The stratigraphy of the Oligocene-lower Miocene deposits of southern Ukraine

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Received: 31.05.2019 • Accepted/Published Online: 07.10.2019 • Final Version: 02.01.2020

Abstract: Lithostratigraphic units (formation, strata, and beds) and regional stages of the Oligocene-lower Miocene succession of southern Ukraine are described based on the results of comprehensive lithological and paleontological data analysis. The historical perspective on the stratigraphical investigations of the Maikop Group in the Crimean and Kerch Peninsulas and their equivalents in the broader Peri-Black Sea Region were also integrated in this overview. Moreover, a correlation was established between the locally defined regional stages and specific stratigraphic horizons of southern Ukraine, the global Oligocene and Miocene stages (defined by the International Stratigraphic Chart), and the stages of the Eastern Paratethys. The Planorbellian regional stage (early Rupelian) includes the Borysfen, Planorbellia, Indol, and Eastern-Kerch Formations and Diurmen Beds. The Molochian regional stage (late Rupelian) includes the Molocha and Azamat Formations and the Kop-Takil Strata. The Kerleutian regional stage (latest Rupelian-Chattian) includes the Kerleut, Sirohozy, Askania, and Hornostaivka Formations and the Chorelek and Clay Stratum. The Bathysiphonian regional horizon (Aquitanian–Burdigalian) includes the Arabatska, Alahol, Chornobaivka, and Mayachka Formations and the Karha Beds. This horizon is also considered as age-equivalent to the Caucasian, Sakaraulian, and Kotsakurian regional stages of the lower Miocene in the Eastern Paratethys. The Oligocene-early Miocene age of all these lithostratigraphic units belonging to the megaregional Maikop Group is substantiated by paleontological data. This work represents the latest stratigraphic model of Oligocene-lower Miocene deposits in southern Ukraine as a part of the Eastern Paratethys Basin.

Key words: Stratigraphy, lithostratigraphic units, Oligocene, lower Miocene, Maikop Group, southern Ukraine

1. Introduction

The Oligocene-lower Miocene deposits are widespread on the mainland of southern Ukraine and represented by the Maikop Group succession on the Crimean and Kerch Peninsulas and its age-equivalent rocks in the northern Peri-Black Sea Region. These sediments are mainly sandy-clays rocks with negligible carbonate content, with a typical thickness ranging from a few tens of meters to 3100 m. Extensive work on these units began in the 1920s and 1940s in the Crimean and Kerch Peninsulas and in the 1950s and 1960s in the broader northern Peri-Black Sea Region. These investigations partly aimed at understanding of oil-gas potential of these deposits, but the potential for prospecting and exploration for some other minerals (e.g., manganese) was also considered. As a result, the Ukrainian Geological Survey has accumulated extensive material on the lithofacies and paleontological features of the Oligocene-lower Miocene units of southern Ukraine. Unfortunately, no single full-scale survey of these deposits has been carried out since the 1980s. Despite the thorough and detailed studies of the Maikop Group, the use of lithological criteria for stratigraphic subdivision of these deposits, especially in geological mapping, was severely hindered by the lithofacial monotony of these sediments, especially in the basinal segments. Stratigraphic subdivision using biostratigraphy was, and still is, limited by the scarcity of both micro- and macrofossils. Moreover, many subsurface sections of the Maikop Group in the region remain insufficiently studied in terms of detailed litho- and biostratigraphic work. All these challenges posed, and continue to pose, difficulties in identifying and defining proper lithostratigraphic units (i.e. formations, members, and strata) in the Oligocene-lower Miocene succession of southern Ukraine as reflected in the numerous and variable stratigraphic schemes published during the last 50 years (e.g., Muratov, 1969; Teslenko, 1984; Makarenko et al., 1987; UMSK, 1993).

The creation of a modern stratigraphic scheme of the Maikop Group in the broader region of southern Ukraine requires the revision of all the available lithological and paleontological features of the Oligocene-lower Miocene deposits in the area. Moreover, the stages defined in

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southern Ukraine need to be correlated with the regional stages of the Eastern Paratethys, including the nearby Ciscaucasian region.

2. Geological setting
In a geographic sense, the study area is located on the mainland of southern Ukraine within the northern Peri-Black Sea Region and the Crimean and Kerch Peninsulas (Figure 1). In geologic terms, it is situated in the southern part of the East-European Platform, the Scythian Plate, the Southern Crimean Orogen, and the western part of the Indol-Kuban Trough. During the Maikop epoch (Oligocene to early Miocene), sedimentation occurred in a shallow-water (northern Peri-Black Sea Region) and a deeper-water (Crimean and Kerch Peninsulas) segment of the broad Scythian Sea, located on the northern shelf of the Eastern Paratethys (e.g., Popov et al., 2009). To the north of the Parpach Ridge and the east of Kerch Peninsula deep Maikop depocenters developed with sediment thicknesses of more than 3000 m.

There are two main tectonic reasons for these observed dramatic Maikop thickness changes across our study area. On the one hand, the Maikop succession appears to be a passive infill in the subbasins formed during the Eocene inversion along the entire northern perimeter of the Black Sea (e.g., Khriachtchevskaia et al., 2010). On the other hand, especially in the SE part of our study area towards the Indolo-Kuban Basin, active tectonic subsidence occurred during the deposition of the Maikop sediments in the foredeep of the already active Great Caucasus thrust-fold belt (e.g., Vincent et al., 2007).

3. Data
This overview is largely based on the results obtained by the authors in the framework of the scientific project “Creation and modernization of the stratigraphic schemes of the Phanerozoic deposits of Ukraine” carried out by the Institute of Geological Sciences of the National Academy of Sciences of Ukraine between 2008 and 2012. During this project, the authors developed and refined the stratigraphic scheme of Paleogene and Neogene deposits of the broader southern Ukraine, including those of the Crimean and Kerch Peninsulas, the northern Peri-Black Sea Region, and adjacent parts of the Ukrainian Shield and Azov Massif (Figure 1). Geological data obtained by the authors in the process of scientific support of other projects, such as the geological mapping of the territory of Ukraine, were also used. These included the results of biostratigraphic investigation and the structure-facial zonation of Paleogene and Neogene deposits of the territory of sheets L-36-XI, L-36-XII, L-37-VIII (in the northern Peri-Black Sea Region), L-36-XXVIII (the Alma Depression on the Crimean Peninsula), L-36-XXX, L-36-XXIV, L-37-XIX, and L-37-XXV (the Kerch Peninsula) (e.g., Vernyhorova, 2014, 2015, 2016; Zernyetskiy et al., 2015; Ryabokon, 2016; Vernyhorova and Ryabokon, 2018).

This study is the result of comprehensive data analysis and integration of litho- and biostratigraphic data of the Maikop deposits in the Crimean and Kerch Peninsulas and their correlative units in the broader southern Ukraine collected for more than a century. In our studies, we followed the stratigraphic classification and nomenclature of the Stratigraphic Code of Ukraine (Gozhyk, 2012).

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Figure 1. Location map of the studied areas in broader southern Ukraine. Note location of stratigraphic correlation transect shown in Figure 2.
4. Results and discussion

In the following subsections we briefly summarize the main characteristics of the Maikop Group in our study area. For a more in-depth and historical perspective on the evolution of stratigraphic schemes in southern Ukraine the reader is referred to the work of Vernyhorova and Ryabokon (2018).

4.1. Lithostratigraphic units of the Oligocene-lower Miocene of southern Ukraine

The Maikop Group was described for the first time by K.I. Bohdanovich, I.M. Hubkin, K.A. Prokopov, and S.I. Charnotskiy (quoted by Borissjak, 1937) as a “Maikop oil-bearing series”, which is “conformably covered by the Second Mediterranean stage and underlain by Foraminifera beds” (translation from Russian; Gubkin, 1912, p. 1). It is named after the city of Maikop in the Russian Caucasus (Likharev, 1956; Vereschagin, 1982). In the first stratigraphic dictionary of the former Soviet Union, the Maikop Group was uniquely defined as “clay and sandy-clay body of rocks, lying between the Foraminifera beds (Eocene) and the Tarkhan horizon of Andrusov (beds with Pecten denudatus)” (see Borissjak, 1937, p. 124).

The Maikop Group in the general southern region of the former Soviet Union is classically divided into three parts, namely lower, middle, and upper, but “in different areas in different ways” (Vereschagin, 1982, p. 272). In the Crimea-Caucasus region (as part of the Eastern Paratethys), the Maikop Group traditionally has different stratigraphic schemes in many areas, with subdivision to various formations (Vereschagin, 1982, p. 272).

The Maikop Group in southern Ukraine has various marine facies sediments, mainly sandy-argillaceous and typically noncalcareous deposits, which were deposited between the top Eocene and the Tarkhanian regional stage of the middle Miocene. The Maikop Group in southern Ukraine is also traditionally subdivided into Lower, Middle, and Upper subgroups (Teslenko, 1984). Chronostratigraphically, the Lower Maikop subgroup corresponds to the Planorbellian and Molochnian regional stages, the Middle Maikop subgroup corresponds to the Kerleutian regional stage of southern Ukraine, and the Upper Maikop subgroup corresponds to the Caucasian, Sakaraulian, and Kotsakhurian regional stages of the Eastern Paratethys. The latter subgroup is also described as the Bathysiphonian regional horizon (Figure 2). It should be emphasized that subgroups of the Maikop Group in southern Ukraine differ in their stratigraphic extent from the lower, middle, and upper Maikop of northern Ciscaucasia and are not equivalent in age (Figure 3).

In the Azov-Black Sea region, in the absence of palaeontological information, the Maikop Group is divided into three subgroups based on the presence or absence of layers of sandstones and siltstones, their relative thickness, frequency, and nature of interbedding with clay rocks penetrating into deep boreholes (e.g., Gozhyk et al., 2006a). However, the stratigraphic correlation of these subgroups to the regional stages of the Oligocene-lower Miocene in southern Ukraine or to the stages of the International Stratigraphic Chart (ISC) remains conditional.

The thickness of the Maikop Group in southern Ukraine reaches 3100 m. Generally, the Maikop Group transgressively overlies the underlying Eocene deposits and it is covered by Neogene and sometimes Quaternary sediments.

4.1.1. Oligocene, Rupelian Stage, Planorbellian regional stage of southern Ukraine

4.1.1.1. Planorbella Formation

The name of this formation comes from the gastropod genus Planorbella frequently found in it (Teslenko, 1984). V.V. Menner and Z.L. Maimin (Maimin, 1951) distinguished the deposits with Planorbella as the Indol (Planorbella) horizon in the lower part of the Maikop Formation of the Crimea. D.Ye. Makarenko (Syabryai, 1963) described beds with Planorbella of the Crimea as a formation. The Planorbella Formation is a type formation of the Planorbella stage and it is widespread in the Crimean Plain and the general northwestern shelf of the Black Sea. Type section: Well 246-k (590–634 m), drilled on the Artemovskoe (Karlovskoe) uplift at the Tarkhankut Peninsula of the Crimea (Pechenkina, 1971; Makarenko et al., 1987; Figure 4). Reference section: Well 2 (59.5–192 m), drilled near Kocherhino village of the Bakhchisaray district, Crimea (Figures 4 and 5).

The Planorbella Formation is composed of clay rocks. It is divided into two members, mainly based on their respective foraminifera assemblages. The Lower Planorbella Member comprises gray, dark-gray, sometimes brownish-gray and greenish-gray clays with thin-layered, irregularly calcareous and noncalcareous intervals. The Lower Member has a thickness of 80–100 m, sometimes up to 150 m. On the NE Crimean Plain the Lower Member consists of clayey sandy aleurolite deposits, with thickness of up to 20–40 m. In SW Crimea, in the Crimean foothills, the Lower Planorbella Member consists of alternating clays (thickness of 0.5–1 m) and aleurolites (thickness 0.3–0.4 m), characteristic for the upper part of the Kzylydzhar strata (Zernyetskiy et al., 2015). The Upper Planorbella Member consists of gray, dark-gray, and brownish-gray laminated clays with siderite intercalations. The thickness of this member varies from 100–150 m to 230–250 m. In SW Crimea, in the Crimean foothills, the Upper Planorbella Member is known as the Zubakino beds. In that area the beds comprise dark-gray, greenish-gray, brownish-gray clays, noncalcareous, silty, sometimes with interbeds of glauconitic sand and gravel (Syabryai, 1963; Nemkov et Shutskaya, 1971). The average thickness of the
Zubakino beds is 10–15 m. The Planorbella Formation conformably and transgressively overlies the Eocene Alma Formation (Bogayets et al., 1972), but with some erosional stratigraphic gaps on the basin margins. In turn, the Planorbella Formation is conformably overlain by the Azamat Formation of the Molochnian regional stage (Figure 2).

The typical biostratigraphic spectrum of the Planorbella Formation (Muratov, 1969; Bogayets et al., 1972; Nosovskiy et al., 1984; Figure 6) includes a mollusk assemblage with _Nucula compta_ Goldf., _Astarte kickxi_ Nyst., _Pleurotoma selysii_ Koen., _Thiasira unicarinata_ Nyst., _Cystodaria angusta_ Nyst & West., and others, characteristic for the Rupelian of Western Europe, the Khadumian horizon of northern Ciscaucasia, and the Borysfen Formation of the northern Peri-Black Sea Region (Popov et al., 1993, 2009), as well as radiolarian _Cenosphaera almaensis_ Moksjak. Accumulations of pteropods (better known in the literature as _Planorbella_), fish scales, teeth and bones, sponge spicules, and fish otoliths are also noted for the formation.

The biostratigraphy of the Lower Planorbella Member (e.g., Shvemberger, 1967; Muratov, 1969; Pechenkina, 1971; Bogayets et al., 1972; Nosovskiy et al., 1984; Kraeva and Lulyeva, 1985; Ivanova, 2003; Bogdanovich, 2005; Anistratenko et al., 2012) includes benthic foraminifera assemblages of zone “_Lenticulina_” _herrmanni_, beds with _Bolivina mississippiensis_ and beds with _Ammomarginulina_, _Haplophragmoides deformabilis_; a plankton foraminifera association with dominating _Globigerina officinalis_ (Subb.) among _Tenuitella Liverovskayae_ (N.Byk.), _T. khadumica_ (N.Byk.), _T. denseconnexa_ (Subb.), _Turborotalia ampliapertura_ (Bolli), _Globigerina praebulloides_ Blow, _Pseudoestigerina micra_ (Cole), and _Dipsidripella ex gr. danvillensis_ (Howe et Wallace); the NP 21 zone; and a spore and pollen assemblage with dominating pollen of _Pinaceae_ ( _Picea_ sp., _Tsuga_ sp.) and _Taxodiaceae_ ( _Taxodium distichiformis_, _Sequoia semperviriflora_, _Glyptostrobus_ sp.).
The biostratigraphy of the Upper Planorbella Member (e.g., Shvemberger, 1967; Muratov, 1969; Pechenkina, 1971; Bogayets et al., 1972; Kraeva and, Lulyeva, 1976, 1985; Nosovskiy et al., 1984; Ivanova, 2003; Bogdanovich, 2005; Anistratenko et al., 2012) includes the Rupelian benthic foraminifera provincial zone *Spiroplectammina oligocenica*; the Oligocene association of plankton foraminifera *Globigerina ouachitaensis* (Howe & Wall.), *G. officinalis* Subb., *G. praebulloides leroy* Blow & Banner, *G. ciperoensis* Bolli, *Turborotalia ampliapertura* (Bolli), *Tenuitella angustiumbilicata* (Bolli), *Chiloguembelina gracillima* (Andreae), and others; the NP 22 zone; and a spore and pollen assemblage with reducing pollen of *Taxodiaceae* and increasing numbers and diversity of *Pinus, Quercus, Juglans*, and *Carya*.

The Rupelian age of the Planorbella Formation was established based on mollusks, foraminifera, and calcareous nannofossils. This formation is correlated with the Borysfen Formation of the northern Peri-Black Sea Region, the Indol Formation on the east of the Crimean Plain, and the Eastern-Kerch Formation of the Kerch Peninsula (Figure 2).

3.1.1.2. Borysfen Formation

The formation was identified first by M.F. Nosovskiy (Nosovskiy and Savenko, 1963). The name is taken after Borysfen, the ancient name of the River Dnieper (Dnipro).
The Borysfen Formation is widespread in the northern Peri-Black Sea Region and in the adjacent part of the Ukrainian Shield and Near-Azov Massif. Type section: Well-1 Stepnoe (331–439 m), drilled near the Nyzhni Sirohozy locality of the Kherson region (Vereschagin, 1982; Ryabokon, 2016; Figure 7). Reference section: Well 6-k (271.5–380 m) drilled near the Nyzhni Sirohozy locality of the Kherson region (Veselov et al., 1968; Ryabokon, 2016; Figure 8).

The Borysfen Formation comprises greenish-gray, dark-gray (with a greenish tint due to glauconite content) silty clayey rocks (Figures 9 and 10). The thickness of the formation is up to 270 m, but decreasing to the north to less than 70 m. In the south of the Ukrainian Shield, within the Nikopol Manganese Ore basin, the Borysfen Formation consists of three beds, namely an under-ore bed, manganese ore bed, and supra-ore bed. Here the thickness of the formation is about 15–20 m or more. In the northern Peri-Black Sea Region the Borysfen Formation is divided into two members. The Lower Borysfen Member consists of greenish-gray, gray silty sandy rocks with clay interbeds. The thickness of the Lower Member is up to 50–60 m. In the west of the region the Lower Member is composed of fine-grained sands and sandstones, with a thickness ranging from 30–40 m to 90 m. The Lower Member in the south of the northern Peri-Black Sea Region comprises dark-gray, greenish-gray clays, noncalcareous and sometimes silty, which are similar to the clays of the Planorbella Formation of the Crimean Plain. Here the thickness of the Lower Member is up to 120 m. The Upper Borysfen Member is
composed of greenish-gray and dark-gray clays and in the upper part of the section sandy and silty clays. In the south the thickness of the Upper Member is up to 200 m. The Borysfen Formation conformably overlies the Eocene Alma, Barmashovo, and Shabo Formations in the northern Peri-Black Sea Region. However, the formation has a disconformity with the top of the middle and upper Eocene successions on the basin margins. The formation is overlain conformably by the Molochna Formation (Figure 2).

The biostratigraphy of the Borysfen Formation (see references in Ryabokon, 2016; Figure 11) is characterized by benthic foraminifera of the Rupelian provincial zone Spiroplectammina oligocenica of the Eastern Paratethys; Rupelian association of plankton foraminifera Globigerina officinalis Subb., G. ouachitensis ouachitensis (Howe & Wall.), G. ouachitensis gnaucki (Blow & Bann.), G. cipepoensis Bolli, T. angustiumbilicata (Bolli), and others; dinoflagellate cysts associations of Rupelian zones Phthanоperidinium amoenum/Wetzeliella symmetrca and Wetzeliella gochtii; the NP 22 zone; Rupelian assemblage of mollusks with Nucula (Lamellinucula) compta Goldf., Pterolucina batalnaschhina (Korob.), Scalaricardita tuberculata (Munst.); lower Oligocene ostracods association Disopontocypris oligocaenica (Zal.), Cuneocythere marginata (Bosq.), Cytherella beyrichi (Reuss), Lineoypiyris majopiensis Scher.; diatoms of Oligocene zone Pyxilla reticulata; and two spore and pollen assemblages, namely a lower complex with Taxodium distichiformis and upper one with Tuxodium distichiformis, Carya ovataformis, and Quercus membranda.

The Rupelian age of the Borysfen Formation was established based on mollusks, the zonal association of plankton and benthic foraminifera, calcareous nannofossils, dinoflagellate cysts, ostracods, and spore and pollen assemblages (Figures 2 and 8). The formation corresponds to the Planorbellian stage of southern Ukraine (Figure 2).

4.1.1.3. Indol Formation

The name is taken from the Mokryi Indol River in the Crimean Peninsula (Maimin, 1951). Menner et al. (1947) distinguished these deposits as clays with casts of Planorbella sp. in the Mokryi Indol River section. Based on
the study of the mollusk assemblage of these clays, Maimin and Korobkov (1946) concluded that these deposits are analogous to the Khadum beds of the Ciscaucasia and the Kharkov stage of the Ukraine. The Indol Formation is widespread on the eastern Crimean Plain and adjacent part of the Crimean foothills. Type section: outcrop on the Mokryi Indol River (Maimin, 1951; Syabryai, 1963).

The Indol Formation comprises gray, dark-gray, sometimes brown sandy clays, with thin interbeds of sands, aleurolites, and siderites. The formation thickness varies from 80–100 m to 350 m. The Indol Formation conformably overlies the upper Eocene Alma Formation but it has an erosional disconformity with the underlying middle Eocene or upper Paleocene units on relatively uplifted areas in the basin. The upper boundary of the formation is marked by the appearance of calcareous clays with ostracods of the Azamat Formation.

The biostratigraphy of the Indol Formation (Figure 6) includes the Rupelian mollusk assemblage of

| Period       | Epoch     | Age Stage | Regional Stratigraphic Units of Southern Ukraine | Characteristic Paleontological Assemblages | Crimea Peninsula |
|--------------|-----------|-----------|-------------------------------------------------|------------------------------------------|------------------|
| Neogene      | Miocene   | Burdigalian | Sakartvelian | Kafkasbian | ASSEMBLAGE WITH CACASSINETTA ELONGATA |
| Paleogene    | Oligocene | Aquitanian | Caucasian | Ressophanian | BEDS WITH GL. OCENICA, GL. OCACHIT-DENOSIS |
|              |           | Chattian  | Karlochian | Lower | BEDS WITH GL. OCENICA, GL. OCACHIT-DENOSIS |
|              |           |          |          | Upper | GL. OCENICA, GL. CIPEROENISS |
|              |           |          |          | Lower | WETZELIELLA GOCHTI |
|              |           |          |          | Upper | BP 22 |
|              |           |          |          | Lower | PHANTOBRIDINUM AMOEUM/ WETZELIELLA SYMMETRICA |
|              |           |           |          |       | CRYPTOCHIARE MARGINATA |
|              |           |           |          |       | ASTERITAE KERNEL, UHDELLIA CHIROMICA, UHDELLIA SULIFERA |

Nuculana perovalis (Koen.), Bathirca saxonica Koen., Corbulina conglobata Koen., Dacridium pygmeum Phill., Abra bosqueti Semp., Pleurotoma odontella Edw., and Pl. laticlavia Beyrich. (Maimin and Korobkov, 1946; Maimin, 1951); Oligocene plankton foraminifera Globigerina officinalis Subb., G. praebulloides Blow, G. praemica Bolli, Tenuitella brevispira (Subb.), and T. munda (Jenkins), T. angustiambilicata (Bolli) and benthic foraminifera Haplophragmoides rotundidorsatus (Hantik.), Cyclammina constrictimargo (R.E. & K.C. Stewart), Spiroplectammina oligocenica J.Nikitina, Causasina schischkinskayae (Samoil.), Uvigerinella californica Cushm., and others (unpublished data, L.M. Holubnichaia and L.G. Mintuzova); also known are radiolarians, fish remains, and pteropods.

A Rupelian age was assigned to the Indol Formation based on its mollusk and foraminifera content (Figures 2, 6, 8, and 12). The formation corresponds to the Planorbellian stage of southern Ukraine (Figure 2).
4.1.1.4. Eastern-Kerch Formation

The name is taken after the area of distribution in the eastern Kerch Peninsula (Vernyhorova and Ryabokon, 2018). The formation is composed of the Planorbillian deep-water deposits of the Kerch Peninsula and it is widespread not only onshore but locally also on the nearby Kerch Shelf (Figure 12). Type section: Well Kolodiazna-1 (2920–3373 m), drilled near the Marfovka locality of the

![Lithological Characteristic Fossils](image-url)
Lenino district, Kerch Peninsula. Reference sections: Well Korenkivska-1 (3904–4853 m), drilled on the Cape Kop-Talile and Well Batalna-1 (2600–3180 m), drilled to the NE of the Primorskoe village on the Kerch Peninsula (Vernyhorova and Ryabokon, 2018; Figure 12).

The formation comprises dark-gray, black, brownish-gray argillites, argillite-like clays, noncalcareous, irregularly silty, with rare very thin interbeds of light-gray aleurolites, with thin interbeds of siderites. The Eastern-Kerch Formation is subdivided into two members. The Lower Member is represented by the irregular alternation of argillite-like clays, thin layers of aleurolite and quartzy, glauconite-quartz sandstones. The Upper Member is composed of dark-gray and black argillites, argillite-like clays, with rare, very thin interbeds of light-gray aleurolites. The Eastern-Kerch Formation has a thickness of up to 700–915 m but to the west it decreases to 350–450 m. The Eastern-Kerch Formation has an overall transgressive character, with erosion at its base on the basin perimeter with respect to the underlying Eocene sediments. The formation has a conformable, gradual transition to the
overlying Kop-Takil Strata and the Azamat Formation (Figure 2).

The biostratigraphy of the Eastern-Kerch Formation (see references in Vernyhorova and Ryabokon, 2018; Figure 13) includes an Oligocene plankton foraminifera assemblage with *Globigerina officinalis*; benthic foraminifera association with *Caucasina schischkinskayae* (Sam.) and *Bolivina mississippiensis* Cushm.; Paleogene dinoflagellate cysts *Deflandrea phosphoritica* Eis. and *Wetzeliella articulata* Wetz., identified in the Upper Member on the Near-Kerch shelf of the Black sea; and two Early Oligocene spore and pollen assemblages, namely a lower one with Taxodiaceae – Fagaceae – Palmae and upper one with Pinaceae – Betulaceae – Juglandaceae.

From the Upper Member of the Eastern-Kerch Formation only rare plankton foraminifera *Turborotalia permicra* (Blow & Banner) and *Globigerina ex gr. trefa* (N.Byk.) (? *Tenuitella munda* (Jenkins)) are known.

The Rupelian age of the Eastern-Kerch Formation is proven by foraminifera (Figures 2 and 13). The formation corresponds to the Planorbellian stage of southern Ukraine.

4.1.1.5. Diurmen Beds

The name is taken from Diurmen Mountain on the Kerch Peninsula and it was V.V. Menner (Maimin, 1951) who first described these deposits as the Diurmen Beds as part of the Khadumian horizon of the Maikop Formation in the SW Kerch Peninsula. The Diurmen Beds can be found in isolated sections on the anticlinal limbs in the central part of the Kerch Peninsula (Figure 12). Type section: outcrop of the Cape Karanhat on the south of Kerch Peninsula (Maimin, 1951).

The Diurmen Beds are composed of alternation of gray, brownish-gray silty clays, sandstones, and aleurolites. The thickness of the clay beds is from 2 m to 12–25 m. The sandstones are quartz-rich, feldspathic, rarely with...
glauconite, fine-grained, inequigranular, occasionally conglomeratic, obliquely laminated, with ripple marks and plant detritus. The thicknesses of the sandstone layers and aleurolites range from 0.3 m to 2–3 m and more. For the Diurmen Beds on the peninsula, alternating clays and sandstones, with a thickness of 3–10 m to 20–30 m, are very characteristic. The formation thickness varies from 60–80 m to 110–240 m. The Diurmen Beds Formation has an erosional contact with the underlying Eocene and older sediments. Upward in the section and along the strike, these beds are gradually replaced by the clay rocks of the East Kerch Formation.

Fossils in the Diurmen Beds are rare (see references in Vernyhorova and Ryabokon, 2018). Based on the studies of V.F. Kozyreva, E.Ya. Kraeva, and L.M. Holubnichaia, the Diurmen Beds are characterized by the benthic foraminifera assemblage of Hyperammina sp., Dorothia sp., Glomospira corona Cushm. & Jarv., Siphonodosaria adolphina (Orb.), Dentalina multilineata Born., Nodosaria calomorpha Reuss, Cibicidina amphisyliensis (Andr.), Caucasina sp., Uvigerinella californica parva Cushm. & Kleinp., Caucasina schischkinkayae (Sam.), Bolivina compta carinata Chal., B. bottgeri maraginica Chal., rare planktonic foraminifera Globigerina officinalis Subb., Turborotalia permicra (Blow & Banner), and Tenuitella angustiumbilicata (Bolli); and calcareous nannofossils of zone NP 21 (Figures 2 and 13).

The early Rupelian age of the Diurmen Beds is constrained by foraminifera and calcareous nannofossil data. The beds correspond to the lower part of the Planorbellan of southern Ukraine (Figure 2).

4.1.2. Oligocene, Rupelian Stage. Molochian regional stage of southern Ukraine

4.1.2.1. Molochna Formation

The name is taken from the Molochna River in the east of the northern Peri-Black Sea Region (Zosimovich et

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**Figure 11.** Biostratigraphic subdivision of the Oligocene-lower Miocene deposits of the northern Peri-Black Sea Region in southern Ukraine.
Figure 12. Geological profile from the Chonhar Peninsula to the Kerch Peninsula.
al., 1963). M.M. Kliushnikov (1952) was the first who described the member of calcareous clays with ostracods in the Molochna River basin. M.F. Nosovskiy (Zosimovich et al., 1963) distinguished these deposits as the Molochna Beds. The Molochna Formation is widespread in the northern Peri-Black Sea Region and adjacent part of the Near-Azov Massif and is the type formation of the Molochanian regional stage of southern Ukraine (Figure 7). Type section: Well-1 Stepnoe (315.5–331.3 m) drilled near the Nyzhni Sirohozy locality of Kherson region (Vereschagin, 1982; Ryabokon, 2016). Reference section: Well 6-k (271.25–256.4 m) drilled at the Nyzhni Sirohozy locality of Kherson region (Veselov et al., 1968; Figure 8).

The Molochna Formation comprises light-gray and greenish-gray silty clays with ostracods. To the south its thickness increases from 3–10 m to 40 m (Figures 10 and 14). The Molochna Formation conformably overlies the Borysfen Formation and it is overlain by the Sirohozy Formation (Figure 2).

The biostratigraphy of the Molochna Formation (see references in Ryabokon, 2016) (Figure 11) includes the Oligocene assemblage of brackish mollusks *Ergenika cimlanica* (Zhizh.) Popov, *Janschinella garetzkii* Merkl., and *J. vinogrodskii* Merkl.; ostracod association of the Rupelian interregional zone *Disopontocypris oligocaenica* of the Eastern Paratethys; endemic calcareous nannofossils association with mass occurrence of *Reticulofenestra ornata*, *Transversopontis fibula*, nonnumerous *Braarudosphaera bigelovii*, *Orthozugus aureus*, and very rare *Sphenolithus distentus*, which corresponds to the NP 23 nanozone; dinoflagellate cysts association of beds with *Hystrichokolpoma* spp. considered as part of the Rupelian zone *Wetzeliella gochtii*; and spore and pollen assemblage of beds with *Pinus cristata*, *Quercus porrectus*, and *Juglans compacta*.

The biostratigraphic subdivision of the Oligocene-lower Miocene deposits of the Kerch Peninsula.
4.1.2.2. Azamat Formation

The name is taken from the Azamat ravine near the village of Azamat (now Malinovka village) in the Belohorsk district, Crimea. Maimin (1951) was the first who distinguished the Azamat (Ostracoda) horizon in the lower part of the Maikop Formation of the Crimea. M.F. Nosovskiy (Grossgeym and Korobkov, 1975) proposed to merge the Molochna horizon deposits in the Crimea with the Azamat Formation. The Azamat Formation is widespread on the Crimean Peninsula, the NW shelf of the Black Sea, and the central part of the Kerch Peninsula (Figures 4 and 12). Type section: outcrop of the Azamat ravine on the Kuchuk-Karasu River near Malynivka village of Belohorsk district, Crimea (Maimin, 1951; Syabryai, 1963). Reference section: outcrop of Cape Karanhat on the south of Kerch Peninsula (Maimin, 1951; Syabryai, 1963).

The Azamat Formation comprises light-gray, greenish-gray, yellowish-brown calcareous clays, aleurolites and argillitic clays with thin siderite interbeds. There are interlayers of clays with ostracods. To the east of the Kerch Peninsula, clays become darker gray, weakly calcareous in character with thin interbeds of sandstones and aleurolites. In the NE part of the Crimean Plain the clays are sandier. The thickness of the Azamat Formation varies from 40–50 m to 80–100 m in the Crimean Plain, increasing in the basinal areas to 200–300 m. In the Kerch Peninsula it is up to 380–410 m. The lower boundary of the Azamat Formation with the Planorrella, Indol, and Eastern-Kerch Formations is transitional and it is marked by increasing carbonate content and by the appearance of ostracods. The formation is conformably overlain by the noncalcareous clays of the Kerleut Formation (Figure 2).

The biostratigraphy of the Azamat Formation (see references in Vernyhorova and Ryabokon, 2018; Figures 6 and 13) includes the ostracod assemblage of the Rupelian interregional zone Disopontocypris oligocaenica; calcareous nannofossils association of beds with Reticulofenestra ornata, corresponding to the NP 23 zone; mollusk Ergenica cimlanica (Zhizh.), Hydrobia sp., Cardium sp., and Corbula sp.; and Tsylman spore and pollen assemblage.

The Rupelian age of the Azamat Formation is proven by the ostracod assemblage of zone Disopontocypris oligocaenica and the NP 23 zone (Figures 2, 6, and 13). The formation corresponds to the Molochnian stage of southern Ukraine (Figure 8).

4.1.2.3. Kop-Takil Strata

The name is taken after Cape Kop-Takil located on the SE Kerch Peninsula (Vernyhorova and Ryabokon, 2018). The formation is composed of Molochnian deep-water deposits located on the eastern part of the Kerch Peninsula and locally on the peri-Kerch shelf of the Black Sea. Type section: Well Korenkivska-1 (3487–3904 m) drilled on the Cape Kop-Takil (Vernyhorova and Ryabokon, 2018; Figure 12).

The Kop-Takil Strata comprises gray, dark-gray, black argillites, argillitic clays, noncalcareous, sometimes with slightly calcareous intervals, with thin to very thin aleurolite interbeds. The lower and upper boundaries of the Kop-Takil Strata are conjectural (Figure 2). The thickness of the Kop-Takil Strata is up to 400–540 m or more.

Paleontological data on the Kop-Takil Strata are too poor to assign a reliable age for this unit. Only sporadic pollen Acer sp., Alnus sp., Corylus sp., Ulmus sp., and Ephedra sp. and tests of benthic foraminifera Ammonia becarii (L.), Quinqueloculina sp., Nonion sp., gastropods, and ostracods were observed in these deposits (Vernyhorova and Ryabokon, 2018).

Based on the stratigraphic position in the section of the Kerch Peninsula, the Kop-Takil Strata is correlated provisionally with the Molochnian stage of southern Ukraine (Figures 2 and 12).

4.1.3. Rupelian–Chattian Stages, Kerleutian regional stage of southern Ukraine

4.1.3.1. Kerleut Formation

The name is taken after the ancient village of Kerleut on the Kerch Peninsula (Maimin, 1951). These deposits were first described by V.V. Menner in 1933 as the Kerleut horizon of the middle part of the Maikop Formation in the Kerch Peninsula (Maimin, 1951). The Kerleut Formation is widespread on the Crimean Plain, the NW shelf of the Black Sea, and the central part of the Kerch Peninsula and it is a type formation of the Kerleutian regional stage of southern Ukraine. Type section: Well 15-r (740–1203 m) drilled in the Kerleut area (Vernyhorova and Ryabokon, 2018; Figure 14).
Figure 15. Section of Well 1, Vladislavovka village of the Kirov district, Crimea (compiled after data of V. F. Kozyreva, 1949).
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Figure 16. The lower member of the Kerleut Formation on the southern part of the Kerch Peninsula, in the western part of Cape Chauda (Akbulat Oba structure).

Figure 17. The upper member of the Kerleut Formation on Cape Chauda of the Kerch Peninsula.

2018). Reference section: Well 1-r (1080–1300 m) drilled on the Vladislavovka area in the Kerch Peninsula (Vernyhorova and Ryabokon, 2018; Figure 15).

The Kerleut Formation comprises gray, dark-gray with brownish tint clays, noncalcareous, with silty or sandy intervals, very thin interbeds of gray aeolurite or fine-grained sands, interbeds and nodules of siderites (Figures 16 and 17). Thickness of the Kerleut Formation in the Kerch Peninsula is up to 860–1100 m, in places even up to 1500 m.

The Kerleut Formation is divided into two members. The boundary between the Lower and Upper members is defined by the appearance of the foraminifera with Haplophragmoides kerleuticus Kosir. The Lower Kerleut Member is composed of clays, sometimes with silty or sandy intervals and siderites nodules (Maimin, 1951). In the Crimean Plain the thickness of the Lower Member is 100–130 m, increasing to 200–250 m to the east. In the Kerch Peninsula the typical thickness of the Lower Kerleut Member is up to 340–600 m, in some places even up to 700–810 m.

The Upper Kerleut Member comprises silty clays with frequent beds of sandy clays or clayey sands, occasionally with interbeds of quartz-rich, glauconitic, fine-grained to medium-grained sandstones. The thickness of the sandy beds ranges from 0.5 m to 3 m. The Upper Kerleut Member has a thickness of up to 450–650 m in the Kerch Peninsula, increasing to 820–1200 m in local basins. In the Crimean Plain the thickness is up to 400–450 m. The lower boundary of the Kerleut Formation with the Azamat Formation is a conformable one and it is marked by the disappearance of calcareous lithologies and ostracods. The upper boundary with the Arabatska Formation is more transitional. In the Kerch Peninsula it is defined by changing the foraminiferal assemblage with Haplophragmoides kerleuticus Kosir. to an assemblage with H. periferonexcavatus Subb. and Caucasinella elongata (Orb.) of the Upper Maikop.

The biostratigraphic character of Lower Kerleut Member of the Kerleut Formation (see references in Vernyhorova and Ryabokon, 2018; Figure 13) includes numerous fish remains and also sponge spicules and radiolarians; a lower Oligocene dinoflagellate cysts association with Wetzeliella symmetrica Weil., W. articulata (Wetzel) Eis., W. gochtii Costa & Dow., Rhombodinium draco Gocht, R. gochtii Costa & Dow., Hystrichokolpoma salacia Eaton, Melitasphaeridium asterium (Eaton) Bujak, and Phthanoperidinium amoenum Drugg & Loeblich Jr.

The Upper Kerleut Member is characterized by benthic foraminifera beds with Haplophragmoides kerleuticus Kosir. and beds with Spiroplectammina caucasica Djan., Uvigerinella californica Cushm., and Bolivina goudkoefi Rankin in the Kerch Peninsula; beds with S. caucasica
The Sirohozy Formation comprises gray, light-gray clayey silty sandy rocks with thicknesses of up to 100 m (Figures 10 and 18). To the south the formation becomes clayey and its thickness increases up to 220 m. On the basin perimeters the formation has more sands and silts with glauconite with a thickness between 2–10 m and 40–60 m. The Sirohozy Formation conformably overlies the Molochna Formation (Figure 2). The upper boundary with the Askaniia Formation is transitional and it is defined by the appearance of a normal salinity mollusk assemblage and the foraminifera association of the *Sphaeroidina variabilis* zone.

The biostratigraphy of the Sirohozy Formation (see references in Ryabokon, 2016; Figure 11) includes an Oligocene mollusk assemblage with *Lenticorbula sokolovi* (Karl.); an ostracod association similar to that of the Molochna Formation (in the lower part of the Sirohozy Formation section); a dinoflagellate cysts assemblage of the Oligocene zone DP 14 *Chiropteridium galea*; and a spore and pollen assemblage of beds with *Pinus cristata*, *Quercus porrectus*, and *Juglans compacta*, and *Fuglans compacta*.

Based on its stratigraphic position in the section and also proven by mollusks, dinoflagellate cysts, ostracods, spores, and pollen, the Sirohozy Formation is dated as late Rupelian–early Chattian in age and it corresponds to the lower part of the Kerleutian stage of southern Ukraine (Figures 2 and 8).

### 4.1.3.3. Askaniia Formation

The name is derived from the Askaniia-Nova locality of the Kherson region (Veselov and Nosovskiy, 1962). These authors distinguished these deposits as the Askaniia beds by finding a stenohaline mollusk assemblage in the Upper Oligocene section of the northern Peri-Black Sea Region. The Askaniia Formation is widespread in the northern Peri-Black Sea Region and it can be found locally in the Syvash region of the Crimean Plain (Figure 8). Type section: Well-1 Stepnoe (164.7–232.7 m) drilled near the Nyzhni Sirohozy locality of the Kherson region (Veselov, 1982; Ryabokon, 2016; Figure 7). Reference section: Well 6-k (157.7–182.7 m) drilled near the Nyzhni Sirohozy locality of the Kherson region (Veselov et al., 1968; Ryabokon, 2016; Figure 8).

The Askaniia Formation comprises gray, greenish-gray silty clays, sometimes sandy, with clayey silt (aleurolite) intervals (Figures 10 and 19). The thickness of the Askaniia Formation varies from 20–95 m to 160 m and increases up to 240 m in the south. The lower boundary of the Askaniia Formation is transitional and it is defined by the appearance of a normal salinity mollusk assemblage and the foraminifera association of the *Sphaeroidina variabilis* zone.

The Askaniia Formation comprises gray, light-gray clayey silty sandy rocks with thicknesses of up to 100 m (Figures 10 and 18). To the south the formation becomes clayey and its thickness increases up to 220 m. On the basin perimeters the formation has more sands and silts with glauconite with a thickness between 2–10 m and 40–60 m. The Sirohozy Formation conformably overlies the Molochna Formation (Figure 2). The upper boundary with the Askaniia Formation is transitional and it is defined by the appearance of a normal salinity mollusk assemblage and the foraminifera association of the *Sphaeroidina variabilis* zone.

The biostratigraphy of the Sirohozy Formation (see references in Ryabokon, 2016; Figure 11) includes an Oligocene mollusk assemblage with *Lenticorbula sokolovi* (Karl.); an ostracod association similar to that of the Molochna Formation (in the lower part of the Sirohozy Formation section); a dinoflagellate cysts assemblage of the Oligocene zone DP 14 *Chiropteridium galea*; and a spore and pollen assemblage of beds with *Pinus cristata*, *Quercus porrectus*, and *Fuglans compacta*.

Based on its stratigraphic position in the section and also proven by mollusks, dinoflagellate cysts, ostracods, spores, and pollen, the Sirohozy Formation is dated as late Rupelian–early Chattian in age and it corresponds to the lower part of the Kerleutian stage of southern Ukraine (Figures 2 and 8).

### 4.1.3.3. Askaniia Formation

The name is derived from the Askaniia-Nova locality of the Kherson region (Veselov and Nosovskiy, 1962). These authors distinguished these deposits as the Askaniia beds by finding a stenohaline mollusk assemblage in the Upper Oligocene section of the northern Peri-Black Sea Region. The Askaniia Formation is widespread in the northern Peri-Black Sea Region and it can be found locally in the Syvash region of the Crimean Plain (Figure 8). Type section: Well-1 Stepnoe (164.7–232.7 m) drilled near the Nyzhni Sirohozy locality of the Kherson region (Veselov, 1982; Ryabokon, 2016; Figure 7). Reference section: Well 6-k (157.7–182.7 m) drilled near the Nyzhni Sirohozy locality of the Kherson region (Veselov et al., 1968; Ryabokon, 2016; Figure 8).

The Askaniia Formation comprises gray, greenish-gray silty clays, sometimes sandy, with clayey silt (aleurolite) intervals (Figures 10 and 19). The thickness of the Askaniia Formation varies from 20–95 m to 160 m and increases up to 240 m in the south. The lower boundary of the Askaniia
Formation with the Sirohozy Formation is marked by the appearance of a stenohaline mollusk assemblage and the foraminifera association of zone *Sphaeroinina variabilis*. The upper boundary with the Hornostaivka Formation is defined by the appearance of a “nonionids” foraminifera assemblage. On the basin perimeter, the Askaniia Formation is disconformably overlain by the Mayachka Formation and younger Miocene sediments (Figure 2).

The biostratigraphy of the Askaniia Formation (see references in Ryabokon, 2016) (Figure 11) includes a Chattian mollusk assemblage with *Plagiocardium abundans* Liv and *Chlamys bifida* (Munst.); upper Oligocene benthic foraminifera provincial zone *Sphaeroidina variabilis*; Oligocene ostracod assemblage with *Cytherella beyrichi* (Reuss), *C. gracilis* Lnkl., and *Disopontocythereis oligocenica* Zal.; dinoflagellate cysts association of subzone *Rhabdodinium draco* of Oligocene zone DP 14 *Chiropteridium galea*, correlating with dinoflagellate zone D15c of the Chattian Stage of southern Ukraine. Association of ostracods *Uvigerinella ornatus* (Bogd.) and *Cibicidoides variabilis* (Bogd.), better known as a “nonionid complex”. In the north these deposits pass into quartz and glauconitic-quartz sandstones and aleurites, while in the south part of the formation consists of silty clays with sandstone and aleurite interbeds. The thickness of the Hornostaivka Formation in the northern Peri-Black Sea Region is up to 140 m and in the Crimean Plain it increases to 350–400 m. The lower boundary of the Hornostaivka Formation with the Askaniia Formation is defined by the appearance of a “nonionids” foraminifera assemblage. The boundary of the Hornostaivka Formation with the Chornobaivka and Arabatska Formation is defined using foraminifera (Figure 20).

The biostratigraphy of the Hornostaivka Formation (see references in Ryabokon, 2016; Figure 11) includes a dinoflagellate cysts association of beds with *Homotrebyllum floripes* of Oligocene zone DP 14 *Chiropteridium galea*. The lower part of the formation is characterized by a benthic foraminiferal assemblage with *Cibicidoides ornatus* (Bogd.) and *Cribronion onerosum* (Bogd.), better known as a “nonionid complex”. In the south, the uppermost part of the formation is characterized by beds with *Spiroplectammina caucasica* Djan. and *Uvigerinella californica* Cushman. The lower part of the formation is also characterized by a mollusk assemblage with *Cerastoderma prigorovskii* (Bog.), *Plagiocardium abundans* (Liv.), and *Corbula helmerseni* (Iljina), known from the upper part of the Kalmykian regiostage of the Eastern Paratethys; association of ostracods *Pontocythere brevis* Lnkl., *Pterygocythereis jonesii* (Baird.), *P. fimbriata fimbriata* (Munst.), *Cytheridea pernota* Oertli & Keij., *Trachyleberis variabilis* Sher., and *Echinocythereis hirstula* (Lnkl.), most of which are known from the Chattian Stage of the Western Europe; and a spore and pollen assemblage similar to that of the Askaniia Formation.

The Chattian age of the Askaniia Formation is proven by dinoflagellate cysts, foraminifera, and mollusks (Figures 2 and 8). The formation corresponds to the Kerleutian stage of southern Ukraine.

4.1.3.4. Hornostaivka Formation

The name is taken from the Hornostaivka locality of the Kherson region (Nosovskiy and Pasichnyi, 1965). The formation was first distinguished by Nosovskiy and Pasichnyi (1965) as silty-clay rocks overlying the Askaniia clays in the Maikop section of the northern Peri-Black Sea Region. The Hornostaivka Formation is widespread on the southern part of our study area and it can be found locally in the Syvash region of the Crimean Plain as well (Figure 8). A type section for this formation has not been specified to date.

The Hornostaivka Formation comprises greenish-gray noncalcareous silty clays, clayey silts, and sands. In the deepest part of the Peri-Black Sea Region basin the lower part of the formation is composed of sandy silty clays. The upper part of the formation consists of aleurites and sandstones with silty clay intervals. To the north these deposits pass into quartz and glauconitic-quartz sandstones and aleurites, while in the lower part of the formation consists of silty clay with sandstone and aleurite interbeds. The thickness of the Hornostaivka Formation in the northern Peri-Black Sea Region is up to 140 m and in the Crimean Plain it increases to 350–400 m. The lower boundary of the Hornostaivka Formation with the Askaniia Formation is defined by the appearance of a “nonionids” foraminifera assemblage. The boundary of the Hornostaivka Formation with the Chornobaivka and Arabatska Formation is defined using foraminifera (Figure 20).
Figure 20. Section of Well 692 and 697 on the Chonhar Peninsula (compiled based on Didkovskiy and Kulichenko, 1975; Kraeva and Lulyeva, 1985; Nosovskiy, 1992; Nosovskiy, 1993b; materials of M.F. Nosovskiy and Ye.Ya. Kraeva).
cysts (Figures 2 and 3). The Formation corresponds to the upper part of the Kerleutian stage of southern Ukraine defined by benthic foraminifera, mollusks, spore, and pollen assemblages (Figures 2 and 8).

4.1.3.5. The Chorelek Strata
The name is taken from the ancient Chorelek village in the SE Kerch Peninsula (Vernyhorova and Ryabokon, 2018). Originally these deposits were named as the Dubrovka Strata, but later the name was replaced by Chorelek to retain the authorship for L.A. Fikolina, N.N. Obsharskaia, and T.S. Ryabokon (Vernyhorova and Ryabokon, 2018). The Chorelek Strata is known from the eastern part of the Kerch Peninsula and traced along the peri-Kerch shelf. Type section: Well Korenkivska-1 (2020–3487 m) drilled on Cape Kop-Takil of the Kerch Peninsula (Vernyhorova and Ryabokon, 2018; Figure 12).
The Chorelek Strata comprises gray, dark-gray, olive-gray noncalcareous argillite, with silty, sometimes thin-layered (millimeter scale) gray glauconitic-quartz aleurolite. The thickness of the Chorelek Formation is 1000–1600 m. The Chorelek Strata has conformable boundaries to the underlying Molochnian Kop-Takil Strata and the overlying Alahol Formation of the Upper Maikop Group (Figure 2).

The biostratigraphy of the Chorelek Strata (see references in Vernyhorova and Ryabokon, 2018; Figure 13) includes diatoms *Istmia* sp. and dinoflagellate cysts *Deflandrea phosphoritica* Eis. On the peri-Kerch shelf of the Black Sea the strata is characterized by an Oligocene association of dinoflagellate cysts *Rhombodinium longimanum* Vozz., *R. glabra* (Cook.), *R. draco* Gocht., and *Deflandrea phosphoritica* Eis., characteristic for the Askaniia and Hornostaivka formations of the northern Peri-Black Sea Region and the Upper Kerleut Member of the Kerch Peninsula; and spore and pollen assemblages.

Based on the stratigraphic position of the Chorelek Strata above the Molochnian Kop-Takil Strata and also on dinoflagellate cyst data, the Chorelek Strata is correlated with the Kerleutian stage of southern Ukraine (Figures 2, 12, 13).

### 4.1.3.6. The Clays Strata

Originally it was described as a strata of greenish gray and dark gray clays (Teslenko, 1984).

The Clays Strata is widespread on the Tarkhankut Peninsula of the Crimea (Figure 4). Type section: Well Mizhvodnenska-1 (542–660 m) drilled near Mizhvodne village of the Chernomorsk region, Crimea. The Clays Strata comprises greenish-gray, gray, and dark-gray clays, with silty intervals. Thickness is up to 250–300 m. The lower boundary of the Clays Strata with the Lower Kerleut Member is transitional and it is defined by the appearance of a foraminifera assemblage. The upper boundary with the Arabatska Formation is also gradual and it is marked by a foraminifera assemblage change.

The biostratigraphy of the Clays Strata (Shvemberger, 1967; Muratov, 1969; Pechenkina, 1971; Teslenko, 1984; Figure 6) includes benthic foraminifera assemblages with *Uvigerina californica* Cushman, *Spiroplectammina terekensis* Bogdanovich, and *Caucasina schischkinskayae* (Samoilova) and beds with *Cibicidoides ornatus* (Bogd.), *Cribrononion onerosum* (Bogd.), and *Saccammina* sp.; an association of Oligocene planktonic foraminifera with numerous *Globigerina ciperoensis* (Bolli), *Globigerina* aff. *officinalis* Subbotina, *Tenuitellinata pseudoedita* (Subbotina), and *Tenuitella brevispira* (Subbotina); and a middle Maikop spore and pollen assemblage. Casts of gastropod shells, fish scales, radiolarians, and diatoms have also been mentioned for the Clays Strata.
Based on its stratigraphic position in the section, the foraminifera associations, and spore and pollen assemblages, the Clays Strata corresponds to the upper part of the Kerleutian stage of southern Ukraine (Figure 4).

4.1.4. Neogene, lower Miocene, Caucasian, Sakarulian, and Kotsakhurian regional stages of the Eastern Paratethys and the Bathysiphonian regional horizon

4.1.4.1. Arabatska Formation
The name is taken from the Arabatska split on the east of the Crimean Peninsula (Barg and Nosovsky, 1993). These deposits were identified first in the Upper Maikop of the Kerch Peninsula as the Bathysiphon horizon by V.F. Kozyreva in 1947–1949 (Teslenko, 1984) according to a large number of foraminifera tests of Bathysiphon in these deposits. M.F. Nosovskiy renamed these deposits as the Bathysiphon Formation (Vereschagin, 1982). Later, the Bathysiphon Formation was renamed as the Arabatska Formation (Barg and Nosovsky, 1993). The Arabatska Formation is widespread in the southwestern, western, and, partly, the center of the Kerch Peninsula (Figures 4, 12, and 21). It is also present on the Tarkhankut Peninsula and most parts of the Crimean Plain (within the Indol, Syvash, and Karkinitskyi Basins; see Ovechkin, 1958; Muratov, 1969; Didkovskiy and Kulichenko, 1975). Type section: Well 1-r drilled near the Vladislavovka village in the western Kerch Peninsula (Vernyhorova, 2014; Vernyhorova and Ryabokon, 2018; Figure 15).

On the Kerch Peninsula, the Arabatska Formation comprises dark gray, olive-brown, brown, gray-brown monotonous, dense, laminated clays often with intercalations of sands (Figure 22). Sandy grains on the bedding planes and thin interbeds of clay siderites are characteristic features of these sediments (Maimin, 1951; Ovechkin, 1958; Nosovskiy, 1975, 1993a, 1993b; Barg and Stepanyak, 2003). In most parts of the Crimean Plain the formation is represented by dark-gray slightly silty clays. There are dark gray clays with a greenish tint, mostly sandy with interbeds and lenses of fine-grained sands, occasionally with silt intervals in the upper part of the section in the NE part of the region (near city of Dzhankoi; see Ovechkin, 1958). The thickness of the Arabatska Formation is up to 340 m in the Indol Depression, up to 200 m on the Tarkhankut Peninsula, and up to 1200 m on the Kerch Peninsula (Muratov, 1969; Barg and Stepanyak, 2003). Both the lower boundary of the formation with the Upper Kerleut Member (upper Oligocene) and the upper boundary with the Nasyr Formation (Tarkhanian regional stage) are gradual. The Arabatska Formation is transgressively overlain by Chokrakian or younger Miocene deposits (Vernyhorova and Ryabokon, 2018).

The biostratigraphy of the Arabatska Formation (see references in Vernyhorova and Ryabokon, 2018; Figure 13) includes various foraminifera beds on the west and southwest of the Kerch Peninsula characterized by V.F. Kozyreva in 1947–1949 (Figure 21):

- Beds with Haplophragmoides periferoexcavatus. They were identified in the lower part of the formation (thickness of these beds is 450–500 m) in the SW Kerch Peninsula and are characterized by rich foraminifera fauna (for list of species, see Vernyhorova and Ryabokon, 2018). Remains of fish and echinoid radioles are also present in these sediments.

- Beds with Cyclamminia. They were identified in the middle part of the formation (thickness of deposits is 150 m) along the Parpach Ridge on the Kerch Peninsula (for list of species, see Vernyhorova and Ryabokon, 2018); there are also echinoid radioles.

- Beds with calcareous foraminifera. They were identified in the upper part of the formation (thickness of deposits is 80–120 m) in the southwestern part of the Kerch Peninsula near Vladislavovka and Marfovka villages (for list of species, see Vernyhorova and Ryabokon, 2018). According to V.F. Kozyreva, deposits between these foraminifera beds (up to 200 m thick) contain only Bathysiphon tests.

- Beds with Saccammina zuramakensis. They were identified at the top of the Arabatska Formation (thickness...
of deposits is up to 300 m) in the central part of the Kerch Peninsula. The beds were first identified by V.F. Kozyreva as the Korolevo horizon in the sediments located above the Bathysiphon horizon (now it is the Arabatska Formation) near Korolevo village on the Kerch Peninsula. Later, they were described as the “Korolevo Beds” or the “Korolevo Formation”. These deposits are recognizable in the top of the upper Maikop succession by the presence of a foraminifera monoassemblage with *Saccammina zuramakensis* Bogdanowicz and by the absence of *Bathysiphon* tests. They also contain fish remnants such as *Clupeonella* sp., *Merluccius cf. lednevi* Bogatschov, and *Centricus* sp.

In the north-northwestern and central part of the Kerch Peninsula (Figure 21), as well on the Crimean Peninsula, the Arabatska Formation does not contain “beds with foraminifera” but comprises only certain species of foraminifera: *Bathysiphon*, *Ammodiscus* sp., *Haplophragmoides periferoexcavatus* Subbotina, *Haplophragmoides* sp., *Ammobaculites* sp., *Rhabdamina* sp., *Trochammina depressa* Subbotina, *Caucasinella elongata* (d’Orbigny), *Nonion* sp., *Nonion aff. nonionides* (Andreae), *N. polymorphum* Bogdanowicz, *Nonionina buxovillana* (Andreae), *Rotalia* sp., *Elphidium onerosum* Bogdanowicz, *Heterolepa ? ornata* (Bogdanowicz), and *Cibicides* sp. Unfortunately, these species are cited in the scientific literature as finds in the Arabatska Formation as a whole, without reference to a specific interval within the Upper Maikop sections.

The mollusks *Plagiocardium abundans* (Liwerowska), *Nucula* sp., *Chlamys* sp., and *Fusus* sp. as well as ostracods *Neomonomeratina helvetica* Oertli are found in the Arabatska Formation on the Tarkhankut Peninsula and in the Syvash area of the Crimean Peninsula (Figure 6).

Diatom beds with *Craspedodiscus elegans* and *Cavitatus jouseanus (= Sinderajouseana) were identified in the Upper Maikop of the Crimean Peninsula, comparable to the assemblages of the *Melosira hispanica* diatom zone of the Eggenburgian of the Central Paratethys (Figure 2); in turn, they are correlated with the lower Burdigalian (i.e. nannofossil zone NN2 of Martini, 1971).

The dinoflagellate cyst assemblage with *Deflandrea phosphoritica phosphoritica* and *D. arcuata* was found in the lower part of the Arabatska Formation (foraminifera beds with *Haplophragmoides periferoexcavatus* by L.A. Portniagina in the well Fontanovskaya-830 (depth 443–452 m) near the Fontanovka village on the Kerch Peninsula (Figure 13). Dinocysts associations are identified in the middle part of the Arabatska Formation (foraminifera beds with *Caucasinella elongata* (Orbigny), *Nonion* sp., *Cibicides* sp.) on the central part of the Kerch Peninsula (the Tohanash structure by Arkhanguelsky et al., 1930) and it was identified as analogous to the *Enslandiella emslendensis* zone of the Sakaraulian regional stage of the Eastern Paratethys (Figure 2).

The lower part of the Arabatska Formation (beds with *Haplophragmoides periferoexcavatus*) corresponds to the Caucasian of the Eastern Paratethys and it is correlated with the Aquitanian based on dinoflagellate cysts data (monoassemblage of *Deflandrea phosphoritica* subsp.; Figure 13). This level is recognized only in a limited area of the Kerch Peninsula (within beds with *Haplophragmoides periferoexcavatus*). This part of the Arabatska Formation is correlated with an unspecified part of the Chornobaivka Formation in the general area (Figure 2) based on common dinocyst assemblages.

The middle part of the Arabatska Formation in the Kerch Peninsula (with beds of *Cyclammina* and beds with calcareous foraminifera) and that part of the formation in the rest area of the Kerch and Crimean Peninsulas, which contain foraminifera *Caucasinella elongata*, *Bulimina tumidula*, and *Trochammina depressa*, mollusk *Plagiocardium abundans*, and ostracod *Neomonomeratina helvetica*, corresponds to the Sakaraulian of the Eastern Paratethys (Figures 6 and 13). The middle part of the Arabatska Formation is also correlated with an unspecified part of the Chornobaivka Formation of the northern Peri-Black Sea Region and also with the Olginskiy Formation of Ciscaucasia based on foraminifera, mollusks, and ostracod assemblages. The age of the Arabatska Formation on the Crimean Peninsula is correlated with the Eggenburgian stage of the Central Paratethys and with the lower Burdigalian (nannofossil zone NN2) of the ISC according to diatom data.

The upper part of the Arabatska Formation (beds with *Saccammina zuramakensis*) corresponds to the Kotsakhurian stage of the Eastern Paratethys constrained by foraminifera (Figure 13). These beds are correlated with the Karha Beds and the Mayachka Formation or only with the Karha Beds of the northern Peri-Black Sea Region in southern Ukraine (Figure 2) and with the Ritsvekyaya Formation of Ciscaucasia constrained by foraminifera data.

Thus, the age span of the Arabatska Formation corresponds to the Caucasian, Sakaraulian, and Kotsakhurian regional stages of the Eastern Paratethys. However, the precise correlation of different segments of this formation with the regional stages is only possible in a limited area of the Kerch Peninsula, namely along the Parpach Ridge where beds with foraminifera are present (Figures 2, 4, and 12). Based on the fossil data, only some unspecified parts of the formation belong to the Sakaraulian in the rest of the Kerch and Crimean Peninsulas.

### 4.1.4.2. The Alahol Formation

The name is taken from the Alahol Mountain in the SE Kerch Peninsula (i.e. Alahol antiline, see: Arkhanguelsky et al., 1930). At first, these deposits were identified in the upper Maikop as “Clay-siderite Strata” (Vernyhorova,
The Chornobaivka Formation comprises dark gray, almost black silty clays and sandy clays (Chekunov et al., 1976; Figure 24). There are dark gray, sometimes almost black clay sands, silts, siltstones or sandy and silty clays at the bottom part of the formation. Increased silt content is observed towards the top of the section (Veselov and Gilkman, 1972). The main characteristic of the Chornobaivka Formation is its black color due to the abundance of charred plant remains (Veselov, 1969). The maximum thickness of the Chornobaivka Formation is up to 98 m on the coast of the Karkinitsky Bay (Muratov and Neveskaya, 1986). The Chornobaivka Formation transgressively overlies the Hornostaivka Formation with an unconformity (Veselov and Gilkman, 1972; Figure 20). A gradual contact between these formations was suggested by others (Veselov, 1969; Didkovskiy and Kulichenko, 1975; Teslenko, 1984). The Chornobaivka Formation is transgressively overlain by the Mayachka Formation. Along the Karkinitsky Bay and Syvash (Kherson region), the Chornobaivka Formation gradually passes upwards into the Karha Beds (Nosovskiy, 1970).

The biostratigraphy of the Chornobaivka Formation (see references in Vernyhorova, 2015; Figure 11) includes mollusks Nucula sp. ind., Nuculana (Sacellida) aff. gracilis (Deshyes) (= Ledaf. aff. gracilis Deshyes), Chlamys ex gr. cornea Sow., Astarte sp., Plagiocardium abundans (Liwerowska), Cyprina sp., Tellina sp., Corbula ex gr. helmerseni Mich., Dentalium sp., and Natica sp. found in wells near the Karkinitsky Bay (Kherson region) (Veselov, 1969; Didkovskiy and Kulichenko, 1975); ostracods Neomonoceratina helvetica Oertli, Haplocytherida strigulosa (Reuss) cf. dacica (Hejjas), H. strigulosa (Reuss), Pterygocytheiris helvetica Oertli., Loxoconcha eggeriana Lnk., Eocorythopteron bruggese Oertli, and Echinocythereis hirsuta (Link.) found in the beds with mollusks; upper Oligocene–lower Miocene calcareous benthic foraminifera assemblage Globulina gibba Orb., Melonis dozularensis Chil., Nonion bogdanowiczi Volosh., N. dendriticus Chalil., Florilus ex gr. boueancus (Orb.), Ammonia beccarii (L.), Elphidium macellum (F. et Moll.), Bolivina ex gr. floridana Cushman., and Bulimina tumidula mainly in the lower part of the formation in wells near Prymorske (formerly Karha) and Lymskane villages (Kherson region); a dinoflagellate cysts monoassembly of dominating Deflandrea phosphoritica subsp. phosphoritica, as well D. phosphoritica subsp. vozzhennikovae, D. arcuata, D. spinulosa, Tuberculodinium vancampoea, Homotryblium spp., Apteodium spiridoide, Labrintodinium sp., Distatodinium sp., and Deflandrea phosphoritica in wells near the Svobodnyi Port, Nyzhni Torgai, Chornobaivka, and Ivanivka villages.

According to the dinoflagellate cysts, the Chornobaivka Formation is correlated with the lower part
of the Arabatska Formation (beds with *Haplophragmoides periferoexcavatus*) of the Kerch Peninsula and the Askaniia Formation of Ciscaucasia. Therefore, the formation corresponds to the Caucasian stage of the Eastern Paratethys, the Egerian of the Central Paratethys, and the Aquitanian of the global timescale (Figure 2).

According to mollusks (*Plagiocardium abundans*), ostracods (*Neomonoceratina helvetica*), foraminifera (*Bulimina tumidula*), and spores and pollen, the Chornobaivka Formation is correlated with the middle part of the Arabatska Formation (beds with *Cyclammina* and beds with calcareous foraminifera) of the Kerch Peninsula, and the Olginskiy Formation of Ciscaucasia. The formation corresponds to the Sakaraulian of the Eastern Paratethys and the Engenburgian of the Central Paratethys and the lower part of the Burdigalian (Figure 2).

Unfortunately, it is impossible to determine the boundary between the Caucasian and Sakaraulian regional stages within the Chornobaivka Formation, since dinocysts, mollusks, ostracods, foraminifera, and also spore and pollen data were obtained from different wells and have not yet been compared with each other in a systematic manner. Therefore, according to the available palaeontological data, the Chornobaivka Formation (Figures 2, 8, and 12) may correspond to the Caucasian and Sakaraulian stages of the Eastern Paratethys (or Aquitanian-lower part of Burdigalian of the ICS).

### 4.1.4.4. The Karha Beds

The name is taken from the Karha village (modern name is Prymorske) of the Kherson region. These deposits were identified first by Nosovskiy (1970). The Karha Beds are widespread in the northern Peri-Black Sea Region along the northern coast of the Karkinitskyi Bay and Syvash (Nosovskiy, 1970; Veselov and Gilkman, 1972; Chekunov et al., 1976; Barg and Stepanyak, 2003; Figures 8, 10, 20, and 25). The type section of the Karha Beds has not been specified so far.

The Karha Beds have ash, steel-gray, dark-gray silty clays and clayey silts in the bottom part of section, which change upwards to clay sands with ochre spots and rare roots of fossil plants (Veselov and Gilkman, 1972; Chekunov et al., 1976). The main features of the Karha Beds distinguishing it from the Chornobaivka Formation are their color and the rare fossils in them (Vernyhorova, 2015, 2016). The thickness of the Karha Beds does not exceed 10–20 m (Chekunov et al., 1976). The Karha Beds gradually overlie the Chornobaivka Formation and are transgressively overlain by the Mayachka Formation (Chekunov et al., 1976) (Figure 20).

Biostratigraphy of the Karha Beds: diatom assemblage of the *Rhaphoneis* (*Delphineis*) *subtilissima* zone (Olshtynska, 1996, 2001).

The Karha Beds are correlated with the upper part of the Arabatska Formation (beds with *Saccammina zuramakensis*) of the Kerch and Crimean Peninsulas (Muratov and Nevekskaya, 1986; Nosovskiy, 1993a, 2003) based on the conformable boundary of these stratigraphic units with the Kotsakhurian stage of the Eastern Paratethys (Figure 2). The Karha Beds are correlated with the Ottangian of the Central Paratethys (nannofossil zone NN3) based on the diatom assemblage of *Rhaphoneis* (*Delphineis*) *subtilissima* zone (Olshtynska, 1996, 2001).

### 4.1.4.5. The Mayachka Formation

The name is taken from the New Mayachka village in the Kherson region. These deposits were identified first by M.F. Nosovskiy and G.V. Pasichnyi (1965). The Mayachka Formation is widespread in a broader region including the Odessa (Karkinitskyi), Syvash, and Indol-Kuban basins, as well as Moldova and the Predobrudza Depressions. It is also found in certain areas on the southern part of the Ukrainian Shield (e.g., the Nikopol district; Chekunov et al., 1976; Teslenko, 1984; Figure 8). Type section for this formation not specified to date.

The Mayachka Formation is distinguished (Figure 7) by its emerald-green sands, sandy clays, and silts with ochre yellow spots and strips (Didkovskiy and Kulichenko, 1975; Chekunov et al., 1976; Barg and Stepanyak, 2003; Figures 10, 20, and 25). The striking green color is due to the very high percentage of glauconite in this formation (up to 37%). We interpret the presence of glauconite as indicative of low-oxygen conditions in a shelf marine depositional environments with slow rates of accumulation. The thickness of the Mayachka Formation varies from 2 to 34 m (Barg and Stepanyak, 2003). The Mayachka Formation transgressively overlies the Oligocene Askaniia Formation and the Miocene Chornobaivka Formation and Karha Beds (Figures 8 and 10). It is gradually overlain by the Chokrakian deposits but it has a disconformable, transgressive boundary with the overlying Karaganian, Konkian, and middle Sarmatian deposits (Teslenko, 1984; Vernyhorova, 2015, 2016).

The Mayachka Formation has very poor fossil content. Only very rare foraminiferal taxa such as *Ammonia beccarii, Elphidium macellum, Nonion granosum* (Orbigny), and *Quinqueloculina* sp., as well as Ostracoda casts, were found in the upper part of the formation in some wells of the Kherson and Odessa regions (Barg and Stepanyak, 2003).

The age of the Mayachka Formation is debatable because of the near absence of fossils in it. Also, the foraminifera finds in these sediments have a wide stratigraphic range and therefore cannot be used for age dating. M.F. Nosovskiy suggested that the Mayachka Formation corresponds to the Kotsakhurian stage of the Eastern Paratethys (Didkovskiy and Kulichenko, 1975; Nosovskiy, 1999). Others correlated the Mayachka
Formation with the Tarkhanian of the Eastern Paratethys (Barg and Stepanyak, 2003). A.G. Nasad (1968) and G.V. Pasechniy (1970) assumed Chokrakanian age for the Mayachka Formation. The overview of the debate about the age of the Mayachka Formation was described in detail by Vernyhorova (2015). Since the age of the Mayachka Formation remains questionable, here it was tentatively assigned to the Kotsakhurian and Tarkhanian stages of the Eastern Paratethys (Figures 2 and 8; Vernyhorova, 2015, 2016). Clearly, the stratigraphic position of the Mayachka Formation requires further studies.

4.2. Regional stratigraphic units of the Oligocene-lower Miocene of southern Ukraine

The Oligocene-lower Miocene regional stages defined in southern Ukraine are regarded as integral components of the regional stratigraphic scheme of the overall Eastern Paratethys (Vernyhorova and Ryabokon, 2018). This is based on the preservation of the three-membered division of the Maikop Group as historical-geological stages of the Maikop Basin located in southern Ukraine and on an understanding of regional stratigraphic units, such as regional stages and horizons, as stages of geological development in the region, reflecting the development of fauna and flora inhabiting this segment of the megaregional Maikop Basin.

The regional stratigraphic scheme of the Oligocene-lower Miocene of southern Ukraine includes the Planorbellian, Molochnian, and Kerletuian regional stages in the Oligocene and the Caucasian, Sakaraulian, and Kotsakhurian regional stages in the Miocene of the Eastern Paratethys. The regional scheme also includes the Miocene Bathysiphonian regional horizon in southern Ukraine (Figure 2). In figures 2 and 3, we have included the Oligocene regional stages of the Eastern Paratethys and their correlation with the stages of the Central Paratethys, as given by Popov et al. (2009, 2019). The position of the Kiscellian/Eggerian boundary in the southern Ukraine section is given after Veselov (1979).

The Oligocene regional stages of southern Ukraine have been approved by the Commission on Paleogene Stratigraphy of the Interdepartmental Stratigraphic Committee of the former Soviet Union (ISC USSR) and the Regional Interdepartmental Stratigraphic Committee of Ukraine (RISC Ukraine) up to the end of the 1980s. All Oligocene regional stages of southern Ukraine are thus identified as valid (real) stratigraphic units according to the Stratigraphic Code of Ukraine (Gozhyk, 2012). They have been accepted in official stratigraphic charts of Ukraine, i.e. in the Regional Stratigraphic Scheme of Paleogene Deposits of the South Ukrainian Oil and Gas Area (Teslenko, 1984), the Stratigraphic Scheme (Unified) of the Ukraine Paleogene Deposits (Makarenko et al., 1987), and the Stratigraphic Scheme of Paleogene Deposits of the Southern Regions of Ukraine (UMSK, 1993).

There is no universally accepted chronostratigraphic framework for the Oligocene of the Eastern Paratethys, encompassing mostly the southern regions of the former Soviet Union. Popov et al. (1993, 2009, 2019) proposed several Oligocene regional stages in the Euxinian and Caspian regions, i.e. the Pshekhian, Solenovian, and Kalmykian stages. In southern Russia, the official Oligocene stratigraphic nomenclature includes the Tsymlanian, Solenovian, and Kalmykian regional horizons defined for the eastern part of the Great Donbas and the Volga-Caspian subregion (Akhmetiev and Nikolaeva, 2008; Akhmetiev, 2015). The Pshekhian, Polbian, Moroskian Balka, and Batalpashinian regional horizons are used for the Russian sector of the Greater Caucasus and the Scythian Plate. In this paper we offer our view of the correlation scheme of the regional stages defined in southern Ukraine with those of southern Russia, mostly based on biostratigraphic data. In general, the stratigraphic subdivision of the Oligocene in the Eastern Paratethys realm is clearly in progress, requiring much more work and leaving room for alternative ideas for discussion.

As for the regional stages of the lower Miocene, the Regional Scale of the Neogene of the Eastern Paratethys was adopted by the ISC USSR in 1983 (Sokolov, 1985). This scale became the basis to work out stratigraphic schemes of Neogene deposits in different regions of the southern realms of the former Soviet Union, but in the official stratigraphic schemes of southern Ukraine (Teslenko, 1984; UMSK, 1993) the Caucasian, Sakaraulian, and Kotsakhurian regional stages of the lower Miocene are not shown.

The history of the Oligocene regional units of southern Ukraine was given by Makarenko et al. (1987) and Zernetskyy and Ryabokon (2013) and the historical perspective on the Neogene units was presented by Vernyhorova and Ryabokon (2018). A critical review of the modern concepts about the Maikop Group stratigraphy of southern Ukraine at the beginning of the 21st century (e.g., Andreyeva-Grigorovich, 2004; Maslun et al., 2004; Gozhyk et al., 2006b, 2010, 2015; Andreyeva-Grigorovic and Maslun, 2014), including the analysis of the regional stratigraphy of Oligocene-lower Miocene sediments in the accepted stratigraphic schemes of the Paleogene and Neogene of southern Ukraine of the second half of the 20th century (e.g., Teslenko, 1984; Makarenko et al., 1987; UMSK, 1993), was presented by Vernyhorova and Ryabokon (2018).

4.2.1. The Planorbellian regional stage

This stage unites sediments formed in the South Ukraine Basin in the time interval from the Eocene/Oligocene boundary to the first desalination of the Eastern Paratethys in the Oligocene (in Molochnian–Polbian time; Zernetskyy
and Riabokon, 2013; Vernyhorova and Ryabokon, 2018). In southern Ukraine the Planorbellian includes the Planorbella Formation of the Crimean Peninsula and the NW shelf of the Black Sea, the Zubakino Strata and the upper part of Kysylzhar Strata of the Crimean foothills, the Indol Formation of the Crimean Plain, the Diurmen Beds and the Eastern-Kerch Formation of the Kerch Peninsula, and the Borysfen Formation of the northern Peri-Black Sea Region (Figure 2). This regional stage is named after the Planorbella Formation of the Crimea Peninsula (Teslenko, 1984). Stratotype: Well 246-k, drilled on the Artemovskoe (Karlovskoe) uplift at the Tarkhankut Peninsula of the Crimea (Malarenko et al., 1987). Reference section: Well-1 Stepnoe drilled near the Nyzhni Sirohozy locality of Kherson region (Vereschagin, 1982; Ryabokon, 2016; Vernyhorova and Ryabokon, 2018) (Figure 7). The Planorbellian regional stage was described for the first time by L.H. Plahotniy and E.Ya. Kraeva, as a regional horizon in the Regional Stratigraphic Scheme of Oligocene–Lower Miocene Deposits of the South Ukrainian Oil and Gas Area (Teslenko, 1984) ratified by the RISC Ukraine in 1982. In subsequent years the Planorbella regional horizon was present in official stratigraphic schemes of Ukraine (e.g., Malarenko et al., 1987; UMSK, 1993). In the actualized regional stratigraphic scale of the Paleogene of Ukraine (Zosimovich et al., 2005) and also in unofficial stratigraphic schemes of the NW shelf of the Black Sea (Maslun et al., 2004; Gozhyk et al., 2006b), the Kerch Peninsula (Vernyhorova and Ryabokon, 2018), and the northern Peri-Black Sea Region (Ryabokon, 2016), it is accepted with the rank of a regional stage (Figure 2). The Planorbellian regional stage is traditionally divided into two regional substages.

The Planorbellian of southern Ukraine is characterized by a Rupelian mollusk assemblage with Nucula compta Goldf., Astarte kickxi Nyst., Pleurotomaria selysii Koen., Thiasira unicaunarata Nyst., and Cystodaria angusta Nyst. & West.; Rupelian ostracod zone Cuneocytthera marginata (Koren, 2006); Rupelian dinoflagellate cysts zones DP 12 Phtanoperidinium amoenum/Wetzeliella symmetrica and DP 13 Wetzeliella gochtii (part) (Andreeva-Grigorovich et al., 2011); and planktonic foraminifera beds with Globigerina officinalis and Dentoglobigerina tapuriensis (upper part) (Zernetskyy and Riabokon, 2013; Vernyhorova and Ryabokon, 2018). The lower regional substage is characterized by the benthic foraminifera provincial zone “Lenticulina” herrmanni and the upper part of calcareous nannofossils zone NP 21; the upper substage is characterized by the Rupelian benthic foraminifera provincial zone Spiroplectammina oligocenica and calcareous nannofossils zone NP 22 (Malarenko et al., 1987; Zernetskyy and Riabokon, 2013). The lower limit of the Planorbellian is considered to be coincident with the Eocene/Oligocene limit defined in southern Ukrainian sections within nannofossil zone NP 21 and planktonic foraminifera beds with Globigerina officinalis and Dentoglobigerina tapuriensis, at the base of dinocysts zone DP 12 Phtanoperidinium amoenum/Wetzeliella symmetrica (Figures 6, 11, and 13).

The Planorbellian regional stage is correlated with the lower Rupelian Stage of the ISC. In the Eastern Paratethys it is correlated with the Pshekhian regional horizon of the Russian sector of the Greater Caucasus and the Scythian Plate, the Tsimlanian regional horizon of the eastern part of the Great Donbas and Volga-Caspian subregion (Akhmetiev and Beniamovsky, 2003; Akhmetiev and Nikolaeva, 2008; Akhmetiev, 2015), the Pshekhian regional stage of the Eastern Paratethys (Popov et al., 2009, 2019), and in northern Ukraine with the Mezhihorian regional stage (Zosimovich and Shevchenko, 2014; Zosimovich et al., 2017).

4.2.2. The Molochnian regional stage

This time period includes sediments formed in the southern Ukrainian region during the first desalination of the Eastern Paratethys in the Oligocene (Popov et al., 2009; Zernetskyy and Ryabokon, 2013; Vernyhorova and Ryabokon, 2018). The Molochnian stage includes the Molochna Formation of the northern Peri-Black Sea Region, the Azamat Formation of the Crimean and Kerch Peninsulas, and the Kop-Takil Strata of the Kerch Peninsula. This regional stage is named after the Molochna Formation (Figure 2). Stratotype section: Well-1 Stepnoe drilled near the Nyzhni Sirohozy locality of Kherson region (Vereschagin, 1982; Ryabokon, 2016) (Figure 7). Reference section: Well 692 drilled on the Chonhar Peninsula (Nosovskiy, 1992, 1993b; Vernyhorova and Ryabokon, 2018). The Molochnian stage proposed by M.F. Nosovkiy was defined by brackish mollusk Ergenica cymlanica Zhizh., ostracods, and Saccammina (Nalvkin, 1968; Figure 20). The Molochnian regional horizon was already present in official stratigraphic schemes (Teslenko, 1984; Makarenko et al., 1987; UMSK, 1993), but in the stratigraphic compilations made during the last two decades (Maslun et al., 2004; Zosimovich et al., 2005; Gozhyk et al., 2006b; Ryabokon, 2016; Vernyhorova and Ryabokon, 2018), it is also accepted as a regional stage of the Oligocene (Figure 2).

The Molochnian regional stage is characterized by a brackish mollusk assemblage with Ergenica cymlanica (Popov) (Nosovskiy, 1998); Rupelian ostracod zone Disopontocypris oligocenia (Koren, 2006); calcareous nannofossil beds with abundant Reticulofenestra ornata and Transversopontis fibula, which are observed in the NP 23 zone in the Eastern Paratethys (Koren, 2006); and dinoflagellate cysts association with Hystrichokolpoma spp. within Rupelian dinocyst zone DP 13 Wetzeliella
The lower and upper boundaries of the Molochian in most studied sections are determined by the appearance and disappearance of calcareous rocks and the above-mentioned plankton microfossils and benthic fauna associations. In the biostratigraphic subdivision of the Paleogene of the southern Ukrainian region, the lower boundary of the Molochian corresponds to the NP 22-23 boundary and it is placed within the DP 13 Wettzeliella gochtii zone (Figures 6 and 11; Zosimovich et al., 2005; Zernetskyy and Riabokon, 2013; Andreyeva-Grigorovich and Maslun, 2014).

Using planktonic microfossils, calcareous nannofossils, and dinoflagellate cysts, the Molochian of southern Ukraine is correlated with the middle part of the Rupelian of the ISC (Figures 6 and 11; Zosimovich et al., 2005; Zernetskyy and Riabokon, 2013; Zosimovich et al., 2017). Based on microfossils and brackish mollusks, the Molochian regional stages of southern Ukraine correspond to the Polbian regional horizon of the Russian sector of the Greater Caucasus and the Scythian Plate and the Lower Solenovian regional subhorizon of the eastern part of the Great Donbas and Volga-Caspian subregion (Akhmetiev and Beniamovsky, 2003; Akhmetiev and Nikolaeva, 2008; Akhmetiev, 2015) in the Eastern Paratethys. Based on dinoflagellate cysts, the Molochian is correlated with the lower regional substage of the Berekian regional stage of northern Ukraine (Zosimovich and Shevchenko, 2014; Zosimovich et al., 2017). In this paper we give the definition of the Molochian regional stage of southern Ukraine as the reflection of the first event of desalinization of the Eastern Paratethys in the Oligocene (Figure 2). In that sense, the Molochian corresponds to the Solenovian stage of the Eastern Paratethys of Popov et al. (2009, 2019). However, the biostratigraphic definition of these regional units is different in some details. A more precise correlation of the Molochian with the Solenovian requires further detailed studies.

4.2.3. The Kerleutian regional stage
It involves sediments formed in the South Ukraine basin in the time interval from the first desalinization of the Eastern Paratethys in Molochian time to the Paleogene/Neogene boundary (Zernetskyy and Riabokon, 2013; Vernyhorova and Ryabokon, 2018). In southern Ukraine the Kerleutian includes the Kerlet Formation of the Crimean and Kerch Peninsulas and the NW shelf of the Black Sea, the Clays Strata of the Crimean Plain, the Chorelek Strata of the Kerch Peninsula, and the Sirohozy, Askania, and Hornostaivka Formations of the northern Peri-Black Sea Region. This regional stage is named after the Kerlet Formation of the Kerch Peninsula (Teslenko, 1984). Stratotype section: Well 1-r drilled on the Vladislavovka area in the Kerch Peninsula (Vernyhorova and Ryabokon, 2018) (Figure 15); reference section: Wells 692 and 697 drilled (Vernyhorova and Ryabokon, 2018) on the Chonhar Peninsula (Didkovskiy and Kulichenko, 1975; Nosovskiy, 1993b) (Figure 20). For the first time, L.G. Plahotnyi and E.Ya. Kraeva proposed the Kerleut regional horizon in the Regional Stratigraphic Scheme of Oligocene-Lower Miocene Deposits of the South Ukrainian Oil and Gas Area (Teslenko, 1984). In the official stratigraphic scheme (Makarenko et al., 1987) it had a rank of a regional superhorizon. In subsequent stratigraphic schemes (Maslun et al., 2004; Zosimovich et al., 2005; Gozhyk et al., 2006b; Ryabokon, 2016; Vernyhorova and Ryabokon, 2018) of the early 21st century, it has the rank of a regional stage in the Oligocene (Figure 2). The Kerleutian traditionally is divided into two regional substages, which correspond to the Lower Kerleut and Upper Kerleut subhorizons in the scheme of Teslenko (1984).

The Kerleutian regional stage of southern Ukraine is defined by the Oligocene dinoflagellate cyst zone DP 14 Chiropteridium galea (Zernetskyy and Ryabokon, 2013; Vernyhorova and Ryabokon, 2018) (Figures 6, 11, and 13). The Lower Kerleutian is characterized by an Oligocene mollusk assemblage with Corbula (Lenticorbula) sokolovi Karl. known from the Sirohozy Formation of the northern Peri-Black Sea Region (Zosimovich et al., 2005). The Upper Kerleutian is characterized by an upper Oligocene benthic foraminifera assemblage of provincial zones Sphaeroidina variabilis and Cribronion onerosum, Cibicidoides ornatus of the northern Peri-Black Sea Region and the Crimean Plain, beds with Spiroplectammina terekensis and Uvigerinella californica and beds with Spiroplectammina caucasia, Uvigerinella californica and Bolivina aff. goudkoffi of the Crimean Plain, and beds with Haplophragmoides kerleuticus of the Kerch Peninsula; and mollusk assemblages with Plagiocardium abundans (Liw.) and Chlamys (Hielberia) bifida (Münst.) of the Askania Formation and with Cerasterodermma prigorovski (Bog.), Plagiocardium abundans (Liw.), and Corbula helmerseni Mich. of the Hornostaivka Formation of the northern Peri-Black Sea Region (Zosimovich et al., 2005; Zernetskyy and Riabokon, 2013).

The lower boundary of the Kerleutian is coincident with the base of the DP 14 Chiropteridium galea zone, so it is placed in the upper part of calcareous nanofossils zone NP 23 (Zernetskyy and Riabokon, 2013). The upper boundary of the Kerleutian is coincident with the top of the dinocyst DP 14 Chiropteridium galea zone (Zosimovich et al., 2005; Zernetskyy and Riabokon, 2013) and therefore it is also regarded as coincident with the Paleogene/Neogene boundary.

Using dinoflagellate cysts and mollusks, the Kerleutian of southern Ukraine is correlated with the upper part
of the Rupelian and Chattian Stages of the ISC. Based on dinoflagellate cysts, foraminifers, and mollusks the Kerleutian corresponds to the Morozkian Balka and Batalpashinian regional horizons of the Russian sector of the Greater Caucasus and the Scythian Plate and, moreover, to the Kalmykian horizon of the eastern part of the Great Donbas and Volga-Caspian subregion of the Eastern Paratethys (Akhametiev and Beniamovskiy, 2003; Akhmetiev and Nikolaeva, 2008; Akhmetiev, 2015). Based on the stratigraphic position and dinoflagellate cysts and mollusks data, the Kerleutian of southern Ukraine is correlated with the upper part of the Berekian regional stage of northern Ukraine (Zosimovich and Shevchenko, 2014; Zosimovich et al., 2017).

4.2.4. The Caucasian regional stage
The Caucasian is the earliest Miocene regional stage in the Eastern Paratethys and it was considered as an analogue to the Aquitanian (Figure 2) by Nosovskiy and Bogdanovich (1980). The Caucasian in southern Ukraine includes an unspecified part of the Chornobaivka Formation in the northern Peri-Black Sea Region, the lower part of the Arabatska Formation, and an indefinite part of the Alahol Formation on the Kerch Peninsula. The Caucasian is not identified in the rest of southern Ukraine. Its stratigraphic position in the Eastern Paratethys is between the upper part of the Morozkian Balka horizon of the Khadumian (beds with Spiroplectammina terekensis) and the Sakaraulian regional stages (beds with Caucasinella elongata), that is, between the sediments belonging, respectively, to the Chattian (late Oligocene) and the Burdigalian (early Miocene) Stages (Nosovskiy and Bogdanovich, 1980). The concept of the Caucasian stage was submitted at the VI Neogene Congress (Senes, 1975) and ratified by the ISC USSR in 1983 (Sokolov, 1985). Stratotype: outcrop along the Kuban River at Cherkessk city; reference sections: Well “Derbetovskaya-37” on the NE slope of the Stavropol uplift, wWell “Novopokrovskaya 4” near Tikhoretsk town (Muratov and Neveskaya, 1986; Nosovskiy, 1992; Neveskaya et al., 2003).

The paleontological characteristics of the Caucasian stage, the determination of its stratigraphic extent, the selection of criteria for tracing its lower and upper boundaries, and its subdivision into regional substages were described originally only for the stratotype region in Ciscaucasia (for a review, see Vernyhorova and Ryabokon, 2018). Recognition of equivalents of this regional stage in other areas of the Eastern Paratethys has been difficult since its ratification (Nosovskiy and Bogdanovich, 1980; Muratov and Neveskaya, 1986). The proposed features for its recognition could not be used, not only for identifying the Caucasian in most of the Eastern Paratethys but even in some Ciscaucasian sections as well (Popov et al., 1993; Andreyeva-Grigorovich, 2004; Neveskaya et al., 2004; Filippova et al., 2010, 2015; Ulanovskaya et al., 2012; Beluzhenko et al., 2018). Therefore, disputes about which of the lower Miocene deposits belong to the Caucasian and where the Paleogene/Neogene boundary is actually located continue to the present day.

It should be noted that the Caucasian was considered by many in terms of local lithostratigraphic units (i.e., formations, strata, or beds) with supposed equivalents in different areas of the Eastern Paratethys (e.g., Askania and Hornostaivka Formations in the northern Peri-Black Sea Region, e.g., Nosovskiy, 1980). The subsequent age changes of these lithostratigraphic units became the basis to revise the age and the other characteristics of the Caucasian stage itself (e.g., Andreyeva-Grigorovich, 2004; Gozhky et al, 2010, 2015). In our opinion, this approach is contrary to the original idea of defining the Caucasian as age-equivalent of the Aquitanian, instead of just being designated to a set of certain lithostratigraphic units. A detailed analysis of these stratigraphic concepts was described by Vernyhorova and Ryabokon (2018).

The Caucasian in the southern Ukrainian sections is determined by a dinoflagellate cyst monoaesemble with Deflandrea phosphoritica spp. (Figures 11 and 13; Portniagina, 1980; Andreyeva-Grigorovich, 2004). Whereas the lower boundary of the Caucasian in deposits of southern Ukraine coincides with the Paleogene/Neogene boundary and it is fixed only in sections of the northern Peri-Black Sea Region and along the Parpach Ridge on the Kerch Peninsula, the upper boundary of this regional stage is determined only in sections along the Parpach Ridge on the Kerch Peninsula. In the other areas of the broader southern Ukraine Caucasian deposits and their boundaries are actually difficult to trace.

4.2.5. The Sakaraulian regional stage
The Sakaraulian is a Miocene regional stage of the Eastern Paratethys characterized by the development of various marine assemblages of mollusks, foraminifers, and ostracods (e.g., Muratov and Neveskaya, 1986). The Sakaraulian stage in southern Ukraine includes a poorly constrained part of the Chornobaivka Formation in the northern Peri-Black Sea Region; the Arabatska (partially?) and Chornobaivka Formations on the Kerch Peninsula; and the middle part of the Arabatska Formation and an undefined part of the Alahol Formation on the Kerch Peninsula. At first, this regional stage was defined in lower Miocene deposits of eastern Georgia as the Sakaraul beds (horizon) by L.Sh. Davitashvili (Davitashvili, 1933; Borissjak, 1937). As a regional stage (Figure 2), it was submitted at the VI Neogene Congress (Senes, 1975) and ratified by the ISC USSR in 1983 (Sokolov, 1985). The name is taken from the Sakaraulskaya ravine in eastern Georgia (Vereschagin, 1982). A stratotype section was not described to date; the hypo-stratotype outcrops in...
the Naderbazevi ravine near Metekhi (Kvaliashvili, 1970; Muratov and Neveskaya, 1986).

The Sakaraulian in the southern Ukrainian sections is determined by mollusks – *Plagiocardium abundans* (the northern Peri-Black Sea Region, the Crimean Plain); foraminifera – *Bulimina tumidula*, *Caucasinella elongata*, and *Trochammina depressa* (the northern Peri-Black Sea Region, the Crimean Plain); diatoms – *Melosira hispanica*; ostracods – *Neomonoceratina helvetica* (the northern Peri-Black Sea Region, the Crimean Plain); foraminifera – beds with *Craspedodiscus elegans- Cavitatus jouseanus* (the Crimean Plain); and dinoflagellate cysts – assemblages of the *Emsiandhiella emslandensis* zone (Veselov, 1969; Savenko, 1973; Andreeva-Grigorovitch, 1980). The lower and upper boundaries of this regional stage can be traced in Ukrainian sections only along the Parpach Ridge on the Kerch Peninsula. In other regions of southern Ukraine, it is possible to find only some levels that comprise associations of the Sakaraulian biota, but without a possibility to determine the boundary with the Caucasian and Kotsakhurian regional stages.

The Sakaraulian is correlated with the Eggenburgian of the Central Paratethys and with the lower part of the Burdigalian (nannofossil zone NN2 by Martini, 1971) defined by benthic foraminifera (Figures 6 and 11; *Bulimina tumidula*, *Caucasinella elongata*, *Trochammina depressa*), ostracods (*Neomonoceratina helvetica*), mollusks (*Plagiocardium abundans*; Muratov and Neveskaya, 1986), and diatoms (by assemblage similar to *Melosira hispanica* zone; Olshtynska, 1996, 2001).

4.2.6. The Kotsakhurian regional stage

The Kotsakhurian is a regional stage of the Miocene in the Eastern Paratethys, which is characterized by the predominance of brackish mollusks of the genera *Eoprosodacna, Congeria, Rzhakia*, and *Melanopsis* as well as the foraminifera of the genus *Saccammina* (Muratov and Neveskaya, 1986). The Kotsakhurian within southern Ukraine includes the Karha Beds and probably an uncertain part of the Mayachka Formation in the northern Peri-Black Sea Region; the upper part of the Arabatska Formation in the central part of the Kerch Peninsula; and some poorly defined parts of the Arabatska and Alahol Formations in the rest of the Kerch Peninsula. The Kotsakhurian has not been identified on the Crimean Peninsula to date. At first, this regional stage was determined in the lower Miocene deposits of eastern Georgia as the Kotsakhur beds (horizon) by L.Sh. Davitashvili (Davitashvili, 1933; Borisjak, 1937). As a potential regional stage (Figure 2) it was submitted at the VI Neogene Congress (Senes, 1975) and ratified by the ISC USSR in 1983 (Sokolov, 1985). The name was taken from the Kotsakhuri village (middle course of the Kura River, Trans-Caucasia; Vereschagin, 1982). A stratotype section has not been designated yet; the hypo-stratotype outcrops near Metekhi station in the Naderbazevi beam (Muratov and Neveskaya, 1986).

The Kotsakhurian in the southern Ukrainian sections is determined by the diatom assemblages of the *Rhaphoneis (Delphineis) subtilissima* zone (Karha Beds in the northern Peri-Black Sea Region), and foraminifera beds with *Saccammina zuramakensis* (upper part of the Arabatska Formation near Korolevo and Marfovka villages on the Kerch Peninsula; Ovechkin, 1958; Nosovskiy, 1993a; Olshtynska, 2001). The lower and upper boundaries of this regional stage can be traced only in a limited area of the Kerch Peninsula. In other regions of southern Ukraine, it is possible to find only one level in the northern Peri-Black Sea Region (the Karha Beds), which comprises an association of the Kotsakhurian biota, but without the possibility of defining the boundaries with the Sakaraulian and Tarkhanian.

The Kotsakhurian is correlated with the Ottnangian and Karpatian stages of the Central Paratethys (Figure 2) and the upper part of the Burdigalian, according to the presence of brackish-water mollusks (e.g., Neveskaya et al., 2003) and the diatom assemblage of the *Rhaphoneis (Delphineis) substiltisima* zone (Olshtynska, 1996, 2001). Also, the Kotsakhurian may be correlated with some parts of the Langhian according to new paleomagnetic data obtained from the sections of Ciscaucasia (Palcu et al., 2019).

4.2.7. Bathysiphonian horizon – regional stratigraphic unit of the Miocene in southern Ukraine

The Bathysiphonian horizon combines deposits and biota formed in the time interval from the end of the Kerleutian (Paleogene/Neogene boundary) to the beginning of the Tarkhanian time. The Bathysiphon horizon was first identified by E.Ya. Kraeva, V.G. Kulchenko, E.B. Savron, and L.G. Plakhotnyi as a regional unit of the lower Miocene in the broader southern Ukraine in the Regional Stratigraphic Scheme of Oligocene-Lower Miocene Deposits (Teslenko, 1984). It was not used later in the official stratigraphic scheme (UMSK, 1993). However, the lithostratigraphic units (formation, strata, beds) corresponding to certain lower Miocene regional stages in most cases were described "as a whole", without indicating a specific part of the section where the data are obtained from. Therefore, it is difficult to find litho- and biostratigraphic criteria for defining the age analogues of the Caucasian, Sakaraulian, or Kotsakhurian regional stages in the Eastern Paratethys and to determine the boundary surfaces between them in the Upper Maikop deposits in the broader southern Ukraine. In this regard, it is proposed to return the regional stratigraphic unit "Bathysiphon horizon" as a regional (chronostratigraphic) unit of the Neogene of southern Ukraine (Figure 2) (Vernyhorova and Ryabokon, 2018).
The Bathysiphonian horizon is proposed to be include in the stratigraphic scheme of southern Ukraine (Figure 2) as an independent regional unit, which corresponds to the Caucasian, Sakaraulian, or Kotsakhurian regional stages of the Eastern Paratethys. The name “Bathysiphon” for this horizon is preserved as historical (Teslenko, 1997; Gozhyk, 2012). The Bathysiphonian horizon comprises the following local units of southern Ukraine: the Chornobaivka Formation, Karha Beds, and Mayachka Formation (probably part of it) in the northern Peri-Black Sea Region; the Arabatska Formation of the Crimean Peninsula; and the Arabatska and Alahol Formations of the Kerch Peninsula. The Arabatska Formation is typical for this regional horizon; the type section is Well 1-r drilled near the Vladislavovka village on the west of the Kerch Peninsula (Vernyhorova and Ryabokon, 2018). In fact, Well 1-r is proposed as the stratotype section (Vernyhorova and Ryabokon, 2018; Figure 15).

The lower boundary of the Bathysiphonian horizon coincides with the Paleogene/Neogene boundary. It is determined by the disappearance of Paleogene dinoflagellate cyst genera Chiropteridium, Wetzeliiella, and Rhombodinium and the presence in the sediments of a dinoflagellate cyst mononuclear with Deflandrea phosphoritica spp. (Figures 11 and 13). According to this criterion, this boundary is fixed between the Hornostaivka and Chornobaivka Formations in some wells of the northern Peri-Black Sea Region, between the Kerleut and Arabatska Formations along the Parpach ridge on the Kerch Peninsula. In the remaining part of our study area, the lower boundary of the Bathysiphonian horizon is determined by foraminifera and mollusks indicating an early Miocene age and by correlation with adjacent areas. According to this feature, the lower boundary of the Bathysiphonian horizon is defined between the Kerleut and Arabatska Formations on the Crimean Peninsula and on the western and northern parts of the Kerch Peninsula, and between the Chorolek Strata and the Alahol Formation of the eastern part of the Kerch Peninsula (Figure 2). The upper boundary of the Bathysiphonian Horizon is determined by the appearance of characteristic mollusks, foraminifera, and ostracods of the Tarkhanian regional stage (Figure 2). In most parts of the northern Peri-Black Sea Region, the upper boundary of the Bathysiphonian horizon cannot be determined due to the disputed age (i.e., Kotsakhurian–Chokrakian) of the Mayachka Formation (Figure 2). Therefore, it is only defined conditionally between the Karha Beds and the Mayachka Formation in a limited area in the northern Peri-Black Sea Region.

5. Conclusions
The stratigraphic model (scheme) of the Oligocene–lower Miocene deposits of southern Ukraine presented in this paper is based on comprehensive data analysis and a historic understanding of the broader southern Ukrainian region as part of the Eastern Paratethys.

The stratigraphic sequence of the northern Peri-Black Sea Region consists of several formations that formed in the shallow Scythian Shelf of the Eastern Paratethys including the Borysfen, Molochna, Serohozy, Askaniia, Hornostaivka, Chornobaivka, and Mayachka formations. These shallow shelf formations are characterized by silty and sandy clayey rocks with rich fossils assemblages (mollusks, foraminifera, ostracods, calcareous nannofossils, dinoflagellates, spores and pollen, and others). In contrast, the stratigraphic succession of the Crimean Plain and the western part of the Kerch Peninsula consists of formations that were formed in the deep part of the Scythian Shelf: the Planorbellina, Azamat, Kerleut, and Arabatska Formations and the Clay Strata. These deeper shelf formations are distinguished by silty and clayey rocks containing mostly microfossil assemblages (foraminifera, ostracods, dinoflagellates, calcareous nannofossils, spores, and pollen). Sedimentary formations of the eastern part of the Kerch Peninsula (the Eastern-Kerch and Alahol Formations, the Kop-Takil and Chorelek Stratum) are distinguished by a monotonous clayey lithologic section with rare silty clayey and siderite interbeds and rare to sporadic microfossils (foraminifera, dinoflagellates, and spores and pollen). These formations were deposited within a deep water basin of the western part of the West Kuban Depression of the Eastern Paratethys.

A very important event is the first desalination of the Eastern Paratethys during the early Oligocene (i.e., Molochanian-Polbian time), which is reflected in sections of the northern Peri-Black Sea Region (the Molochna Formation) and the Crimean Peninsula (the Azamat Formation), which is within the Scythian Shelf of the Eastern Paratethys. In the section of the deep-water depression on the east of the Kerch Peninsula this early Oligocene brackish-water stage in Eastern Paratethys history is not recognized.

The sections of the Oligocene–lower Miocene in each of the regions of the broader southern Ukraine are characterized by lithological similarity. The stratigraphic subdivision of the entire section is based on distinguishing the first brackish-water stage of the Eastern Paratethys and on using paleontological data. The subdivision of the Maikop Group developed in more deep-water facies of the eastern part of the Kerch Peninsula is questionable due to the relative lack of fossils, so the limits of the Eastern-Kerch Formation, the Kop-Takil and Chorelek Stratum, and the Alahol Formation are conjectural at present.

For the regional Oligocene and lower Miocene stratigraphy of our study area the first brackish-water stage in the history of the Eastern Paratethys is very significant.
because it is connected with the formation of calcareous clay rocks containing endemic and brackish-water assemblages of mollusks, calcareous nannofossils, and dinoflagellates. The Molochnian regional stage corresponds to deposits of this stage in southern Ukraine. The Molochnian divides the Oligocene–lower Miocene section in our study area into two parts. The lower, pre-Molochnian, part of the section corresponds to the Planorbellian regional stage as described above. Recognition and correlation with the Eastern Paratethys stages for the post-Molochnian succession in southern Ukraine is only possible based on paleontological data.

In the regional stratigraphic scheme of the southern Ukraine the Kerleutian regional stage belongs to the Oligocene and the Bathysiphonian regional horizon, as the age analogue of the Caucasian, Sakaraulian, and Kotsakurian regional stages of the Eastern Paratethys corresponds to the lower Miocene.

Benthic fossils of the Oligocene-lower Miocene deposits of southern Ukraine together with known levels of plankton microfossils in the Maikop section of the region have importance for the regional correlation of regional stages and formations within the Eastern Paratethys. For the Planorbellian regional stage there are the benthic foraminifera zone Spirolectammina oligocenica, calcareous nannofossils of the NP22 zone, dinocyst zones Phthanoportidinium amoenum/Wetzielliya symmetrica and Wetzielliya gochtii, ostracod zone Cyneocythere marginata, and a mollusk assemblage with Nucula (Lamellinucula) compta and Pterolucina balatalaschina. For the Molochnian stage there are mollusk assemblages with Ergenica cymlanica, ostracod zone Disopontocypris oligocaenica, a calcareous nannofossil association with abundant Reticulofenestra ornata and Transversopontis fibula, and a dinoflagellate cyst assemblage of beds with Hystrichokolpoma spp. For the Kerleutian stage there is a benthic foraminifera zone with Sphaeroidina variabilis and Spirolectammina terekensis, a dinocyst zone with Chiroteridium galea, and a mollusk assemblage with Chlamys bifida. For the lower Miocene deposits there are also levels of correlation with separate stages of the Eastern Paratethys. The middle part of the Bathysiphonian regional horizon is determined as the Sakaraulian regional stage based on the common occurrence of mollusk Plagiocardium abundans, ostracod Neomonoceratina helvetica, and foraminifera Caucasinella elongata, Bulimina tumidula, and Trochammina depressa. The upper part of the Bathysiphonian regional horizon corresponds to the Kotsakurian regional stage based on the foraminifera monoassociation of Saccammina zuramakensis.

For the interregional correlation of the Oligocene–lower Miocene regional stages described in this work the planktonic microfossils known from separate levels of the Maikop section of the region are used. Mollusks are also important for interregional correlation.

The Eocene/Oligocene boundary in our study area is defined within the calcareous nannofossil zone NP21 at the base of dinocyst zone Phthanoportidinium amoenum/Wetzielliya symmetrica. The Paleogene/Neogene boundary is coincident with the top Chiroteridium galea dinocyst zone. The Planorbellian regional stage is correlated with the lower Rupelian based on dinocyst zones Phthanoportidinium amoenum/Wetzielliya symmetrica and Wetzielliya gochtii, calcareous nannofossil NP22 zone, and a mollusk assemblage with Nucula (Lamellinucula) compta. The Molochnian regional stage is equivalent to the middle part of the Rupelian based on dinocyst zone Wetzielliya gochtii and calcareous nannofossil NP23 zone. The upper Kerleutian is correlated with the Chattian based on dinocyst zone Chiroteridium galea and a mollusk assemblage with Plagiocardium abundans and Chlamys bifida. The Aquitanian stage is defined in the southern Ukrainian succession by the dinoflagellate monoassociation of Deflandrea phosphoritica subsp. The lower part of the Kotsakurian regional stage is correlated with the Ottnangian of the Central Paratethys based on the diatom assemblage of Phaphoneis (Delphinea) subtilissima zone, which corresponds to calcareous nannofossil zone NN3.

5.1. Outlook for further studies
This paper was written with a focus only on the lithological and biostratigraphical aspects of the Maikop Group in broader southern Ukraine. Follow-up studies should address many other important aspects of this key sequence in the Black Sea region, such as the context of basin evolution with the associated paleogeographic changes, sequence stratigraphy, and petroleum geology, just to name a few. For this kind of more specialized future studies, we consider the other papers in this special issue as useful templates (e.g., Okay et al., 2020; Simmons et al., 2020; Tulan et al., 2020).

Acknowledgments
The authors are sincerely grateful to L.A. Fikolina and N.N. Obsharkaya (Yuzhekogeoconsr, Simferopol) and I.L. Kniazkova (Pivdenukrgeologiya, Dnipro) for joint geological studies. The assistance provided by I.I. Ishchenko (Naukamftogaz, Kiev) in providing geological well data, comments, and suggestions is appreciated. The authors would like to thank V.I. Poletaev (Institute of Geological Sciences of National Academy of Sciences of Ukraine, Kyiv) for discussing stratigraphic issues, classification, and nomenclature. Furthermore, the reviews of the first draft of this paper by Z. Bati, M. Simmons, and G. Tari were very helpful and therefore are much appreciated.
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