. Their numerous tests are visible when studying the polished flints under a binocular. In this case, the taxonomic composition of the microfauna, like the lithologic features of the flints, may vary within the same stratum of rocks (for example, different sizes and amounts of terrigenous impurities, the presence of predominantly quartz or glauconite). This is probably due to the diversity of biocenoses as well as sedimentation conditions in this shallow part of the paleobasin. As noted earlier when analyzing the participation of siliceous sponges in the flints formation (Stefanskyi and Stefanska, 2018), their composition and classification largely depends on the paleontological component. So, flints, formed on algae, often contain large foraminifera, such as *Nummulites* (?), *Discocyclina* (?), as well as small tests of Polymorphinidae, *Nodosaria*, *Dentalina*, *Discorbis*, *Cibicidoides*, *Bolivina* indistinguishable at species level. In some flints, there are small planktonic foraminifera: four- or five-chambered *Acarinina* sp. (resemble *Acarinina kiewensis* Morosova), *Globigerina* sp., *Pseudohastigerina* sp. (*Pseudohastigerina* cf. *micra* (Cole)), as well as benthic *Dentalina*, *Bolivina*.

Sometimes the algae remains are not fully silicified. In this case, when sawing, a vegetative pattern is observed, created by alternating dark bands of silicification and light strips of non-silicified tripoli (Tab. IV, Fig. C, D). When studying such a structure using a binocular microscope, it is seen that completely silicified axial sections of the *Nummulites* (?) and *Discocyclina* (?) tests stand out against the background of the dark bands (Tab. IV, Fig. F, G). In non-silicified tripoli, traces of large foraminifera are often found in the form of lenticular cavities (sometimes with remnants of internal whorls) or heavily altered imprints of equatorial sections.

The structure of the algae turned out to be extremely interesting. Preliminary data from their study suggest that they belong to the red algae Corallinacea. They are represented by fragments of large branching specimens (Tab. IV, Fig. A-E) with a thallus organization like *Lithophyllum* (Maslov, 1962). The large foraminifera remains have been found together with such algae in the packet 2 (Tab. IV, Fig. F, G).

Single prints of *Discocyclina* (?) were also found in the ochre-coloured ferruginous interlayer that separates packets 2 and 3. Here, encrusting coralline algae completely replaced by iron hydroxides are also present.

It should be noted that part of the lower pack of tripoli (Tab. III, Fig. A, C) was saved during the quarry development; therefore the natural structure of the rocks was retained. It is interesting that this structure has a hummocky character (Tab. III, Fig. C), typical of fossil rhodolith buildups (for example, Bassi and Nebelsick, 2003; Bassi, 2005; Bassi et al., 2009). Finds of coralline algae and large foraminifera suggest that these siliceous rocks have emerged based on carbonate algal structures with accompanying fauna. A large amount of silica for such transformations was obtained due to the presence in the Middle Eocene basin of numerous sponge populations; in the samples, the remains of the lithistids were detected in situ (presumably the genus *Jerea*). In addition to fragments of lithistid skeletons, numerous remains of loose spicules are observed in the rock, which indicates a broad development of soft demosponges in the paleobasin.

The preservation degree of sponges is varied even within one individual. In tripoli, some sponges were partially preserved as core with the identifiable structure of the framework, and partly turned into flint. When flint is wetted with water, the lithistid network becomes visible. Unfortunately, most sponges were preserved only in the form of cores, unclearly isolated from the host rocks.

Numerous fragments of silicified finger-like organisms have been found in the roof of the

tripoli (Packet 4) (Tab. III, Fig. E). Some of them, the smallest (7.5 x 1.5 cm), in polished kind reveal a microstructure characteristic of dasycladalean green algae. There are also remnants of large foraminifera in polished samples. The nature of many other elongated silicified fossils leaves unclear.

Corals. Silicified branched colonies of scleractinian corals (up to 0.5 m in diameter and larger) are also found in this part of the section (Packet 4). Previously, they were described as ichnofossils - ophiomorpha (Shekhunova et al., 2015b) or fossil corals of the genus *Acropora* (Zernetsky, 2016). The general morphology of the studied objects shows they are undoubtedly colonial marine organisms (Fig. 4). The version of ophiomorphs cannot be accepted because of the clear branching appearance of the colony, which is characteristic of modern corals acropores (Wallace, 1999), as well as the internal structure of the branches. The latter

show a clear differentiation of the filling terrigenous material and the development of silicification according to the growth of axial and radial corallites, the concentric and radial arrangement of the system of cavities and channels as well. A similar radial and concentric pattern in the branch sections is also observed in fossil acropores (Wallace and Bosellini, 2015, fig. 5, E, fig. 6, D). Despite the poor preservation, the study of colonies in polished samples using a binocular microscope allowed us to see the mesh structure of the coenosteum and, thus, to confirm the findings of B.F. Zernetsky (2016) on the taxonomic identity of these fossils. These Acroporidae findings are the first for the Middle Eocene deposits of the Ukrainian Shield. In the Eocene of other regions of Europe acropores are known: in North-East Italy, the former Yugoslavia, Spain (Wallace, 1999), Northern France, and South England (Wallace and Rosen, 2006; Wallace, 2008), as well as Romania (Król et al, 2017).

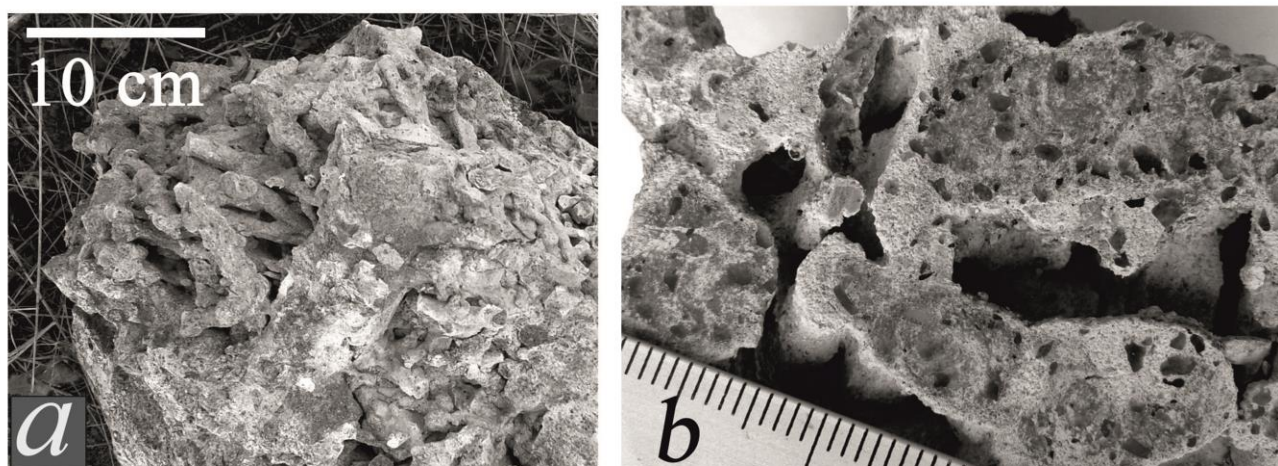


Fig. 4. Silicified colony of corals of the family Acroporidae: *a* – general view; in the central part of the colony, a powerful stem is clearly visible, from which smaller branches ratoon; *b* – view of the part of the colony in a random section (polished specimen); a regular distribution of terrigenous material and silicification zones along concentric circles corresponding to the growth structures of individual corallites and system of cavities and channels are observed.

Voronovka. The most complete information on the fauna, stratigraphical and lithological structure of gaize-like rocks in the vicinity of Voronovka village can be found in the production report of B.U. Mastisty (1963) and a number of publications (Kljushnikov, 1951b, 1953; Krajeva and Luljeva, 1977; Schwartz et al., 2004). So, for example, in works of M.N. Kljushnikov (1951b, 1953) the features of bedding as well as lithological changes of siliceous rocks from fine-grained gaize-like sandstones to marls in a profile and the area in the Southern Bug River basin are in details described. In the same works, extensive lists of the malacofauna are given, which are generally confirmed by our paleontological materials (Tab. V, Fig. A).

Foraminifera of the Eocene sediments of Voronovka are known from the data of O.K.

Kaptarenko-Chernousova (in the work of Kljushnikov, 1951b), as well as the materials of E.Ya. Krajeva (Krajeva and Luljeva, 1977). Based on the listed fauna, the Voronovka siliceous rocks (sandstones) are also difficult to be treated for microfau-na analysis, as well as the rocks of other studied locations. Therefore, the taxonomic diversity of established foraminifera is not great, which is obviously due to the poor preservation of the calcareous fauna in siliceous rocks. So, M.N. Kljushnikov pointed only three species of benthic foraminifera (*Robulus inornatus* (d'Orb.), *Cibicides dutemplei* (d'Orb.), *Cibicoides ungerianus* (d'Orb.)) and indeterminable nummulites as well, although he noted that the rocks contain a large number of their cores. Among the large foraminifera B.F. Zernetsky identified the species *Operculina* cf. *thracensis* Leym. (Zernetsky, 1962).

E.Ya. Krajeva examined the foraminifera of Paleogene sediments of the same region in several facies and discovered a richer fauna complex. E.Ya. Krajeva and S.A. Luljeva described a section of the Eocene with three packs (from the bottom up): calcareous or slightly calcareous silt, calcareous gaize-like sandstones, and calcareous clays. Foraminifera have been found only in the top two packs. Moreover, the microfauna is substantially poorer in gaize-like sandstones than in clays and contains mainly spiral-convoluted tests of *Nonion*, *Cibicides*, *Pseudoparella*, *Asterigerina*, *Discorbis*. Numerous *Bolivina* and *Virgulina* are added to them in clays. In general, according to E.Ya. Krajeva, the Voronovka foraminifera complex is composed of the following species: *Acarinina rugosoaculeata* Subb., *A. ex gr. interposita* Subb., *Hastigerina micra* (Cole), *Nodosaria annulifera* (Cushm. et Berm.), *Lenticulina inornata* (Orb.), *Bulimina eccentrica* Cushm., *Baggina ifigenia* (Saml.), *Bolivina pseudointermedia* (Chal.), *Gumbelitra aff. columbiana* Howe, *Heterolepa pygmeiformis* Krajeva, *Turrilina alsatica* (Andr.), *Uvigerina costellata* Mor., *Cassidulina globosa* Hantk., *Cibicides costatus* Hantk., *Caucasina* sp., etc.

We have studied foraminifera in thin sections from siliceous rocks analogous to those described by M.N. Kljushnikov. The fauna complex was poor as well. Single foraminifera were identified such as *Lenticulina* sp. (Tab. V, Fig. B), *Anomalinoidea cf. granosa* (Hantk.), *Cibicidoides* sp., and also forms resembling the genera *Nonion*, *Bolivina*, *Chilogumbelina*. Obviously, the low taxonomic diversity in this and other similar sections is due to the peculiarities of fossilization and does not connect with paleoecology and the evolution of the Eocene basin.

Sponges. The quantity and preservation of the sponges is close to that observed at previous sites. In the rocks there are remnants of spicules of soft sponges and fragments of lithistid skeletal frameworks with differently preserved canals (apophyses) and desmas.

Lithological and mineralogical data. New data that substantially supplemented our ideas about the Voronovka sandstone genesis were obtained by means of X-ray diffraction analysis (XRD) and scanning electron microscopy. The XRD revealed that the main mineral of the rock is quartz. Its X-ray reflection 0.332 nm has the highest intensity in the diffractogram. The rest of the mineral's diffraction peaks such as 0.4201, 0.2447, 0.1537 nm and others were also registered. There are diffraction peaks of admixture phases as well. The majority of them are calcite (maximums corresponding to d-spacings 0.3018 and 0.1869 nm), opal-CT (0.439 nm and 0.408 nm) and minerals of

the zeolite group. The first of them is a mineral of the Heulandite-Clinoptilolite Series. Its characteristic diffraction peaks which correspond to interplanar spacings 0.9782, 0.8857, 0.3934 and 0.3458 nm were registered. These maxima have relatively low intensity in the experimental diffractogram (13, 11, 32 and 8%, respectively). The second zeolite mineral was identified as laumontite. Typical prismatic crystals of this mineral were observed under the scanning electron microscope (Tab. V, figs. C, E, F). X-ray diffraction maximums 0.886, 0.4087, and 0.3551 nm were attributed to laumontite. The zeolites natrolite and phillipsite that have similar crystal habit are not consistent with the obtained X-ray data. A few equidimensional crystals were also detected in the electron microscopy study (Tab. V, fig. D). Such crystal shape is distinctive for another zeolite mineral, analcime. Only the most intense diffraction peaks of analcime were identified in the diffractogram: 0.345, 0.539, and 0.293 nm. They have low intensity due to an insignificant amount of the mineral in the sample. A large number of opal-CT lepispheres with lamellar structure were observed under the electron microscope together with the zeolites.

Discussion. The data presented above testify or do not contradict the belonging of multi-facial siliceous rocks of the central part of the Ukrainian Shield to the Middle Eocene. The literature data from the study of calcareous nannoplankton from gaize-like sandstones of Voronovka village (Krajeva and Luljeva, 1977) and the gaize-like marls of Kalinovka village (Berezovsky and Vaga, 2003) prove these rocks belonging to the lower part of the Kiev Regiostage. Malacofauna complexes also make it possible the close-facial gaize-like sandstones of Verblyuzhka and Tsybuluvo villages to be corresponded with the Middle Eocene. Pervozvanovka tripoli deposits are poor by the archistratigraphic fossil groups. However, the transgressive character of bedding and the mollusks association suggest their Middle Eocene age.

The obtained results indicate a significant presence of originally calcareous organisms in Pervozvanovka siliceous rocks, as well as development of lithistid and soft sponges. Subsequent silicification of the sediments with the formation of tripoli occurred with the active participation of siliceous bacterial communities, as evidenced by the mass of the lepispheres.

It is known that the total silica content in oceanic water is not enough for the formation of siliceous biota skeletons. Therefore, in many cases, the development and flowering of rock-forming siliceous organisms is primarily associated with the entry of SiO₂ into the water basins due to volca-

nism, as well as with the denudation of the effusive material (Strakhov, 1966).

The establishment of signs of volcanism in the Paleogene siliceous rocks of the Ingul megablock and the territory of the Golovanevskaya suture zone is a complex task due to the transfer and disintegration of the ash material by currents, its transformation into smectites, zeolites, and thanks to silicification processes as well. Meanwhile, the research area is located in the junction zone of geological structures, which are characterized by high tectonic activity (Kruhlov et al., 2007; Antsiferov, 2008; Isakov, 2017). Also Cretaceous and Paleocene tuffs as well as marine pyroclastic deposits were directly determined within the Ingul megablock (Nechajenko et al., 2007; Antsiferov, 2008; Falkovich, 2008; Stefanskyi et al., 2009; Yatsenko, 2009). Along with this, the siliceous rocks of the Cretaceous – Middle Eocene age are widely developed in the Ukrainian Shield paleovalleys and the Dnieper-Donets Depression (Kljushnikov, 1951a, 1951b, 1953; Bushinsky, 1954; Moroz, 1970, Schwartz et al., 2004; Nechajenko et al., 2007; Shekhunova et al., 2015). On the adjacent territories of the Dnieper-Donets Depression, we also have evidence of the influence of volcanic products on the formation of the Eocene siliceous rocks such as the joint presence of zeolites of the Heulandite-Clinoptilolite Series, smectites and relicts of volcanic glass (Zorina et al., 2012a, 2012b; Zorina and Afanasjeva, 2013). Such a combination has acquired the name "disguised" pyroclastic proposed by S.O. Zorina and her co-authors, following A.G. Kossowskaya (1973, 1975).

In less silicified sandstones of Voronovka village, we also have found elements of "disguised" pyroclastic, in particular zeolites of the Heulandite-Clinoptilolite Series, as well as lomontite and analcime (Tab. V, Fig. C-F). Zeolites were also identified in tripoli of quarries near the village of Pervozvanovka (Shekhunova et al., 2015b). Our petrographic studies showed a certain amount of montmorillonite as well. Previously, montmorillonite was found by B.U. Mastistyi (1963) in gaize-like rocks of the Southern Bug River basin. It is known, even at the beginning of the previous century, that scientists consider floridin clays (a kind of montmorillonite clay) as a volcanic ash transformed by secondary processes (Vassoevich, 1935). Very interesting isotropic fragments (0.5-0.7 mm) have been found in thin sections; with some degree of caution, we have preliminary diagnosed them as relicts of volcanic glass.

It is noteworthy that the textural and structural features of the siliceous rocks of Verblyuzhka village (nest-like distribution of sandy-silty and

siliceous material, characteristic lumpy split) are very similar to those of platform gaize which formed due to instant impact of ash material (Murav'ev, 1973). This texture could also arise thanks to insufficient mixing of terrigenous material with sea water because of the accumulation of numerous sponge skeletons in the sediment.

The listed facts suggest the income of silica in the Middle Eocene marine basins of the studied territory due to volcanic activity within the Ingul megablock of the Ukrainian Shield and the Golovanevskaya suture zone. The presence of heavy weathering crusts in the volcanosedimentary Raygorod stratum (Antsiferov, 2008; Falkovich, 2008; Stefanskyi et al., 2009) also indicates active denudation of volcanic material and enrichment of marine basins with silica at the end of the Paleocene and later.

Conclusions. The lithological and mineralogical features as well as faunal composition of the siliceous rocks of the central part of the Ukrainian Shield testify to their multi-facial character, the Middle Eocene age, the multistage nature of their genesis, and the influence of Paleogene volcanism on their formation.

For the first time, numerous remains of rock-forming organisms have been found in the siliceous rocks of this region: lithistids (lithistid Demospongiae), coralline (Corallinaceae, *Lithophyllum* (?)) and green algae (Dasycladales, Halimedaceae). For the first time, the siliceous rocks of the Pervozvanovka deposit were determined to be originally biogenic buildups formed by organisms with calcareous (coralline and green algae, large foraminifera) and silicate (sponges) skeletons.

The malacofauna complex of gaize-like sandstones of Verblyuzhka village was supplemented due to new findings of bivalve species *Lentipecten corneus* (Sow.), *Chlamys* ex gr. *ubimbricata* (Münst.), *Chl. refa* Berezovsky, *Chl. orientalis* Sok., *Crassatella* aff. *fushi* Slodk., *Eomiltha contorta* (Deft.), *Solena (Eosolen) plagiaulax* Cossm., as well as gastropods *Tectus* aff. *margaritaceus* Desh., *Cirsotrema rotula* Koen., *Haustator* sp., *Tomyris ukraineae* Mich., *Motyris fasciata* Lamck., *Hadriana flandrica* Koen., *Mithra* sp., *Pachicrommium* sp., *Volutidae (Athleta* sp.?). Based on these new findings and malacofauna analysis, the Middle Eocene age of the gaize-like sandstones of Verblyuzhka village was determined.

For the first time the mollusks association composed of *Spondilus tenuispina* Sandb., *S. bushi* Phillipi, *Lentipecten (Lentipecten) corneus* (Sow), *Chlamys refa* Berez., *Chl. (Aquapecten)* sp., *Motyris ukraineae* Mich, *Motyris fasciata* Lamck. has been determined for tripoli of the productive

formation of the Pervozvanovka quarry. The Middle Eocene age of the tripoli is determined by mollusks and the deposits bedding character.

For the first time "disguised" pyroclastic have been found in the Middle Eocene siliceous rocks of the studied region; this fact emphasizes the influence of volcanism on the formation of marine biota and processes of sedimentogenesis.

Middle Eocene volcanism in the tectonically active zones of the Ukrainian Shield (Ingulsky megablock, Golovanevskaya suture zone), as well as denudation of volcanic products, caused the mass SiO₂ entry into the paleobasin; the amount of SiO₂ was enough for the wide development of rock-forming siliceous organisms (first of all, sponges which formed mass settlements in shallows).

The presence of numerous lepispheres along with a large number of silicified remains of calcareous organisms (various algae, foraminifera, mollusks) in the gaize-like rocks and tripoli of the central part of the Ukrainian Shield presupposes the active participation of silicon-containing bacterial communities in the formation of these siliceous rocks, including opal-cristobalite deposits.

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Explanation of the tables

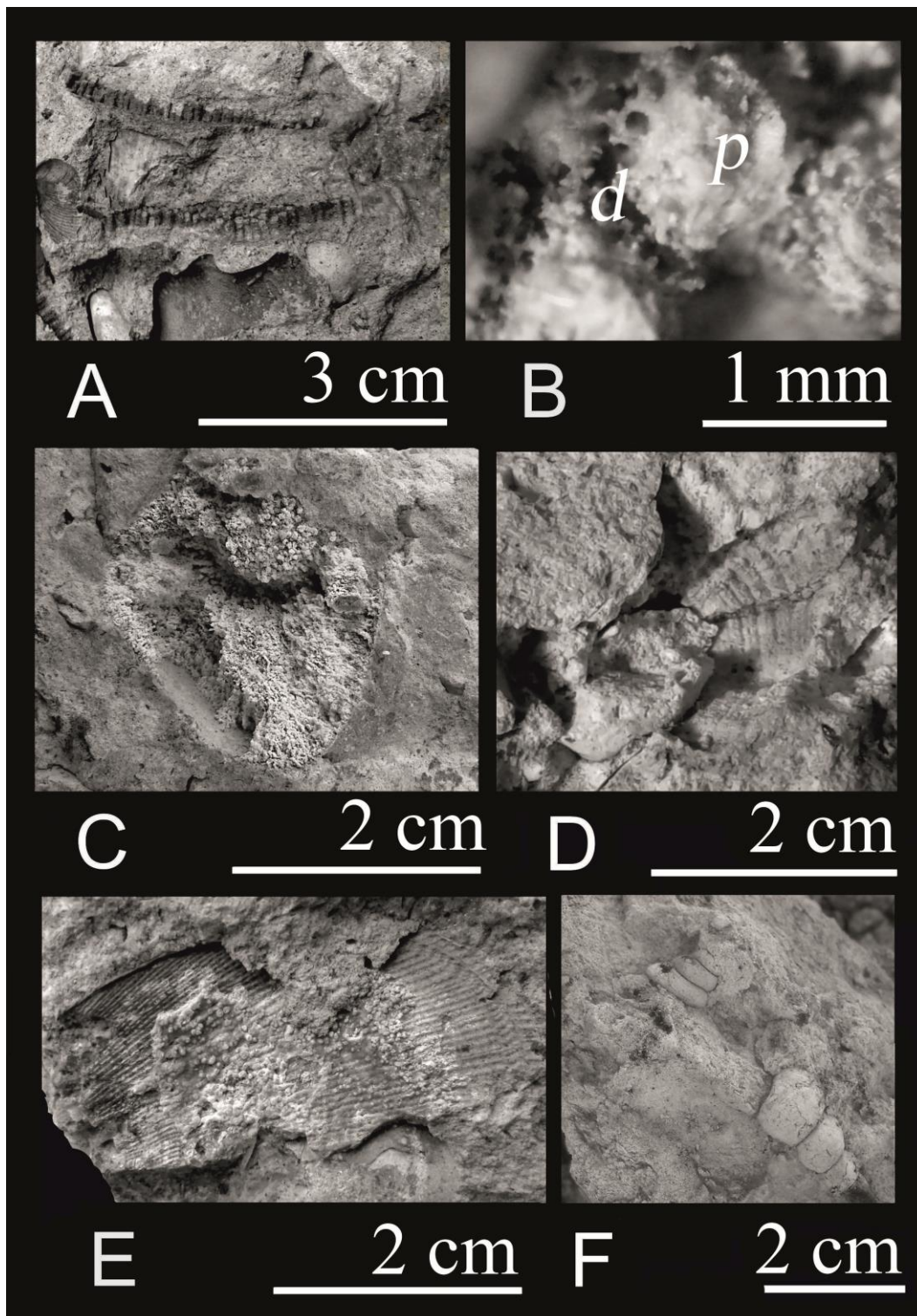


Table 1. Fauna of Middle Eocene siliceous rocks of Tsybulevo and Verblyuzhka villages

Fig. A. Piece of the gaize-like sandstone with mollusk cores and skeleton fragments of lithistid sponges. Outcrop, Tsybulevo village.

Fig. B. Remains of the lithistid skeleton: *d* – desmas; *p* – space of the pores replaced by silica. Outcrop, Tsybulevo village.

Fig. C. Piece of the gaize-like sandstone with a fragment of the lithistid skeleton of sponge *Siphonia* (?). The Middle Eocene, outcrop, Verblyuzhka village.

Fig. D. Shell imprint of the sea urchin. Outcrop, Verblyuzhka village.

Fig. E. Imprint of the valve of pelecypod *Ctenoides explanatus* Koen. Outcrop, Verblyuzhka village.

Fig. F. Gastropod shell core of the genus *Motyris* Outcrop, Verblyuzhka village.

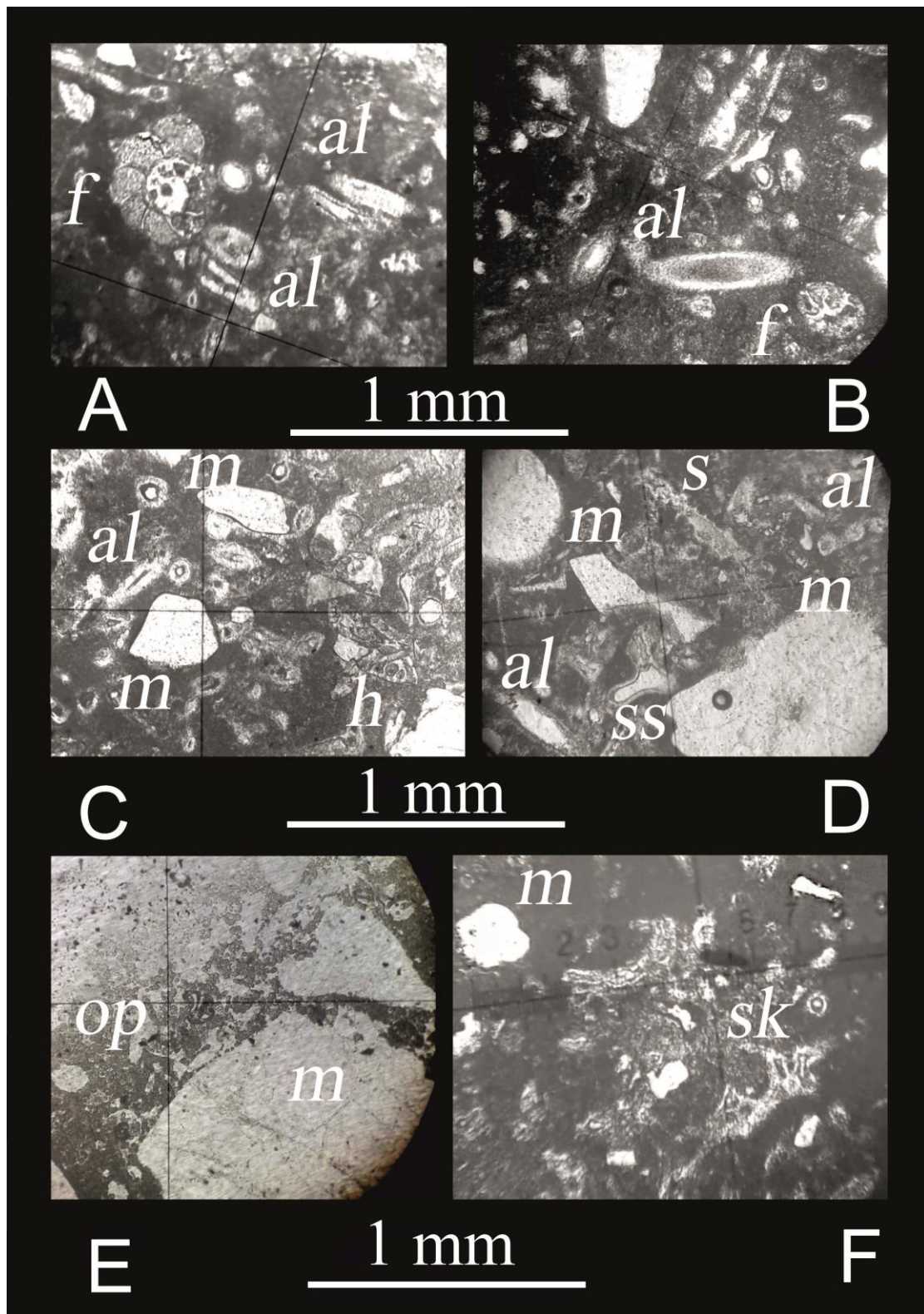


Table II. Thin sections of siliceous rocks of the Middle Eocene of Verbylyuzhka village (without analyzer)

Fig. A: *f* – section of the foraminifera test *Lobatula* cf. *lobatula* (Walker et Jacob); *al* – dasycladalean green algae.

Fig. B: *f* – sections of the foraminifera tests; *al* – dasycladalean green algae.

Fig. C: *h* – green algae *Halimeda* (?); *al* – dasycladalean green algae; *m* – detritus of mollusk shells.

Fig. D: *s*, *ss* – sponge spicules (*s* – rhizoclone, *ss* – triod (?)); *al* – dasycladalean green algae; *m* – detritus of mollusk shells.

Fig. E: *op* – globules of opal; *m* – detritus of mollusk shells.

Fig. F: *sk* – fragment of sponge skeleton; *m* – detritus of mollusk shells.



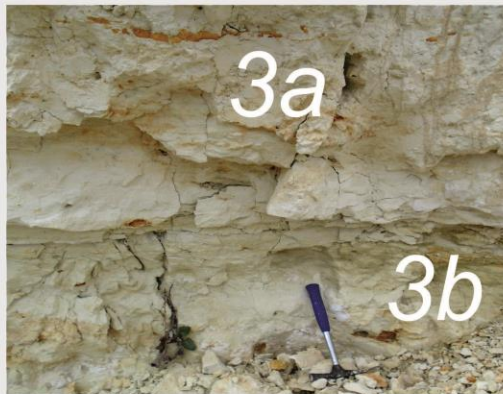
A



B



C



D



E

Table III. Outcrops of the Middle Eocene siliceous rocks and paleontological remains in the Pervozvanovka quarry

Fig. A. Outcrop of tripoli.

Fig. B. Outcrop of silicified gaize-like “Kalinovka marls”.

Fig. C. Lower pack – biogenic buildup with lumpy-tuberculate structure and ferruginous weathering crust at the top.

Fig. D. Interlayer of clay in the tripoli pack.

Fig. E. Tripoli of the terminal part of the section with silicified paleontological remains.

The numerals in the figures correspond to the numbers of the packs in the described section of the siliceous rocks of the Pervozvanovka quarry in the text: 1 – the gaize-like “Kalinovka marls”; 2 – tripoli of lumpy-tuberculate structure (biogenic buildup); 3 – a pack of interlayering tripoli and clays (3a – tripoli, 3b – clays); 4 – tripoli with silicified remains of organisms.

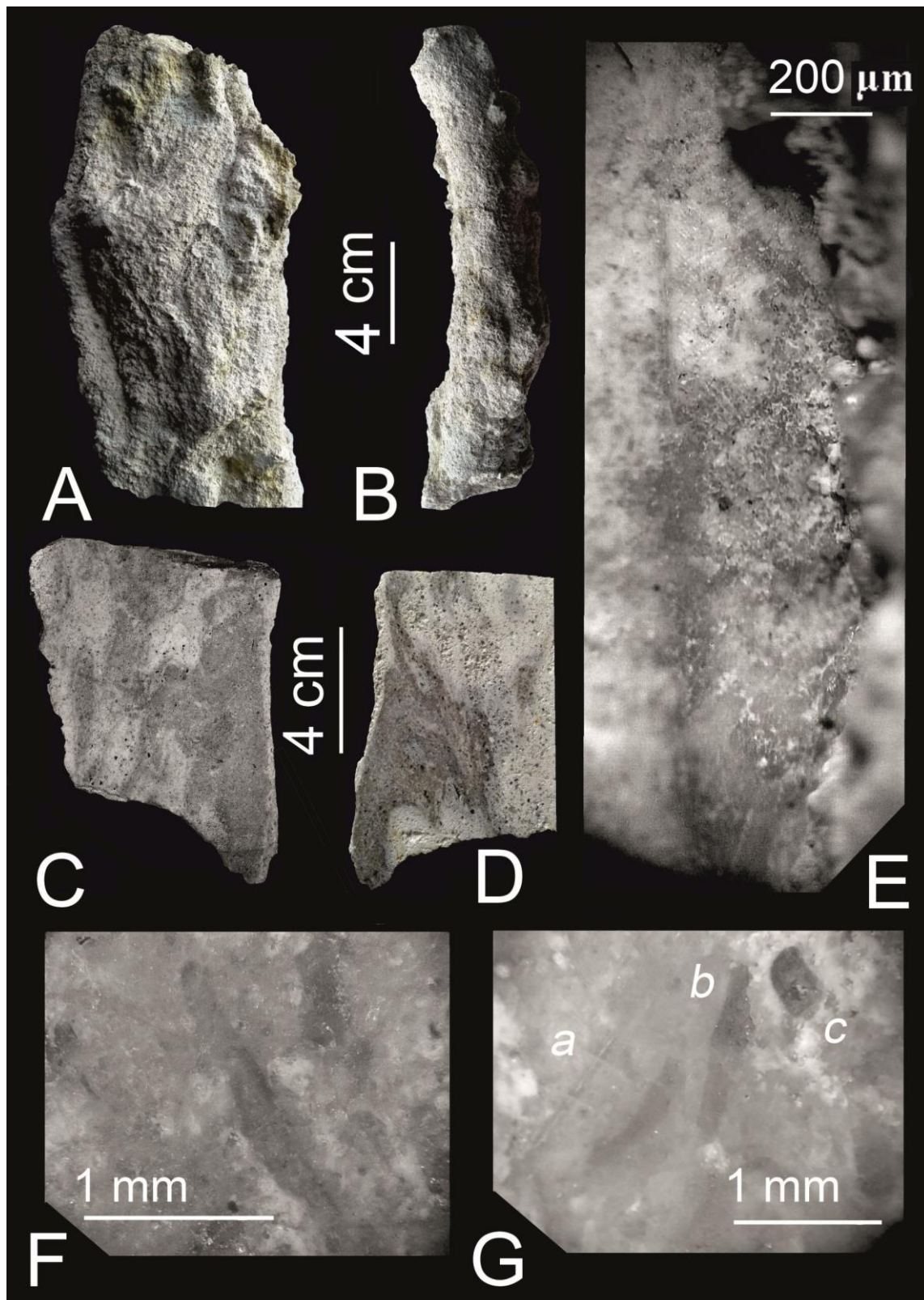


Table IV. A partially silicified fragment of the branching colony of red algae *Lithophyllum* sp. (?) from the lower pack of tripoli (biogenic buildup) and accompanying fauna of the large foraminifera.

Fig. A. General view of the fragment.

Fig. B. View of the fragment from the side.

Fig. C. View of the fragment in the section (ground-in).

Fig. D. View of the fragment in the section (polished).

Fig. E. Structure of the thallus like *Lithophyllum*.

Fig. F. Axial section of the *Discocyclina* (?) test. A view in a polished sample (Fig. D).

Fig. G: *a* – sponge spicule (rhabd); *b* – axial section of the *Discocyclina* (?) test; *c* – glauconite. A view in a polished sample (Fig. D).

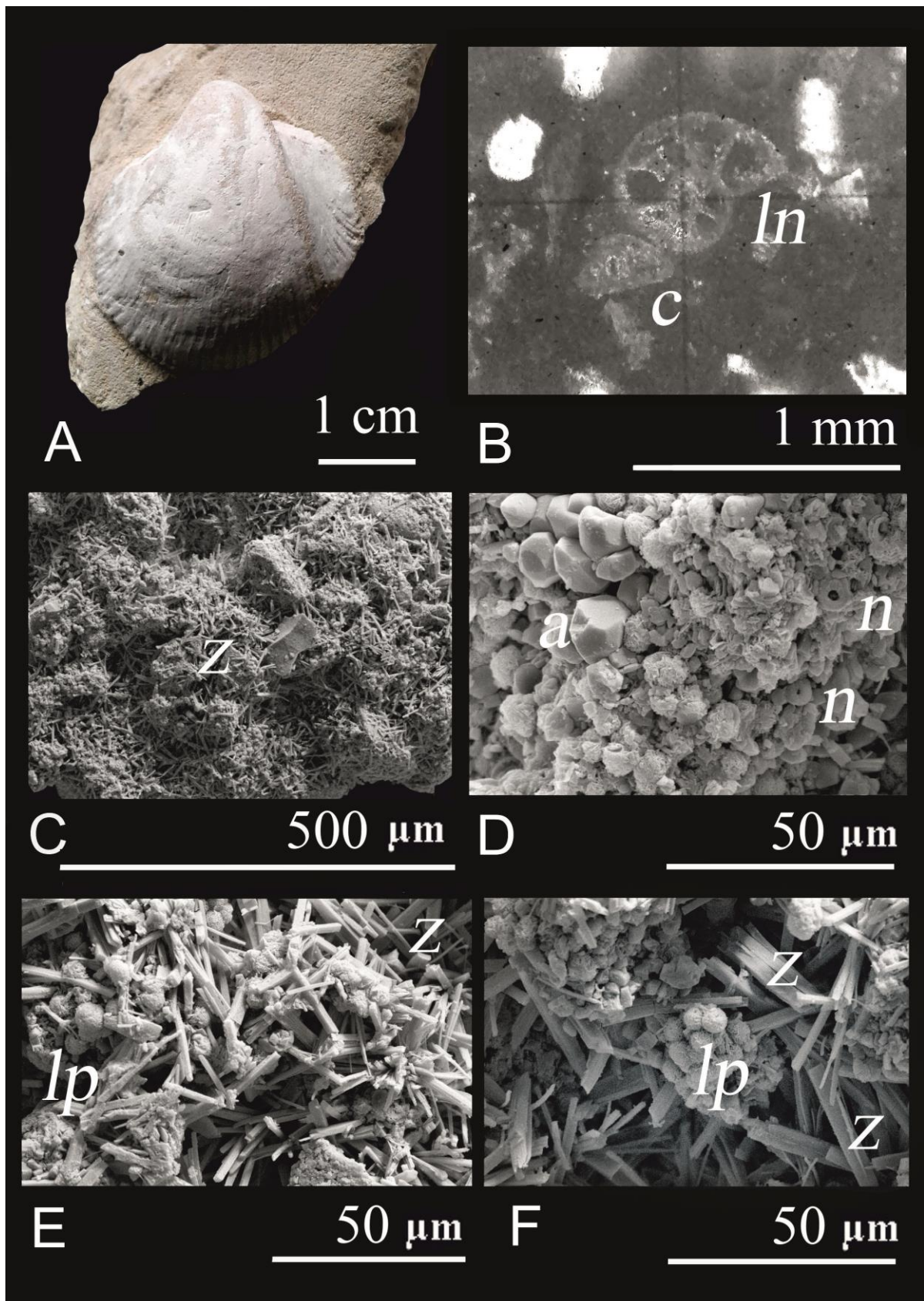


Table V. Fauna and minerals of gaize-like rocks of the Middle Eocene of Voronovka village

Fig. A. Valve of pelecypod *Vepricardium praepitatum* (Słodk.).

Fig. B. Foraminifera in thin section (with analyzer): *ln* – *Lenticulina* sp.; *c* – *Cibicoides* sp.

Fig. C. Zeolites (*z*).

Fig. D: *a* – zeolite analcime; *n* – calcareous nannoplankton.

Fig. E: *z* – zeolite lomontite; *lp* – lepispheres.

Fig. F: *z* – zeolite lomontite; *lp* – lepispheres.