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**THE FIRST RECORD ON THE PALEOBACTERIAL OBJECTS FINDINGS  
ON THE WALLS OF FORAMINIFERAL TESTS FROM THE LOWER  
OLIGOCENE OF SOUTHERN UKRAINE AND THEIR IMPORTANCE FOR THE  
RECONSTRUCTION OF SEDIMENTOGENESIS CONDITIONS**

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The article presents the first information about the paleobacterial objects which have been found on the walls of the foraminiferal tests from the Borysthenian (Planorbella) Regional Stage of the Lower Oligocene of Southern Ukraine. 145 agglutinated and calcareous tests have been selected and studied from the Lower Oligocene (Borisphenian) sediments opened by boreholes in the South-Western Crimea and the Northern Black Sea region. Microscopic objects have been established on the walls of 50 tests and attributed to paleobacterial formations on the basis of a number of characteristics. Most of the bacterial objects are represented by biogenic sulphides, as well as bacterial films and mats found on foraminifera tests of various taxonomic affiliation. Coccoid clusters are often observed on the tests of agglutinating foraminifera. Chlorophytes of cyanobionts (?) are frequently seen on the calcareous and finely agglutinated tests. Actinomycetes (?) are found on calcareous and agglutinating foraminifera, mainly on infauna.

An analysis of the infauna-epifauna ratio in foraminifera associations suggested that gas regime was fluctuating in the Early Oligocene (Borysthenian) basin of Southern Ukraine mainly from low oxic to sub- and dysoxic conditions. Rare episodes of oxygenation increasing contributed to the development of epifauna with a large test (representatives of the genera *Neogyroidina*, *Baggina*, *Heterolepa*, *Cibicidoides*), as well as the appearance of planktonic foraminifera. Sometimes, the gas regime changed to anoxic, as indicated by the intervals without the fauna of foraminifera. At the end of the Borysthenian basin, anoxic conditions were presumably established.

A significant difference between the initial composition of foraminifera in biocenoses and their composition in oryctocoenoses is assumed. Frequent findings of remains of paleobacterial communities and traces of their vital activity in the foraminiferal tests suggested these communities could have an important influence on the preservation and completeness of the oryctocoenoses, being involved in the processes of diagenesis.

*Key words:* microbioliths, foraminifera, Borysthenian Regional Stage, Maikop Series, Lower Oligocene, Southern Ukraine.

Foraminifera are the acknowledged tool of biostratigraphic, paleoecologic, paleogeographic investigations; they are also indispensable for environment monitoring in modern marine basins. Recent investigations of agglutinating genus *Spiroplectammina* from Oligocene of Southern Ukraine [19, 39] have showed that foraminiferal tests can also be used as a valuable source of information about development of other even-aged organisms, their taphonomy and habitat. In these cited works, there are results of findings of imprints and cores of diatom alga and sponge spicules to be rarely well preserved in Oligocene of this region. Further studying of foraminifera from these deposits has showed presence of other microscopic objects probably bacterial origin on both agglutinated and calcareous tests. It should be noted that paleobacterial communities of South-Ukrainian Oligocene have practically not been studied.

Paleobacterial communities are very important and often fundamental to the evolution of geological settings, the processes of lithogenesis, and the formation of mineral deposits. This fact causes the active development of bacterial paleontology today [1, 2, 8, 41]. However, works on the paleobacteriology of the Paleogene, in particular, the Oligocene of Ukraine, are extremely rare. Thus, there are known only a few publications on results of petrographic study of the paleobacterial forms from some siliceous and calcareous rocks of the Lower Oligocene of the Ukrainian Carpathians [15, 16, etc.]. The petrographic features of the paleobacterial structures diagnosed in these studies, as well as the established connection between the genesis of some rocks of the Menilitic Formation and the activities of the paleobacterial communities, are generally convincing. At the same time, the paleontological definitions of bacterial objects given in these publications were made on the basis of the limited capabilities of the petrographic method and the use of Yelenkin's systematics of 1936 [5] without taking into account modern data [1, 2, 6–8, 20, 21, 29, 46, etc.].

Based on study using SEM of some specimens from the Oligocene of the Northern Black Sea region, V.N. Kuleshov suggested a wide participation of various paleobacterial forms in the formation of various types of manganese ores from the Nikopol deposit [12]. V. L. Stefansky has proposed the manganite concretions of the Nikopol manganese ore basin to be considered as stromatolites [22]. The latter have clear diagnostic signs pointed in a number of works [e.g., 1, 13, 31, 41, etc.].

Thus, previous paleobacteriological studies of Oligocene rocks in the south of Ukraine point out not only the presence of various fossil bacterial objects in them, but also demonstrate the important role played by bacterial communities in the formation of mineral deposits (in particular, manganese and hydrocarbons) in this territory. In this paper, we present the first preliminary information on some paleobacterial objects established using SEM on the foraminiferal tests from the Lower Oligocene of Southern Ukraine. These findings also complement the data on the processes of sedimentation and diagenesis of the Oligocene (Lower Maikop) sediments of the studied territory.

The material for research was the core from boreholes that revealed the Lower Oligocene sediments in the South-Western Crimea (borehole 9, Kluchi village, borehole 16, Kubanskoje village) and the Northern Black Sea region (borehole 29, Menchikury village) (Fig. 1).

The stratigraphic position of the studied sections is shown in Fig. 2. Here, the Lower Oligocene includes the deposits of the Borysthenian regional stage [17, 18], which in the Stratigraphic Scheme of the Paleogene of Southern Ukraine is considered as the Planorbella regional stage [23–25]. In the South-Western Crimea, Borysthenian (Planorbella) regional

stage is subdivided into the Kyzyl-Dzhar Horizon and the Zubakino Layers; in the Northern Black Sea region it corresponds to the suite of the same name (Borysthenian) with the division into Rubanovka and Nikopol Subsuites [23].

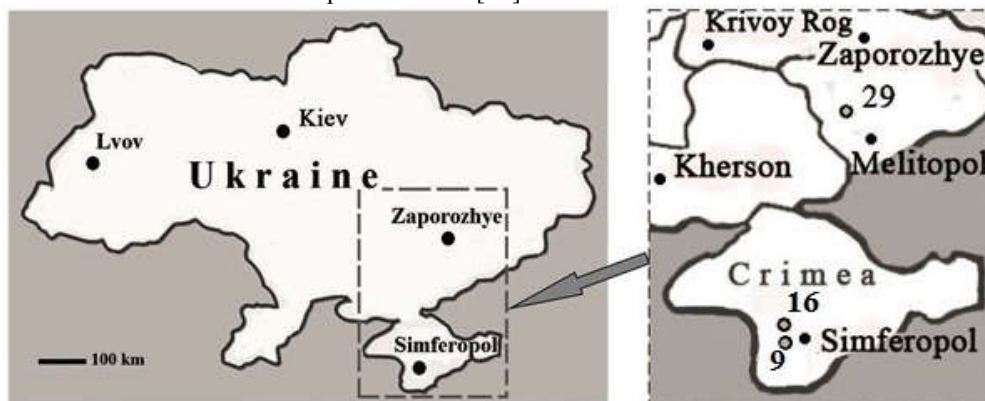


Fig. 1. Location of studied sites. The South-Western Crimea: borehole 9 – Kluchi village; borehole 16 – Kubanskoje village; the Northern Black Sea region: borehole 29 – Menchikury village

The age of the studied rocks was determined by foraminifera (lists of foraminifera in boreholes 9 and 16 are given earlier [10]). The microfauna is extracted from the rock samples by the standard method, according with [4]. The foraminiferal tests and paleobacterial objects preserved on their walls were examined using electron microscope PММА 102-02, SELMI (Dnipropetrovsk branch of UkrGGRI, Dnipropetrovsk). 145 tests were investigated. Of these, 82 belong to agglutinating benthic foraminifera, 45 – to calcareous benthic and 18 – to planktonic. During paleoecological reconstructions and definitions of the morphotypes of the foraminiferal tests, the results of numerous studies of their modern and fossil representatives were taken into account [28, 34, 35, 38, 43, etc.].

The high convergence of prokaryotes makes their taxonomic definitions very difficult, even at the level of higher taxa. However, in the process of paleontological research, we proceeded from the fact that the use of phenotypic classifications [20, 21, etc.] for the detection and analysis of bacterial morphoforms remains an important step in paleobacterial, paleoecological and lithogenetic studies [1, 20]. Examples of the successful use of artificial fossil classifications for solving geological and paleogeographic problems are widely known [11]. At the same time, the authors of the cited works tried to maximally correlate the obtained phenotypic data with phylogenetic classifications based on the results of the analysis of the 16S p RNA sequencing of biological objects and reflected in the Bergey Handbooks of recent decades [29, etc.]. Modern diagnostics of paleobacterial objects also implies the use of biomarkers [7, etc.]. For our materials, this type of diagnosis is assumed in the future. Phenotypic methods for studying of paleobacterial objects should be combined with the reconstruction of the chemo- and eco-conditions of their habitat. In this light, we consider that the study of bacterial fossils on the test walls of fossil foraminifera, for which taxonomic identity, habitat and lifestyle are well known, to be informative. This information, as well as the material composition of the foraminiferal tests, the position and relationship of the paleobacterial ob-

jects with respect to the different morphological elements of the skeletons of the foraminifera and with respect to each other are valuable additions to taxonomic constructions.

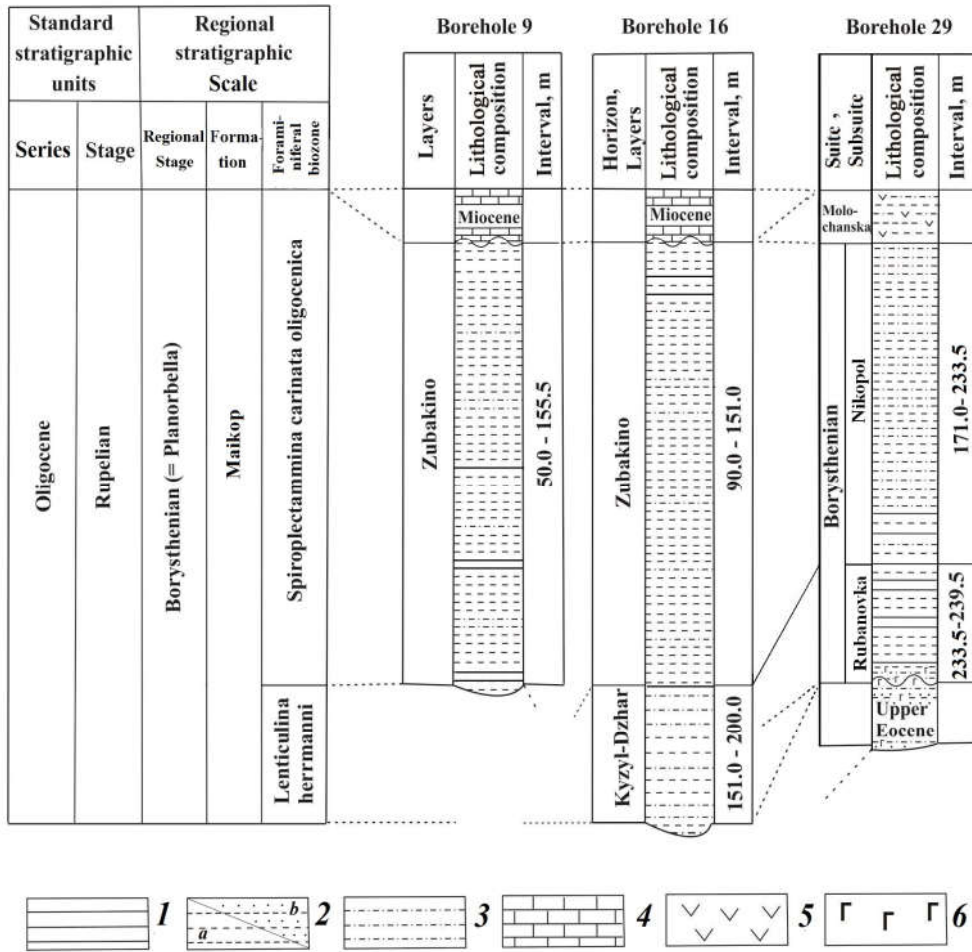


Fig. 2. Stratigraphic correlation of the studied sections: 1 – clay; 2 a – silty clay; 2 b – sandy clay; 3 – clayish silt (siltstone); 4 – limestone; 5 – carbonate content; 6 – glauconite

**The stratigraphic distribution of foraminifera and the bionomic analysis of their complexes. Borehole 9.** The borehole has only opened the upper part of the Borysthenian Regional Stage (the Zubakino Layers). The depth of occurrence is 50.0–155.5 m. Rocks are represented by light and dark gray clays, silty, sometimes shaly, slightly calcareous to carbonate-free, characterized by the foraminifera complex of the Spiroplectamina carinata oligocenica biozone. In this section, the microfauna is not numerous, rather monotonous,

small-sized, often pyritized, absent in separate intervals. Its main background is represented by the following taxa: *Spiroplectammina carinata oligocenica* J. Nikitina, *Sp. ex gr. carinata* (d'Orbigny), *Gyroidina soldanii* (d'Orbigny), *Neogyroidina memoranda* Subbotina, *Baggina iphigenia* (Samoilova), *Cibicidoides pseudoungerianus* (Cushman), *Pullenia bulloides* (d'Orbigny), *Melonis dozularensis* (Chalilov), *Caucasina schischkin-skayae* (Samoilova), *Uvigerinella ex gr. californica* Cushman, *Bolivina aff. aenariensis-formis* Mjatluk, *Brizalina mississippiensis* (Cushman), *Furssenkoina schreibersiana* (Czjzek). They pass through almost the entire interval. Periodically, the below-listed single forms are added to the complex in different variations: *Hyperammia* sp., *Reophax* sp., *Cyclammina ex gr. consrictimargo* K.E. et K.C. Stewart, *Triloculina trigonula* (Lamarck), *Marginulina* sp., *Nodosaria* sp., *Lagena aff. sulcata* (Walker et Jacob), *Robulus inornatus* (d'Orbigny), *Lenticulina* sp., *Globulina rotundata* (Bornemann), *G. amygdaloides* Reuss, *Oolina ovulum* (Subbotina et Chutzieva), *Chilostomella cf. balkhanensis* Dain et Chalilov, etc. The level of appearance of not numerous but relatively diverse plankton foraminifera (depth 87 m) is established. The total amount of fauna decreases to the upper part of the section (until it disappears completely), the number of pyritized fossils increases.

During its life time, the listed benthic foraminifera occupied different levels relative to the sediment surface, that is, they belonged to epi- or infauna. Given the literature data [34, 35, 43], in our samples, such genera as *Spiroplectammina*, *Cyclammina*, *Triloculina*, *Lenticulina*, *Gyroidina*, *Neogyroidina*, *Baggina*, and *Cibicidoides* should be considered as epifauna, *Hyperammia*, *Marginulina*, *Nodosaria*, *Lagena*, *Globulina*, *Oolina*, *Pullenia*, and *Melonis* – as shallow and middle infauna, *Reophax*, *Caucasina*, *Uvigerinella*, *Bolivina*, *Brizalina*, *Furssenkoina*, and *Chilostomella* – as deep infauna. It should be noted that various authors regard the foraminifera of the *Spiroplectammina* genus as the surface epifauna [34, 43, etc.], shallow [38] or deep infauna [28]. Spiroplectammins inherent in the studied sediments are distinguished by flattened leaf-shaped shells with a jagged keel. We believe that the presence of such a keel is more likely characteristic of the surface epifauna, as indicated in studies of the Late Cretaceous and Paleogene foraminiferal morphogroups [34, 43].

In the section, constant fluctuations of the infauna / epifauna ratio are observed, which may indicate an unstable gas regime in the bottom waters. Considering the rarity or absence of typical oxic indicators in the foraminiferal complex (according to K. Kaiho [33], these include epifauna with large,  $\geq 350 \mu\text{m}$ , thick-walled tests, mainly representatives of the genera *Cibicides*, *Cibicidoides*, and some miliolides; in addition, in our material we refer to oxic indicators as large *Heterolepa*, *Neogyroidina*, *Baggina*, *Planorbulina*) and the predominance of small-growth, thin-walled infauna, one can assume mainly suboxic (Oxygen level is 0.3–1.5 mL/L) and dysoxic (Oxygen level is 0.1–0.3 mL/L), less often – low oxic (Oxygen level is 1.5–3.0 mL/L) conditions in the bottom waters of this part of the Early Oligocene basin.

The most noticeable change in associations is observed in a narrow interval at a depth of 87 m with the appearance of planktonic foraminifera *Globigerina officinalis* Subbotina, *G. praebulloides praebulloides* Blow, *G. praebulloides leroyi* Blow et Banner, *G. trefa* N. Bykova, *G. angustiumbilitata* Bolli, *G. ouachitaensis ouachitaensis* Howe et Wallace, *G. ouachitaensis gnaucki* Blow et Banner, *Tenuitella khadumica* (N. Bykova). Their emergence in the section coincided with a sharp increase in the number of epifauna (up to 77%), in particular, of *Neogyroidina memoranda* Subbotina, that can be indicate a slight increase in oxygenation.

The rarity or lack of fauna at the top of the section may indicate anoxic conditions at the end of the basin's existence. Given the ambiguity of the interpretation of the terms used to assess the oxygen content in the near-bottom waters ("oxic", "dysoxic", "suboxic", "anoxic") [30, 32, 33, 47], we emphasize that all the results here and below in the oxygen regime reconstruction of the Early Oligocene basin was obtained taking into account the work of K. Kaiho [33]. As for the term "anoxic", we adhere to the opinion of the authors [32], using it only for environmental conditions in which oxygen is not recorded at all.

**Borehole 16.** The borehole has passed through the Kyzyl-Dzhar Horizon, represented by gray siltstones and silty clays (interval 151.0–200.0 m), and Zubakino Layers, mainly represented by gray, dark gray siltstones and silty clays (interval 90.0–151.0 m). The Kyzyl-Dzhar Horizon is characterized by the foraminifera of the "Lenticulina" herrmanni biozone, the subzones (from the bottom up) *Heterolepa almaensis* and *Cibicidoides* aff. *pseudoungerianus*. In the sediments of the first of them, epifauna (*Heterolepa*, *Cibicidoides*) and shallow infauna (*Nodosaria*, *Lagena*, *Globulina*, *Oolina*, *Pullenia*, *Melonis*) quantitatively predominate; scarce planktonic foraminifera continuously occur. In *Cibicidoides* aff. *pseudoungerianus* subzone, besides above mentioned foraminifera, some epifauna (*Baggina*, rarely *Milolinella*, and *Planorbulina*), shallow ("*Lenticulina*" (*Astacolus*)) and deep infauna (*Subreophax*, *Bolivina*, *Brizalina*) are added. From the depth of 188 m, numerous pyritized remains of rod-shaped agglutinated foraminifera appear (fragments of *Nothia* (?), *Rhizammina* (?), *Rhabdammina* (?)); planktonic foraminifera disappear from the same depth.

Zubakino Layers contain the foraminiferal association of the *Spiroplectammina carinata oligocenica* biozone. Here, in comparison with the underlying deposits, there is less epifauna (*Cibicidoides pseudoungerianus* (Cushman)), and more deep infauna (*Subreophax*, *Caucasina*, *Uvigerinella*, *Bolivina*, *Brizalina*). Planktonic foraminifera *Globigerina praebuloides praebuloides* Blow, *G. trefa* N. Bykova, *G. ouachitaensis gnaucki* Blow et Banner, as well as in borehole 9, appear in a very narrow interval (depth 114 m). Along with this event there was an increase in epifauna *Neogyroidina*, *Baggina*, *Cibicidoides*.

Judging by the distribution of oxic indicators in the section, the most optimal gas regime (low oxic conditions) was maintained during *H. almaensis* time. In the middle of *C. aff. pseudoungerianus* time, the gas regime deteriorated to suboxic conditions. The formation of the Zubakino Layers was characterized by fluctuation from low oxic to sub- and dysoxic conditions. Episodes of increased oxygenation were reflected in the section by the appearance of fragments of massive bryozoa colonies (depth 132 m), the planktonic foraminifera emergence and an increase in the number of epifauna (106–114 m).

The almost complete absence of fossils at the top of the section, with the exception of fragments of agglutinating foraminifera and pyritized diatoms, presumably indicates anoxic conditions at the end of the basin.

**Borehole 29.** In the Northern Black Sea region, greenish-gray clays and silty clays of the Borysthenian Suite were opened by the borehole 29 in the interval 171.0–239.7 m between the glauconitic sandy clays of the Upper Eocene and the carbonate silty clays of the Ostracoda Stratum (the Molochanska Suite). The lower part of the section, the Rubanovka Subsuite is partially eroded (drilled in the interval 233.5–239.7 m). It contains predominantly agglutinating foraminifera *Saccammina variabilis* Bogdanowicz, *Psammospaera fusca* Schulze, *Hyperammina* cf. *caucasica* Bogdanowicz, *Reophax* sp., *Subreophax scalaris* (Grzybowski), *S. splendidus* (Grzybowski), *Trochammina parva* Cushman et Laiming, *Trochammina* sp., *Trochamminoides* sp., *Haplophragmoides deformabilis* Subbotina,

*H. stavropolensis* Ter-Grigorjantz, *H. fidelis* Ter-Grigorjantz, *Ammomarginulina* sp., *Spiroplectammina* ex gr. *carinata* (d'Orbigny), *Sp. carinata oligocenica* J. Nikitina, *Sp. vicina* Eremeeva, *Sp. azovensis* J. Nikitina, *Gaudryina gracilis* Cushman et Laiming, *Gaudryina* sp., *Verneuilinoides* sp., *Cyclammina consrictimargo* K.E. et K.C. Stewart., etc. Calcareous foraminifera are contained in a small amount; include the zonal species "*Lenticulina*" *herrmanni* (Andreae), as well as *Globulina rotundata* (Bornemann), *G. gibba* d'Orbigny, *G. amygdaloides* Reuss, *Guttulina problema* d'Orbigny, *Neogyroidina memoranda* Subbotina, *Cibicidoides pseudoungerianus* (Cushman), *C. oligocenicus* (Samoilova), *C. speciosus* (Cushman), *Heterolepa crimaensis* (Schutzkaja), *Melonis dozularensis* (Chalilov), *M. stavropolensis* Bogdanowicz, *Caucasina schischkinskayae* (Samoilova), *Uvigerinella* ex gr. *californica* Cushman, *Bolivina* ex gr. *beyrichi* Reuss, *Brizalina mississippiensis* (Cushman), etc.

Representatives of epifauna (*Spiroplectammina*, *Trochammina*, *Trochamminoides*, *Cyclammina*, *Neogyroidina*, *Cibicidoides*) and shallow infauna (*Saccammina*, *Psammosphaera*, *Hyperammina*, *Haplophragmoides*, "*Lenticulina*" (*Astacolus*), *Globulina*, *Guttulina*, *Melonis*) predominate in this part of the section. Deep infauna (*Reophax*, *Subreophax*, *Gaudryina*, *Verneuilinoides*, *Caucasina*, *Uvigerinella*, *Bolivina*, *Brizalina*) is developed in a somewhat smaller amount.

Nikopol Subsuite was drilled in the range of 233.5–171.0 m; the subsuite is represented by clays only in the lowest part and above it – by silty clays interstratified with siltstones. Here, the zonal taxon *Spiroplectammina carinata oligocenica* J. Nikitina is noticeably more common as well as *Cyclammina consrictimargo* K.E. et K.C. Stewart., *Subreophax scalaris* (Grzybowski), *S. splendidus* (Grzybowski), and calcareous fauna, in particular, *Pullenia bulloides* (d'Orbigny), *Melonis dozularensis* (Chalilov), *Caucasina schischkinskayae* (Samoilova), *Brizalina mississippiensis* (Cushman), *Furssenkoina schreibersiana* (Czjzek). In the range of 231.5–226.8 m, the planktonic foraminifera *Globigerina officinalis* Subbotina, *G. praebulloides praebulloides* Blow, *G. aff. senilis* Bandy, *G. ouachitaensis ouachitaensis* Howe et Wallace, *G. ouachitaensis gnaucki* Blow et Banner, *Turborotalia brevispira* (Subbotina) appear along with the large thick-walled benthic *Cibicidoides* aff. *oligocenicus* (Samoilova), and miliolids *Triloculina trigonula* d'Orbigny.

From a depth of 228.8 m, the amount of fauna decreases; in the range of 219.3–215.5 m, numerous pyritized fragments of rod-shaped *Nothia* (?), *Rhizammina* (?), *Rhabdammina* (?) emerge. Approximately from a depth of 195 m, the foraminifera almost disappear, pyritized radiolarians, diatoms, and reworked Eocene microfauna are observed.

Presence of epifauna, shallow and deep infauna, as well as the rare planktonic foraminifera are characteristic of the Nikopol Subsuite. Among the oxic indicators there are large thick-walled *Cibicidoides*, miliolids, as well as numerous *Neogyroidina* and *Baggina*.

At the Rubanovka time, unfavorable conditions for the preservation of the microfauna with a calcareous skeleton were existed in this section of the Early Oligocene basin. Presumably, the gas regime was low oxic. At the beginning of the Nikopol time, low oxic conditions persisted. A sharp decrease in oxygenation occurred in the second half of Nikopol time; this event was reflected in the depletion of the fauna and the appearance of pyrite pseudomorphs.

**Microbial objects.** *The frequency of occurrence and morphological forms.* Microscopic objects have been established on a third of the studied foraminiferal tests and attrib-

uted to paleobacterial formations on the base of a number of signs. In the **borehole 9**, they were determined in the range of 77–132 m. 40 tests of agglutination and calcareous foraminifera were selected from this interval. They belong to 16 genera: *Reophax*, *Spiroplectammina*, *Marginulina*, *Globulina*, *Spiroloculina*, *Neogyroidina*, *Baggina*, *Pseudoparella*, *Cibicidoides*, *Pullenia*, *Melonis*, *Caucasina*, *Uvigerinella*, *Brizalina*, *Furssenkoina*, *Tenuitella*.

The 30 investigated tests have on their surface both directly microbial objects, and evidence of secondary (direct (?)) biogenesis (traces of vital activity, for example, framboids of pyrite). Among the nannofossils, remains of lithified bacterial covers, bacterial mats and films, as well as actinomycete (?) remnants are identified. According to [43], we have attributed the pyrite and marcasite framboids to objects of secondary biogenesis.

In the **borehole 16**, paleobacterial objects were studied in the range of 106–197 m. 23 tests of agglutinating and calcareous foraminifera were selected from this interval. They belong to 10 genera: *Spiroplectammina*, *Arenogaudryina* (?), *Haplophragmoides*, *Ammomarginulina*, *Cyclammina*, *Marginulina*, *Lenticulina*, *Heterolepa*, *Planorbulina*, *Brizalina*.

Of the 23 tests, 10 have microbial objects on their surface. The following nannofossils have been identified: the remains of lithified bacterial covers, bacterial coccoid colonies, bacterial films, as well as the remains of actinomycete (fungi (?)), and chlorophytes of cyanobacteria (cyanobacteria (?)).

In the **borehole 29**, paleobacterial objects were studied in the range of 225–238.5 m. 27 tests of agglutinating and calcareous foraminifera were selected from this interval. They belong to 20 genera: *Saccammina*, *Psammosphaera*, *Martinotiella*, *Subreophax*, *Spiroplectammina*, *Gaudryina* (?), *Gaudryinopsis*, *Haplophragmoides*, *Ammomarginulina*, *Ammobaculites*, *Cyclammina*, *Lenticulina*, *Nodosaria*, *Heterolepa*, *Robertina*, *Globobulimina*, *Bolivina*, *Brizalina*, *Globigerina*, *Turborotalia*.

Paleobacterial objects and evidence of secondary biogenesis are found on the surface of 10 tests. They are mostly represented by bacterial covers. Coccoid and isometric-rounded bacterial mats and framboidal pyrite aggregates have also been established. Many tests bear the framboids of marcasite and pyrite on the wall surface. In some cases the tests are occupied inside with framboids.

**Description of microbial objects.** Most of the bacterial objects are biogenic sulfides, especially widely developed in the upper part of the sections. These formations are present on all foraminifera taxa, as well as the remnants of the accompanying biota (diatoms, radiolarians, mollusks). Bacterial films and mats are also very often present on the foraminiferal tests of different taxonomic affiliation; these nannofossils are observed throughout the section. Coccoid clusters are found less widely, but rather often; so far we observed these formations to be on the tests of agglutinating foraminifera only. Chlorophytes of cyanobionts are mainly found on the tests of calcareous foraminifera and finely agglutinated tests. Actinomycetes are found on calcareous and agglutinating foraminifera, which mainly belong to infauna.

**Biogenic iron sulfides.** In general, the finds of pyritized microfauna tests are common for the Lower Oligocene of Southern Ukraine, which is confirmed by our research. Using SEM, framboids and aggregates of pyrite and marcasite framboids were found in the foraminiferal agglutinate, and pyrite pseudomorphs were also found in fragments of microfauna skeletons. Near them, on the framboids or on particles of agglutinate, bacterial films were found, which may indicate the involvement of sulfur bacteria in the genesis of the detected iron sulfides. According to [3], the octahedral habit of pyrite crystals (and its combinations)



established by us in framboids can also indicate their biogenic origin. Frequent finds of iron sulfides indicate the decomposition of organic residues at the bottom of the Borysthenian basin without free oxygen [3, 31, 42, 44, 45, etc.]. Below are descriptions of some framboidal forms of iron sulphides that have been found on the foraminiferal tests.

*A pyrite framboids aggregate* was found on the test of an agglutinating foraminifera of the genus *Cyclammina* from the Zubakino Layers of the borehole 16. Pyrite framboids are developed almost throughout the test (Table III, Fig. 2, a), occupying the space between agglutinated quartz grains (Table III, Fig. 2, b, c). Here, their clusters are observed, and sometimes rounded isometric aggregates up to 50  $\mu\text{m}$  in diameter. Framboids are round, have a diameter of 1–8  $\mu\text{m}$ , and are formed by numerous octahedral pyrite crystals. Sometimes the framboids are partially or completely covered with a bacterial film (Table III, Fig. 2, c, d).

An aggregate of marcasite framboids was found in a sample from the Zubakino Layers of the borehole 9. Framboid aggregate fills the inner part of the test of the planktonic *Tenuitella* having a diameter of about 200  $\mu\text{m}$  (Table III, Fig. 1, a, b). The part of the aggregate, visible through the damaged test wall, consists of marcasite framboids with a diameter of 6–12  $\mu\text{m}$ . Framboids consist of radially diverging spear-shaped marcasite crystals (about 3  $\mu\text{m}$  along the long axis). In places, the framboids and their aggregate are covered with bacterial films (Table III, Fig. 1, b).

**Clusters of coccoid forms.** The coccoid round and isometric rounded remnants of paleobacterial colonies, which are among the most frequently observed microbial objects found on the foraminifera shells (Table I, Fig. 3, a, b; Table I, Fig. 1, a, b; 2, a–d) are of great interest. Interestingly, their findings are confined to the tests of agglutinating foraminifera, mainly of the genus *Spiroplectammina*. Test cement is calcareous. It contains numerous imprints of diatoms and sponge spicules [19, 39], which have been a part of agglutinate. The absence of the skeletal substance of these fossils indicates leaching of their silicate skeletons. The remains of bacterial colonies (maximum size of 85–130  $\mu\text{m}$ ) were found on the test surface of the genus *Spiroplectammina* in Zubakino and Rubanovka deposits. Colonies consist of round globular aggregates of about 5  $\mu\text{m}$  in diameter, which can form clusters of one to 100 or more specimens covered with a fossilized microbial film. The form of clusters varies from rounded isometric to linearly elongated formations located along the septal sutures. Obviously, the growth of colonies was confined to the negative morphological elements of the tests. Spherical aggregates have a knobby surface characteristic of microbial objects and, in turn, consist of numerous coccoid forms less than 1  $\mu\text{m}$  in diameter. The morphology and dimensions suggest the bacterial genesis of the established formations. More detailed diagnosis is problematic and requires additional research based on data from genetic paleontology.

It is noteworthy that the described coccoid forms were found on *Spiroplectammina* tests with agglutinate was almost completely represented by opalized material of organisms with a silicate skeleton (diatoms, sponges) and quartz grains. Also, single finds were recorded on the tests of *Reophax* and *Rhabdammina*. No similar objects were found on calcareous tests. Possibly, the confinement of colonies to a silicate substrate indicates a favorable habitat for paleobacteria that are enzymatically involved in the process of intensifying the destruction of silicate minerals (quartz, smectites), which was described in [27]. Unlike chemogenic lepispheres, characterized by unsystematic growth, the detected objects have the shape typical for bacterial colonies, as well as the presence of bacterial biofilms [1, 2, 8, 20, 21, etc.].

**Chlorophytes (Cyanobacteria?).** Chlorophytum remnants are represented by flagellate formations (covers) embedded in the foraminiferal tests (Table I, Fig. 1, a, b) with the help of

numerous filamentous ramifications. Outside the foraminiferal tests, arcuate colonies are observed (Table I, Fig. 1, b) up to 25  $\mu\text{m}$  in length and 2.5–4.0  $\mu\text{m}$  in width. Segments are connected by one or two filaments due to the growth of colonies, which tend to develop in circles. Flagella consist of thin (about 1  $\mu\text{m}$ ) beaded threads (trichomes?) twisted together (from two or more individuals). Each of these filaments with the help of ramifications (0.5–1.0  $\mu\text{m}$  in diameter) is introduced into the foraminiferal test, creating corrosive forms on its surface (tuberosity, mechanical disturbances). The filaments are beaded, have bulges of various sizes (4x2  $\mu\text{m}$ ; 4x1  $\mu\text{m}$ ) and shapes (blown-oval, rounded rhomboid, irregular-cylindrical).

The general structure of fossils introduced into the test is most likely to be attributed to the remnants of drilling chlorophytum, which are in symbiosis with foraminifera. However, it is possible that the detected covers are the remains of cyanobacteria with signs of unbalanced growth of trichomes (“giant” oval and oval-rhomboid swellings on the filaments), which, according to [9], are characteristic of syncyanotic cyanobionts.

*Actinomycetes* (Table I, Fig. 2, a, b). They are mainly represented by bacterial films with thin filamentous formations enclosing terrigenous material and parasitizing on coccoid bacterial colonies (?). Sometimes the films thicken and form outgrowths with well-developed branching filaments. In other cases, the filaments are poorly defined and veiled by film cover. The filaments have a diameter of 0.1–0.4  $\mu\text{m}$ , which is their distinguishing feature from the structurally similar, but thicker mycelia of fungi.

Probably, irregular-rounded coccoid formations connected by thin filaments could also be attributed to actinomycetes. However, it is more likely that only a film cover coating coccoid colonies and connecting them with thin filaments is actinomycete formations.

**Paleoecological features of the Borysthenian Basin at the locations of microbial objects.** Summarizing the results of the conducted bionomic analysis of the microfauna to characterize the environment in which the established and assumed bacterial communities were developed, we note the following details specifying the paleoecology of the Borysthenian basin in the studied points.

1. The established benthic foraminifera associations are generally characteristic of the inner shelf of the marine basin with normal salinity.

2. The uneven vertical distribution of infauna, epifauna, and oxic indicators points out fluctuations in the oxygen regime. In particular, the intervals without foraminifera indicate anoxic conditions at separate intervals.

3. Extremely small amount of planktonic foraminifera in all studied sections, as well as the predominance of agglutinating benthos in the lower part of the Borysthenian Suite of the borehole 29 probably associated with the processes of stagnation, a decrease in pH, and the dissolution of calcareous tests. The reasons for the transition of associations of living foraminifera with the initial dominance of calcareous forms into fossil agglutinated complexes were considered in the works of many authors [e.g., 36, 37, 40]. The influence of the dissolution processes on the preservation of the fauna is confirmed by frequent finds of tests with traces of dissolved skeletal matter or damaged chambers (Table IV, Fig. 1–3).

4. The rare findings of organisms remnants that need in clean water saturated with oxygen (bryozoans, sponges) along with some foraminifera, characteristic of oxygen depleted environments, suggests an episodic occurrence of oxic conditions in some parts of the basin, from which fragments of skeletons could be carried by currents to places of stagnation.

5. The absence of fauna in the tops of the studied sections may indicate anoxia at the end of the Borysthenian Sea existence.

In considering the ecology of the marine environment, it is also necessary to take into account our recent findings of the zeolites of the Heylandite-Clinoptilolite group in the wall of foraminiferal tests from the same localities (in press) and Z. L. Maymin's data about the presence of bentonite clays in the Lower Maikop deposits of the Crimea [14]. Such findings suggest entering acidic volcanic products into the basin, their effect on the water chemistry and, accordingly, on biota and preservation of its remnants.

Considering the above, it is necessary to assume significant differences between the initial composition of the associations of Early Oligocene foraminifera and their composition in oryctocoenoses. The presence of paleobacterial communities' remains and products of their vital activity on the foraminiferal tests indicates their active participation in the taphonomic and diagenetic processes. The latter, in particular, is demonstrated in Table IV, Fig. 1, which shows the surface of the early part of *Caucasina* test with traces of possible dissolution, as well as with remnants of paleobacterial microbial objects. On the Table I, Fig. 3, b, and Table II, Fig. 2, c, coccoid bacterial clusters are shown on *Spiroplectammina* test adjacent to imprints of silica-skeletal biota; possibly, bacterial activity caused the destruction of these skeletons. Images on the Table III, Fig. 1, 2 show the replacement of the tests of planktonic and benthic foraminifera by biogenic sulphides, which leads to the destruction of the shells.

**Conclusions.** Preliminary data from the study of the foraminiferal tests under SEM indicate that the sediments of the Lower Oligocene of Southern Ukraine are sufficiently characterized by various paleontological remnants of bacterial communities and traces of their vital activity. Among microbial objects, bacterial covers, films, coccoid colonies, remnants of actinomycete (fungi?), Cyanobacteria and chlorophytes (?) were found. Some bacterial forms are confined to foraminiferal silicate agglutinate, others are associated with calcareous tests.

Reconstruction of sedimentation conditions according to a joint study of foraminifera and microbial objects allowed to assume the oxygen regime fluctuations in the bottom waters of the South Ukrainian Early Oligocene basin, as well as common unfavorable conditions for the preservation of calcareous skeletons. Findings of paleobacterial communities' remnants and traces of their vital activity on the foraminiferal tests suggest a significant influence of the microbiota on the fullness of the fossil record in the Borysthenian sediments of Southern Ukraine.

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#### EXPLANATION TO THE TABLES

##### Table I

Fig. 1, *a–b*. *Caucasina schischkinskayae* (Samoilova), No.155f/9, borehole 9, 130 m. *1a* – general view; *1b* – fragment of the test surface with cyanobacterial chlorophyte remnants (ch).

Fig. 2, *a–b*. *Gaudryina* (?) sp., No.156f/16, borehole 16, 106 m. *2a* – general view; *2b* – fragment of the test surface with remains of actinomycetes (fungi?) (a), coccoid bacterial objects (b), bacterial films (bf), thin threads (th).

Fig. 3, *a–b*. *Spiroplectammina carinata oligocenica* J. Nikitina, No.141f/16, borehole 16, 140 m. *3a* – general view; *3b* – fragment of the test surface with clusters of coccoid bacterial objects (b), with imprints of diatoms (d) and sponge spicules (s).

The rectangles on the images of tests limit the area with the studied microbial objects.

All samples have been originated from Zubakino Layers of the Lower Oligocene (*Spiroplectammina carinata oligocenica* biozone) of the South-Western Crimea (Alma Depression).

##### Table II

Fig. 1, *a–b*. *Spiroplectammina ex gr. carinata* (d'Orbigny), No.157f/29, borehole 29, 238,5 m. *1a* – general view; *1b* – fragment of the test surface with cluster of coccoid bacterial objects (b).

Fig. 2, *a–d*. *Spiroplectammina carinata* (d'Orbigny), No.158f/29, borehole 29, 237,5 m. *2a* – general view; *2b* – initial part of the test with clusters of coccoid bacterial objects (in rectangles); *2c* – fragment of the test surface with some coccoid bacterial objects (b), imprints of diatoms (d) and sponge spicules (s); *2d* – fragment of initial part of the test with cluster of coccoid bacterial objects (b).

The rectangles on the images of tests limit the area with the studied microbial objects.

All samples have been originated from Borysthenian Suite of the Lower Oligocene (*Lenticulina herrmanni* biozone) of the Northern Black Sea region.

## Table III

Fig. 1, *a–b*. *Tenuitella khadumica* (N. Bykova), No. 159f/9, borehole 9, 87 m. *1a* – general view; *1b* – crystal-jams of marcasite crystals (m) and bacterial films (bf) in the cavity of the last chamber (chamber wall is destroyed).

Fig. 2, *a–d*. *Cyclammina cancellata* Brady, No. 160f/16, borehole 16, 106 m. *2a* – general view; *2b–d* – fragments of the test surface with numerous pyrite framboids (pi), their aggregates (ag) and bacterial films (bf).

The rectangles on the images of tests limit the area with the studied microbial objects.

All samples have been originated from Zubakino Layers of the Lower Oligocene (*Spiroplectammina carinata oligocenica* biozone) of the South-Western Crimea (Alma Depression).

## Table IV

Fig. 1. *Caucasina schischkinskayae* (Samoilova), No. 155f/9, borehole 9, 130 m. Fragment of the early part of the test with paleobacterial objects' remnants (b). Asterisks indicate the most obvious places of the skeletal substance dissolution.

Fig. 2. *Heterolepa* sp., No. 161f/9, borehole 9, 80 m. View from the abdominal side. Asterisks indicate chambers damaged due to dissolution.

Fig. 3. *Neogyroidina memoranda* Subbotina, No. 162f/9, borehole 9, 80 m. View from the dorsal side. Asterisks indicate the sites of dissolution of the skeletal substance.

All samples have been originated from Zubakino Layers of the Lower Oligocene (*Spiroplectammina carinata oligocenica* biozone) of the South-Western Crimea (Alma Depression).

**ПЕРШЕ ПОВІДОМЛЕННЯ ПРО ПАЛЕОБАКТЕРІАЛЬНІ ОБ'ЄКТИ НА  
СТІНКАХ ЧЕРЕПАШОК ФОРАМІНІФЕР ІЗ НИЖНЬОГО ОЛІГОЦЕНУ  
ПІВДЕННОЇ УКРАЇНИ ТА ЇХ ЗНАЧЕННЯ ДЛЯ РЕКОНСТРУКЦІЙ  
УМОВ СЕДИМЕНТОГЕНЕЗУ**

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Наведено перші відомості про палеобактеріальні об'єкти, знайдені на стінках черепашок форамініфер з борисфенського (планорбеллового) регіоярису нижнього олігоцену Південної України. Вивчено 145 агглютинуючих та секретійних черепашок, відібраних з нижньоолігоценових (борисфенських) відкладів, розкритих свердловинами у Південно-Західному Криму і Північному Причорномор'ї. На стінках 50 черепашок простежено мікроскопічні об'єкти, які за багатьма ознаками віднесені до палеобактеріальних утворень. Більшість бактеріальних об'єктів та слідів життєдіяльності бак-

теріальних спільнот представлено біогенними сульфідами, а також бактеріальними плівками і матами, які трапляються на черепашках форамініфер різної таксономічної належності. Досить часто простежуються сіліцитові коккоїдні скупчення, що присутні на черепашках агглютинуючих форамініфер. Залишки хлорофітов-бурильників (ціано-біонти?) трапляються виключно на черепашках секретійних та дрібноагглютинованих черепашок.

Аналіз співвідношень інфауни та епіфауни у форамініферових асоціаціях дав змогу припустити коливання газового режиму в ранньоолігоценовому (борисфенському) басейні півдня України від низькоокисних до суб- і дізоксичних умов. Рідкісні епізоди посилення оксигенації сприяли розвитку епіфауни з великою черепашкою (представники родів *Neogyroidina*, *Baggina*, *Heterolepa*, *Cibicidoides*), а також появи планктонних форамініфер. Наприкінці існування борисфенського басейну, ймовірно, визначено аноксичні умови.

Припущено значну відмінність між початковим складом біоценозів форамініфер і складом ориктоценозів. Часті знахідки залишків палеобактеріальних спільнот та слідів їх життєдіяльності на черепашках форамініфер дали змогу припустити начний вплив мікробіоти на повноту палеонтологічного часопису в борисфенських відкладах півдня України. Будучи залученими у процеси діагенезу, дані спільноти могли бути критично важливими для збереження ориктоценозів.

*Ключові слова:* мікробіоліти, форамініфери, борисфенський регіоярус, майкопська серія, нижній олігоцен, Південна Україна.

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