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Lower Miocene Sediments of the Maikop Group in the Central Eastern Paratethys

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Abstract—The composite section of upper Maikop sediments compiled for the central part of the Eastern Paratethys is presented. The section (more than 1000 m) comprises the Karadzhalgan, Sakaraulian, and Kotsakhurian regional stages.[1] The lower boundary of the Miocene drawn at the base of the Karadzhalgan regional stage is unambiguous only in the southern part of the central Ciscaucasia. In most areas of the Ciscaucasia, this boundary is drawn arbitrarily because of uniform lithology in the Oligocene–Miocene boundary interval and poor paleontological substantiation. Generally, the Maikop sequence is insufficiently studied and incomplete in many areas because of a discordant upper boundary of the Maikop Group. Nevertheless, materials presented in the paper characterize for the first time the composition and structure of the Lower Miocene sequence over a vast area of the Eastern Paratethys. The horizonwise reconstruction of Early Miocene basins has made it possible to reveal the major features of final stages in the formation of the Maikop clayey sequence.

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In recent years, we carried out a sequential (horizonwise) study of the composition, structure, and formation conditions of the Maikop (Oligocene–Lower Miocene) sediments in the Ciscaucasia, Volga–Don, and Mangyshlak regions. These works were started in the framework of the IGCP Project 174 dedicated to geological and biotic events in the Late Eocene–Early Oligocene (Stolyarov, 1991; *Geologicheskoe…*, 1996). Subsequently, we investigated the upper part of the Lower Oligocene (Solenovian) and Upper Oligocene horizons that make up the Kalmykian regional stage (Stolyarov, 1999, 2001; Stolyarov and Ivleva, 1999, 2004).

The upper part of the Maikop Group includes the Karadzhalgan, Sakaraulian, and Kotsakhurian regional stages that correspond to the Karadzhalga, Ol'ga, and Ritsa formations in the Ciscaucasia. The underlying Kalmykian regional stage is confidently correlated with the Chattian Stage of the Upper Oligocene in the standard scale. The position of the Paleogene–Neogene boundary and age of the Karadzhalgan regional stage are less certain. The last unit is now arbitrarily correlated with the Miocene part of the Egerian Stage in Central Europe and the Aquitanian Stage in the international scale, while the Sakaraulian and Kotsakhurian regional stages are considered analogues of the Burdigalian (Popov *et al.*, 1993a, 1993b).

At present, the stratigraphic range and status of the Karadzhalgan regional stage (or horizon) is the most difficult issue, because this part of the Maikop section, including upper (Zelenchuk) beds of the Kalmykian regional stage, is almost lacking fossils. Therefore, their subdivision and correlation is a challenging task.

The **Karadzhalgan regional stage** (Horizon, Formation) with the stratotype section along the Kuban River downstream of the town of Cherkessk. In the eastern Ciscaucasia, recognition of stratigraphic analogues of the Karadzhalgan regional stage meets some difficulties. Therefore, the Oligocene–Lower Miocene boundary is uncertain.

The **Sakaraulian regional stage** (Davitashvili, 1933) with the stratotype section in the Sakaraul Ravine opposite the town of Kaspi (Voronina *et al.*, 1991). The Ol'ga Formation characterized by the high silt content in clays and the appearance of benthic foraminiferal assemblage (*Neobulimina elongata*) is traditionally considered an analogue of the Sakaraulian regional stage in the Ciscaucasia (Popov *et al.*, 1993b).

The **Kotsakhurian regional stage** (Davitashvili, 1933) with the stratotype section at the western outskirts of the town of Kaspi (Popov and Voronina, 1983). According to (Popov *et al.*, 1993a, p. 64), although the fauna of the stratotype area is also unique, the Kotsakhurian sediments are relatively easily and unambiguously correlated based on the appearance of typical features of lower salinity, such as a very poor foraminiferal assemblage with *Saccammina zuramakensis* and mollusks usually represented by monospecific assemblage with *Rzehakia dubiosa*. The authors also noted that the

[1] The term "regional stage" for Maikop sediments was first used in (Popov *et al.*, 1993a, 1993b).

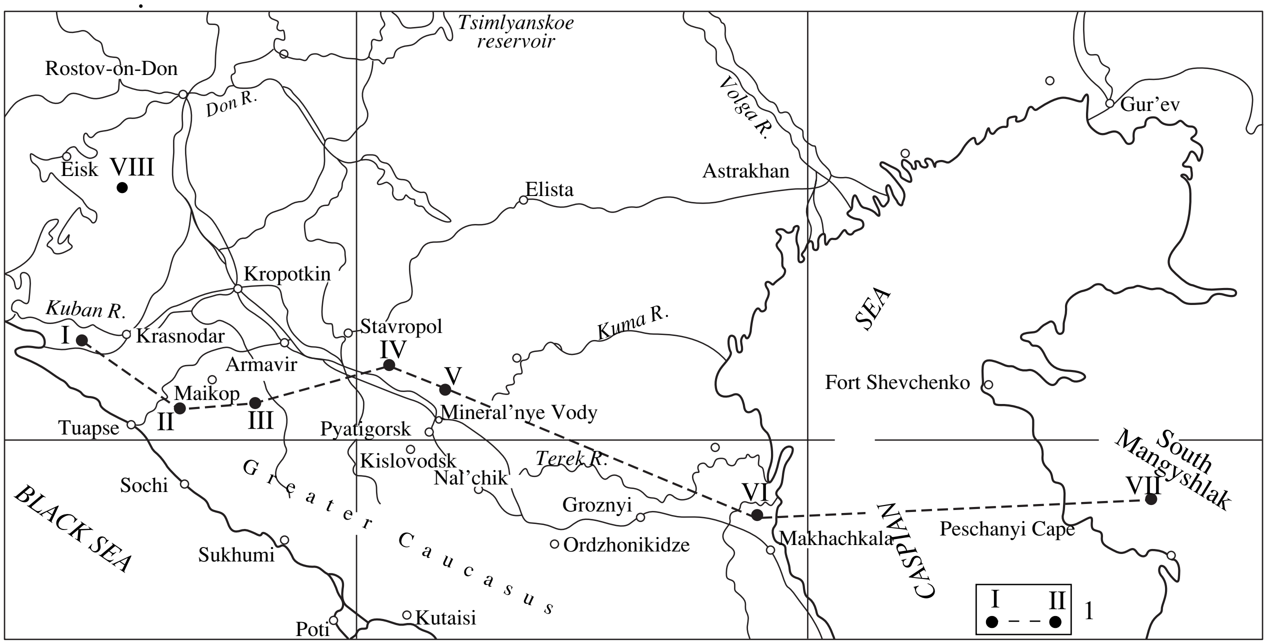

Fig. 1. Schematic location of Lower Miocene reference sections. (1) Reference sections and their numbers.

upper boundary of the Maikop Group is also poorly discernible in the deepest part of the basin corresponding to the Kerchenskii Peninsula, Ciscaucasia, and Transcaucasia, where clayey sections are continuous. The boundary is usually marked by the appearance of some carbonate admixture and marine fossils in sediments. However, the Tarkhanian regional stage of the Middle Miocene (Kuva Beds) in deep parts of the basin is composed of the Maikop facies. Therefore, its discrimination from the underlying Kotsakhurian sediments is possible only in sections with fossil remains.

COMPOSITION, STRUCTURE, AND STRATIGRAPHY OF LOWER MIOCENE SEDIMENTS

In the central Eastern Paratethys, the upper part of the Maikop Group is characterized by significant variations in lithology, structure, and completeness of sections in different areas due to the uneven erosion of sediments in the Neogene and Quaternary. The most complete upper Maikop sequence is observed in foredeeps of the Ciscaucasia, where it is conformably overlain by Middle Miocene (Tarkhanian) sediments. However, the available materials are unequal and fragmentary due to the significant lithofacies variability of upper Maikop sediments and scarcity of organic remains.

The Central and Western Ciscaucasia and Lower Reaches of the Don River

The typical, most complete, and well-studied sections of the upper Maikop Group are developed in the southern part of the study region with stratotypes of the Karadzhalga, Ol'ga, and Ritsa formations. Traditionally, this region attracted the attention of researchers primarily owing to the hydrocarbon potential of the Maikop sediments (Gubkin, 1912) and presence of the Laba manganese deposit (Kalinenko, 1990) and uranium–rare metal occurrences (Kochenov and Stolyarov, 1996) in Lower Miocene sediments (Ol'ga Formation).

Stratotype sections of all formations of the upper Maikop Group are located in the eastern Kuban region (Prokopov, 1938), where they are penetrated by many boreholes. In these areas, the Maikop sediments are represented by the thickest relatively deep-water clayey facies.

The **Karadzhalga Formation** (150–300 m) is composed of dark gray clays with scattered fish remains that form the more or less distinct "fish facies" (Figs. 1, 2; sections IV, V). These facies are typically developed in the lower part of the Karadzhalga Formation as thin (0.1–0.3 m) beds that extend over several kilometers and contain abundant iron sulfides (up to 35–40%) but a small amount of fish bone detritus (up to 5–6%). They extend along the South Stavropol Swell and include a number of uranium–rare metal occurrences. The clayey sequence is characterized by patches of frequently rudimentary siderite concretions (sideroplesites). Clays of the North Caucasian homocline also contain silt admixture in the form of powdery coating and thin laminae.

Ter-Grigor'yants (1969) found agglutinated foraminifers *Cyclammina cubanica* sp. nov., *Haplophragmoides kjurendagensis karadjalgensis* Ter-Grig., *Trochammina depressa* Subb., and others in the Karadzhalga Formation.

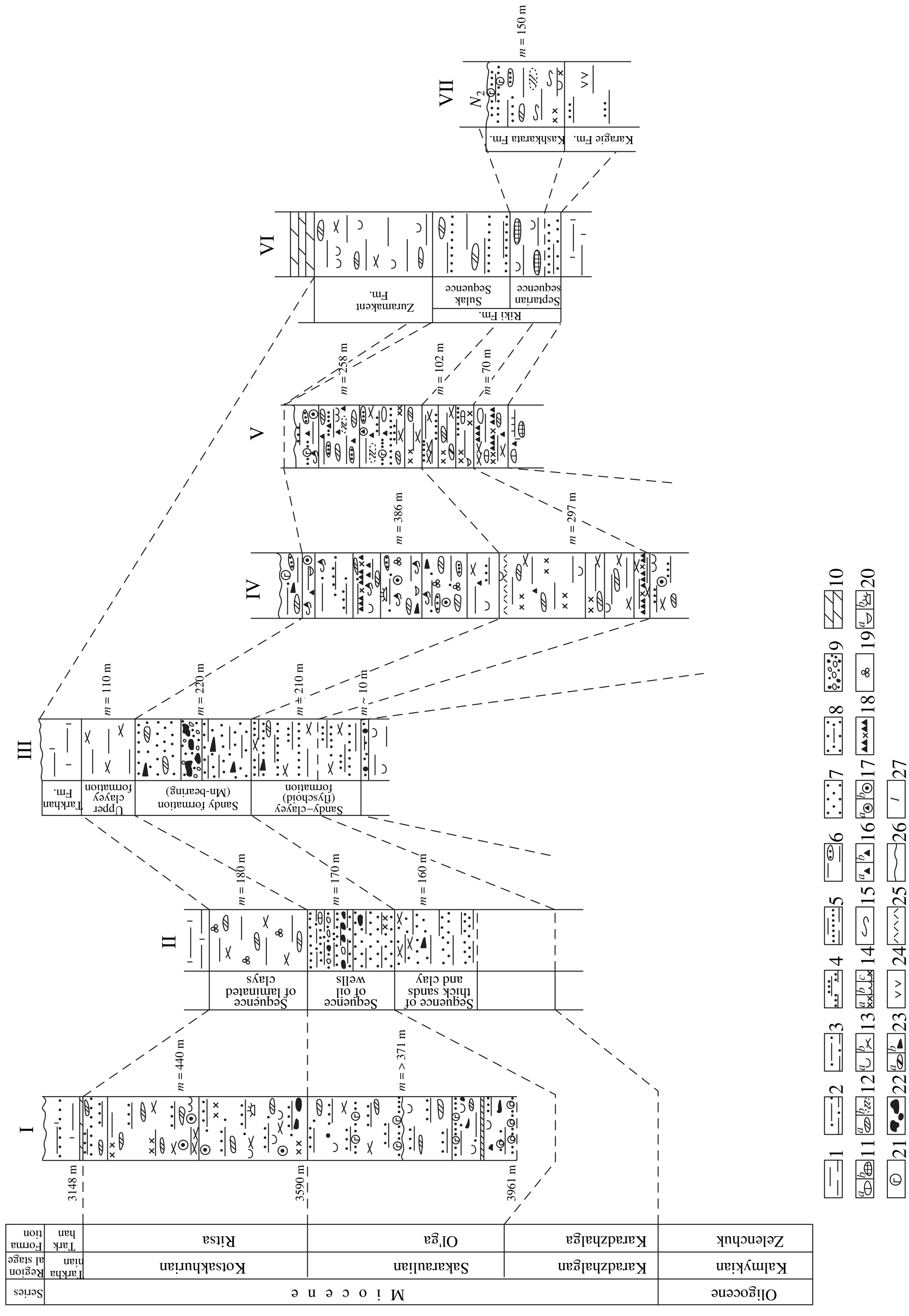
I
II
III
IV
V
VI
VII
3148 m
3590 m
3961 m
m = 440 m
m = > 371 m
m = 180 m
m = 170 m
m = 160 m
m = 110 m
m = 220 m
m = 210 m
m = ~ 10 m
m = 386 m
m = 297 m
m = 258 m
m = 102 m
m = 70 m
m = 150 m
Sequence of laminated clays
Sequence of oil wells
Sequence of thick sands and clay
Tarkhan Fm.
Upper clayey formation
Sandy formation (Mn-bearing)
Sandy–clayey (flyschoid) formation
Zuramakent Fm.
Riki Fm.
Sulak Sequence
Septarian sequence
Kashkarata Fm.
Karagie Fm.
Series
Regional stage
Formation
Miocene
Oligocene
Kotsakhurian
Sakaraulian
Karadzhalgan
Kalmykian
Ritsa
Ol'ga
Karadzhalga
Zelenchuk

Fig. 2. Correlation of Lower Miocene reference sections (locations of sections are shown in Fig. 1). (1) Clay; (2) calcareous clay; (3) silty clay; (4) clay with silt admixture; (5) clay with thin silt and fine-grained sandstone intercalations; (6) clay with silty lenses and nests; (7) fine-grained sand, sandstone, and siltstone; (8) siltstone and clayey sandstone; (9) gravel, sandstone, and pebblestone; (10) marl; (11) concretions: (*a*) calcite, (*b*) septarian; (12) siderite concretions: (*a*) beaded, (*b*) others; (13) scattered fish remains: (*a*) scale, (*b*) scale and bones; (14) accumulations of fish remains in clay: (*a*) bones, (*b*) scale, (*c*) scale and bones; (15) fucoids; (16) pyrite: (*a*) fine-dispersed, (*b*) fine-grained; (17) nest-shaped accumulations of pyrite: (*a*) fine-dispersed, (*b*) fine-grained; (18) interbeds of iron sulfides with admixture of bone detritus; (19) foraminifers; (20) other organic remains: (*a*) mollusks, (*b*) echinoderms; (21) glauconite; (22) manganese carbonate ores; (23) organic matter: (*a*) jet, (*b*) humic, bituminous; (24) algal remains; (25) tuffite interbeds; (26) unconformable boundaries; (27) numbers of reference sections.

The **Ol'ga Formation** (200–400 m) consists of gray clays with admixture of silty material and sporadic fish remains. The clays are usually massive with fucoids filled with iron sulfides, which also make up spotty ("sooty"), globular, and buckshot aggregates. Some section fragments are characterized by the presence of various siderite structures ranging in size from thin (up to 5 cm) vague segregations to well-developed (0.10–0.15 m thick) aggregates.

Organic remains are represented by impressions of echinoderms, fragments of molluscan shells, coaly detritus, and relatively large (1–2 mm across) foraminiferal tests. In the stratotype section near the Ol'ginskaya (now Kochubeevskaya) Settlement, Ter-Grigor'yants (1969) identified *Neobulimina elongata* Orb., *Bolivina* ex gr. *floridana* Cushm., and other foraminifers.

We assume that the lower part of the Maikop sequence recovered at the depth interval of 3590–3961 m (apparent thickness 371 m) in the superdeep Borehole SG-12000[2] drilled in the western part of the Indol–Kuban Trough also belongs to the Ol'ga Formation (Fig. 2, Section I).[2] It is largely composed of uniform, gray to dark gray, massive or lenticular–bedded silty clays with rare thin (up to 0.1 m) interbeds of fine-grained sandstone, sometimes with the sinuous basal surface. Siderite concretions are scattered throughout the entire section.

Clayey sediments in the basal part of the recovered section (89 m) are characterized by the high sand content and relatively thick (several meters) sandstone units with cross- and lenticular-bedded structures indicating high-energy hydrodynamics of sedimentation environments. The fine-grained glauconite-bearing sandstones are mainly composed of quartz.

T.A. Malakhova and T.N. Pinchuk determined the following foraminiferal species in sediments attributed to the Ol'ga Formation: *Hyperammina djanaica* Bogd., *H. caucasica* Bogd., *Haplophragmoides* ex gr. *kjurendagensis* Moros., *H.* ex gr. *rotundidorsatus* (Hantk.), *Ammodiscus tenuiculus* Subb., *Trochammina* aff. *floridana* Subb., *Neobulimina* sp., and others.

The **Ritsa Formation** (depth interval 3148–3590 m) is composed of dark gray to black clay with silty coating on bedding surfaces and dispersed fish remains that represent the more or less developed "fish facies." The abundance of silt in the lower part of the formation (210 m) is atypical of sediments of the fish facies.

The uppermost layers of the Ritsa Formation (50 m) at the contact with the conformably overlying Middle Miocene Tarkhanian sediments consist of similar dark gray clays without fish remains.

The Ritsa sequence is characterized by siderite concretions and the specific *Saccammina* foraminiferal assemblage of the Kotsakhurian regional stage: *Saccammina zuramakensis* Bogd., *S. ovalis* Subb., *S.* aff. *suzini* Bogd., *Hyperammina djanaica* Bogd., *H. caucasica* Bogd. (determinations by T.A. Malakhova and T.N. Pinchuk).

It should be noted that this assemblage of guide species in the Ritsa Formation is supplemented with typical forms of the underlying Ol'ga Formation: *Haplophragmoides* aff. *kjurendagensis* Moros., *H.* aff. *rotundidorsatus gratus* Ter-Grig., and *Neobulimina elongata* Orb. These species are probably redeposited forms.

We should once more mention the issue of the boundary between the Maikop and Tarkhan sediments in this section. This issue arises in connection with findings of the Tarkhanian species *Globigerina* ex gr. *tarchanensis* Subb. in the upper layers (50 m) that belong to the Maikop Group (unknown clays) in terms of lithology. This fact implies a gradual, lithologically ulterior transition between the Maikop and Tarkhan (Kuva Beds) sediments.

Thus, the thickest, relatively deep-water Lower Miocene sediments of the central and western areas of the Ciscaucasia are characterized by the abundance of fish facies in the Karadzhalga and Ritsa formations, whereas fish remains are scarce in the transitional Ol'ga Formation. The abundance of sandy–silty material in the fish facies of the Ritsa and, particularly, Ol'ga formations in the central Indol–Kuban Trough (Borehole SG-12000), i.e., far from its possible sources, is rather unusual.

According to (Kalinenko, 1990), substantial facies changes in the Lower Miocene sections are related to the presence of deltaic facies that control the Laba manganese deposit in the Ol'ga Formation of the western Ciscaucasia; the Batalpashinsk Formation in the deposit is overlain by sands (up to 10 m thick) with lenses of gibbsite–kaolinite material that includes nests of manganese hydroxides; and the overlying sandy–clayey formation (up to 210 m thick) is represented by flyschoid alternation of thin (millimeter-scale) silt and clay laminae (Fig. 2, Section III). Kalinenko

[2] The detailed characteristics of the Kuban superdeep Borehole SG-12000 section will be considered in a separate paper.

attributes this entire sequence to the Upper Oligocene Zelenchuk Formation.

The flyschoid sediments are overlain by the so-called sandy formation. Despite the name, this sequence is largely composed of sandy–silty–clayey sediments. Sands form a relatively thin unit (5–40 m) in the middle part of the sequence, which contains manganese carbonate ores recognized as the manganese ore unit. Moreover, Kalinenko termed the entire sandy formation as the three-member manganiferous sequence. He correlated its subore part (110 m) with the Karadzhalga Formation and the manganese ore and supraore sediments (90 m) with the Ol'ga Formation.

It should be noted that such stratigraphic subdivision of sediments in the Laba deposit area is virtually unsubstantiated and is based only on the arbitrary attribution of flyschoid sediments to the Upper Oligocene Zelenchuk Formation. However, the flyschoid sequence should also be correlated with the Karadzhalga Formation. As will be shown below, the similar undivided Zelenchuk–Karadzhalga sequence is also observed in other areas of the Ciscaucasia. Therefore, we refer the whole manganiferous sequence to the Ol'ga Formation. Such interpretation is supported by findings of diatom species *Jsthmia szaboi* Pant, which is typical of Miocene sediments of the Paratethys, in flyschoid sediments (Kalinenko, 1990).

The manganiferous sequence is conformably overlain by thin clayey sediments with fish remains, which are defined in the study area as the upper clayey formation (up to 110 m thick). They contain the guide foraminiferal assemblage of the uppermost part of the Maikop Group (*Saccammina*) that is typical of the Ritsa Formation.

The manganiferous sediments are characterized by erosional boundary in the south. They are replaced by ore-barren clays in the northern and latitudinal directions and are confined to deltaic complex of the Laba deposit.

Westward in the Neftegorsk area, Lower Miocene (and Oligocene) sediments include thick olistostromes without manganese mineralization (Fig. 2, Section II). The Maikop sequence characterized by a very intricate structure has attracted the attention of researchers owing to the presence of oil (Gubkin, 1912). Stratification of these sediments is ambiguous because of sharp lithofacies variations. Terrigenous sandy–clayey sediments make up extended NW-striking sleevelike gravitite bodies (hereafter, gravitite branches) that are traced over tens of kilometers.

In the Neftegorsk area, Gubkin defined the "laminated clay unit" up to 180 m thick in the uppermost part of the Maikop sequence. It matches the rather uniform Ritsa Formation of noncalcareous clays with fish remains, siderite concretions, and guide foraminiferal species *Saccammina ovalis* Subb.

These clays rest with a sharp lithological boundary upon a unit of alternating gravelstones, sandstones, siltstones, and clays up to 170 m thick. This "oil well horizon" defined by Gubkin correlates with the manganiferous sequence defined by Kalinenko (1990) at the Laba deposit. Its middle part (35–50 m) is composed of the coarsest rocks, such as gravely sandstones and small-pebbly conglomerates, probably, corresponding to the manganiferous sequence. They also include guide foraminiferal species of the Ol'ga Formation: *Neobulimina elongata* (Orb.), *Cibicides stavropolensis* Bogd., and *Bolivina* ex gr. *plicatella* Cushm. (Kalinenko and Svemberger, 1963).

Gubkin defined the underlying sediments (up to 160 m thick) as the "thick sand and clay horizon," which can correspond to the flyschoid sequence of the Laba area in terms of its stratigraphic position.

Thus, sediments of the Neftegorsk area underlying the Ritsa Formation are characterized by a frequent irregular alternation of compositionally diverse sediments. They include a more or less distinct stratigraphic analogue of the Ol'ga Formation (oil well horizon). Identification of sediments corresponding to the Karadzhalga Formation remains a problematic issue.

The presence of stratigraphic analogues of the Sakaraulian and Kotsakhurian regional stages in the Neftegorsk section makes it possible to correlate it with the Kuban superdeep Borehole SG-12000 section (Fig. 2, Section I). Basal layers of the Ol'ga Formation section (interval 3872–3961 m), which encloses the coarsest sandy layers, should presumably be correlated with the lithologically similar (coarsest) beds of the oil well horizon and the manganiferous horizon of the Laba section. In this case, the domain of coarse-grained sandy sediments of the Ol'ga Formation, which was previously limited by the North Caucasian homocline, can be significantly wider.

Thus, the structure of Lower Miocene sections in the Indol–Kuban Trough of the western Ciscaucasia is complicated by gravitite branches that are composed of coarse-grained oil-bearing rocks and deltaic sediments with manganese mineralization. The relatively deep-water clayey sediments enclose sulfide interbeds with metalliferous fish bone detritus and they are characterized by the maximal total thickness (~1100 m).

In northern areas of the central and western Ciscaucasia, the composition and structure of sediments in the upper part of the Maikop sequence demonstrate substantial changes, because they accumulated on relatively elevated structural–facies zones (Stavropol and Azov uplifts).

On the Stavropol Uplift, lithological features of stratotype sections of the Ol'ga and Ritsa formations are retained, whereas the underlying sediments demonstrate substantial variations. In this area, it is generally difficult to distinguish the Karadzhalga and Zelenchuk formations based on lithological properties. Therefore, they are united into the single *Uvigerinella californica* foraminiferal zone (Ter-Grigor'yants, 1969). As a result, the Oligocene–Miocene boundary, which corresponds to the base of the Karadzhalgan regional stage, is also indiscernible. At the same time, the roof of the Batalpashinsk Formation with analogues of the Alkun Beds (*Bolivina goudkoffi* Zone) is quite distinct.

In this area, the Zelenchuk–Karadzhalga complex is composed of greenish gray clays with an insignificant admixture of sandy material in the lower part (30–40 m), which is typical of the Zelenchuk Formation. Upsection, the clays become darker greenish to brownish gray and contain pyrite, siderite concretions, and abundant fish remains that are typical of the Karadzhalga Formation. According to (Ter-Grigor'yants, 1969), the total thickness of these sediments ranges from 70 to 174 m and the most characteristic foraminiferal species in them are *Uvigerinella californica* Cushm., *Haplophragmoides granatus* Ter-Grig., *Trochamminoides rotaeformis* Subb., and *Cibicides ornatus* Bogd.

The **Ol'ga Formation** (up to 160–180 m) in the central and northern parts of the Stavropol region shows lithological and faunal similarity with the stratotype section along the Kuban River (*Neobulimina elongata* Zone). The Ol'ga section is developed everywhere. However, it is reduced in some places because of the erosion of its upper layers that are overlain by the Chokrakian and Karaganian sediments. The Ol'ga Formation consists of greenish to brownish gray carbonate-free clays with an irregular admixture of sandy–silty material. In addition to zonal foraminiferal species, the sediments always contain *Cibicides stavropolensis* Bogd., and *Nonion polymorphus* (Ter-Grigor'yants, 1964).

West of the Stavropol Uplift, the Ol'ga Formation yields a diverse assemblage of shallow-water mollusks and echinoderms, which includes, in addition to numerous species inherited from the Oligocene, large *Glossus, Saxolucina*, and *Modiolus* resembling species described from the Sakaraulian regional stage (Popov *et al.*, 1993a).

In most of the sections, the uppermost part of the Maikop Group corresponding to the Ritsa Formation is preserved as a thin (10–30 m, 100 m in rare cases) sequence of brownish gray clays with interbeds of siderite concretions and euryhaline foraminifers (*Saccammina zuramakensis* Bogd.).

Nikitina (1958, 1962, 1963) studied Maikop sequences in western areas up to the Azov Uplift. Like in the Stavropol region, she defined three foraminiferal zones in their upper part (*Uvigerinella californica, Neobulimina elongata*, and *Saccammina zuramakensis*) corresponding to the Zelenchuk–Karadzhalga, Ol'ga, and Ritsa stratigraphic complexes, respectively.

In the study area, the Oligocene–Miocene boundary is placed at the base of clays with *Uvigerinella californica* or *Neobulimina elongata* underlain by carbonate-bearing (or carbonate-free) clays with *Bolivina goudkoffi* or *Cibicides ornatus* that are stratigraphically correlated with the Alkun Horizon (Nikitina, 1958, 1962).

In the eastern Azov region, the complete section of the uppermost Maikop Group was penetrated by the Novominsk reference borehole (Fig. 1, Section VIII). This section contains both lithological analogues and all foraminiferal zones beginning from the *Bolivina goudkoffi* Zone of the Alkun Horizon. The overlying stratigraphic analogues of the **Zelenchuk Formation** (30 m) with foraminifers of the *Uvigerinella californica* Zone are composed of silty clays with a fine-grained sandstone interbed (2–3 m). Upward the section (20–25 m), sediments are sharply different and are represented by dark gray clays with fish remains that are typical of the **Karadzhalga Formation** in its stratotype section.

Similarity with the Kuban section is also noted in the composition of the overlying (40 m) sediments correlated with the **Ol'ga Formation.** They are composed of silty clays with an interbed (5–6 m) of slightly lithified sandstone with the foraminiferal assemblage of the *Neobulimina elongata* Zone.

The uppermost layers of the Maikop Group (25–30 m) overlain by the Karaganian sediments include thin-bedded clays of the *Saccammina zuramakensis* Zone that are typical of the **Ritsa Formation.**

Thus, the considered section offers opportunity to outline the lower boundary of the Karadzhalga Formation, which is accepted as the base of the approximately 90-m-thick Lower Miocene section.

With respect to their structural position, the northern areas represent relatively uplifted zones of the southern Russian Platform and Karpinsky Ridge fringed by the Manych Trough. Within lower reaches of the Don River and the Ergeni area, Lower Miocene sections are usually incomplete and composed of stratigraphic analogues of the Karadzhalga and Ol'ga formations. The thickest sections of relatively deep-water sediments are confined to troughs, while elevated surfaces include the shallow-water poorly stratified sediments.

Panteleev (1947) proposed the first stratigraphic subdivision of Maikop sediments for the southern Ergeni area. He defined the following stratigraphic units in the upper part of the section (from base to top): Nugra, Aradyk, and Tsagankhak formations. They are correlated with the Zelenchuk, Karadzhalga, and Ol'ga formations. Panteleev did not identify analogues of the Ritsa Formation at lower reaches of the Don River and in the Ergeni area, Nikitina (1958) established the following three foraminiferal zones (from base to top): *Cibicides ornatus, Uvigerinella californica*, and *Caucasinella (Neobulimina) elongata.*

The Maikop Group was scrutinized in many boreholes drilled in connection with the wide development of uranium–rare metal deposits in this region (Stolyarov and Ivleva, 2004). Based on these materials, the new stratigraphic scheme was proposed for the subdivision of Maikop sediments (Semenov and Stolyarov, 1988; Voronina *et al.*, 1988). According to this scheme, the Kalmyk and Nugra formations were initially included into the Upper Oligocene. Subsequently, it became clear that the Nugra Formation should be correlated with the Karadzhalga Formation rather than the not Zelenchuk Formation. In the modified scheme, the Oligocene–Miocene boundary was drawn at the roof of the Kalmyk Formation (Stolyarov and Ivleva, 2004).

The transition between the Kalmyk and Nugra formations is usually gradual. The boundary is more distinct in relatively thick sections of depressions (Stolyarov and Ivleva, 2004). In other areas of the Volga–Don region, the Nugra Formation is preserved only fragmentarily and is recognizable based on finds of mollusks *Nucula gracilis, Polliolum incomparible* (Risso), and *Plagiocardium* cf. *abundans* (Voronina *et al.*, 1988). The foraminiferal assemblage in the Nugra Formation is similar to that in the underlying upper Kalmykian sediments (*Cibicides ornatus* Zone).

The overlying Aradyk and Tsagankhak formations (250–300 m in total) are only preserved in the Manych Trough. Their boundary with the Nugra Formation is usually obscure because of uniform lithology in the upper part of the Maikop Group composed of greenish to brownish clays with sandy and silty units. According to Ter-Grigor'yants, they contain foraminifers of the *Neobulimina elongata* Zone.

The Eastern Ciscaucasia

In the eastern Ciscaucasia, the composition and structure of the Maikop sequence are governed by the development of the Terek–Kuma (Terek–Caspian) Trough bordered by the Stavropol Uplift in the west. The Maikop sequence demonstrates substantial lithofacies variations partly related to the formation of large clinoform bodies and olistostromes (Kosova, 1994; Sharafutdinov *et al.*, 1999; Stolyarov, 2001; Stolyarov and Ivleva, 2004). The variable composition of sediments and their impoverishment in fossils make it difficult to define stratigraphic analogues of regional stages mentioned above and to correlate the Oligocene–Lower Miocene boundary with the base of the Karadzhalga regional stage.

Shatsky (1929) distinguished the Riki and Zuramakent sequences (formations) in the upper part of the Maikop sequence above Upper Oligocene (Miatly–Mutsidokal) sediments in Dagestan sections. Subsequent studies showed that only the Zuramakent Formation is distinctly traced in the entire eastern Ciscaucasia (Sharafutdinov *et al.*, 1999). Correlation of the Riki Formation, which is usually subdivided into the Assa and Sulak beds, is less certain. The Assa Beds were correlated with the Zelenchuk and Karadzhalga formations of the eastern Ciscaucasia, while the Sulak and Zuramakent sediments were correlated with the Ol'ga and Ritsa formations, respectively (Popov *et al.*, 1993a). Consequently, the Oligocene–Miocene boundary was conditionally placed inside the Assinian sediments. As was shown above, similar situation with determination of the Oligocene–Miocene boundary is typical of some areas in the western Ciscaucasia, where discrimination between the Zelenchuk and Karadzhalga formations is impossible.

In the Terek–Kuma Trough, several boreholes virtually recovered the complete Maikop sequence, except for the Ritsa Formation at the termination of the Mineral'nye Vody Uplift. The Alkun Beds of calcareous clays in the uppermost part of the Batalpashinsk Formation and overlying Upper Oligocene Zelenchuk Formation are distinctly defined in this region. Therefore, we could draw the lithological boundary between the Karadzhalga and Zelenchuk formations (Fig. 2, Section V).

The **Zelenchuk Formation** (100 m) is composed of dark gray clays with numerous sulfide intercalations, like in the eastern Kuban region, where this unit hosts the large Cherkessk sulfide lode (Stolyarov and Ivleva, 2004). Similar to western areas, the overlying **Karadzhalga Formation** (115 m) largely consists of sediments of the fish facies locally with large bone remains. Sometimes, the clays contain a coating of silty material and siderite concretions up to 5 cm thick.

The upper part of the Maikop sequence penetrated at the interval of 30–220 m corresponds to the **Ol'ga Formation**. It is composed of light gray massive clays with abundant lenticular inclusions of silty material mostly represented by quartz and subordinate glauconite. Siderite aggregates are abundant. They occur mainly as rudimentary concretions ranging from tiny to thin (1 cm) lenticular-nested accumulations that impart the brownish spotty pattern to sediments. One can also see well-developed concretions up to 0.1 m across.

Various iron sulfide aggregates, which range in size from buckshot and sooty (spotty) structures to crystalline formations developed after fucoids, are widespread. Fish remains are relatively rare. They do not form the typical "fish facies." However, accumulations of fish scales and small bones locally occur along bedding surfaces.

It should be noted that accumulations of silty material locally crosscut the bedding surface at an angle of 45° and fill up vertical fissures in clays. This indicates high-energy hydrodynamics during sedimentation.

Thus, the Upper Oligocene Alkun and Zelenchuk beds, as well as the Lower Miocene Karadzhalga and Ol'ga formations, are distinctly traced at the southwestern flank of the Terek–Kuma Trough, whereas the Ritsa Formation is missing (eroded).

In eastern areas of the Ciscaucasia, the upper part of the Maikop Group is composed of the Riki and Zuramakent formations identified by Shatsky. In these areas, Prokopov (1938) also established the Alkun Beds (calcareous clays), which confidently indicate the base of the Riki Formation. The latter was subdivided into the lower Assa (Prokopov, 1938) and upper Sulak (Zolotnitskii, 1933) sequences. In terms of stratigraphic range, the Assa sediments correspond to the Zelenchuk and Karadzhalga formations; the Sulak sediments, to the Ol'ga Formation.

It is worth mentioning that the identification of the Assa and Sulak sequences is ambiguous in some areas of the eastern Ciscaucasia. Moreover, the Assa sediments are locally defined as the Septarian Horizon (Sharafutdinov *et al.*, 1999). Poor paleontological substantiation of these sediments and facts mentioned above hamper the establishment of the Oligocene–Miocene boundary in the eastern Ciscaucasia.

According to Zolotnitskii, the Alkun sequence in the northeastern Ciscaucasia is overlain by a sequence of gray clays (150–200 m) with thin sandy interbeds (Assa sequence) that contain marly septarian nodules, which are missing from some sections. The sand content is also variable. In the lower part overlying the Alkun Horizon, sandstone beds are frequent and thick (sandy members). This meter-scale interval of the Assa sequence is correlated with the Zelenchuk Formation.

The upper (major) part of the Assa sequence, which probably corresponds to the Karadzhalga Formation, is composed of gray clays with rare thin sandy–silty interbeds and irregularly scattered carbonate concretions.

Zolotnitskii defined the overlying Sulak sediments (100–150 m) in the eponymous river valley based on the appearance of various siderite aggregates in gray clays. The siderite aggregates range from rudimentary structures, which impart brownish spotty patterns to rocks, to bead-shaped concretions similar to those in the Ol'ga Formation in western areas of the Terek–Kuma Trough. The Sulak clays are generally gray. However, they become darker in the upper part of the section.

In recent works devoted to Dagestan, Sharafutdinov *et al.* (1999 and others), did not distinguish the Assa sediments and divided the Riki Formation into the Septarian and Sulak sequences that are most distinctly traced in natural outcrops of the Sulak tectonic ledge (Fig. 2, Section VI).

The **Septarian (Assa) Horizon** (80–100 m) is composed of gray clays with silty interbeds in the lower part of the section. Large lenticular septarian nodules of dark gray marls (up to 1 m thick) make up reference units.

The **Sulak Horizon** (100–150 m) is also composed of clays with thin silty intercalations and siderite concretions in the upper part.

According to (Sharafutdinov *et al.*, 1999), the Riki Formation is clearly distinguished in the Maikop Group by a notable natural radioactivity in gamma-logging records, including the gamma-logging reference P_3-GL level, which is traced in the lower part of the section in almost all boreholes.

Let us remind that the Zelenchuk and Karadzhalga formations in the western areas of the Ciscaucasia enclose both the U-bearing "fish facies" and stratiform bone–sulfide deposits with uranium–rare metal mineralization (Cherkessk and Urakovo–Bogoslovskoe). Thus, high uranium concentrations in the Oligocene–Miocene boundary strata are also typical of eastern areas of the region, where clayey sediments locally contain abundant fish and plant remains. Other fossils are relatively scarce and represented by foraminifers *Ammodiscus tenuiculus* Subb. and *Orbulina micra* Subb., sponges, and spherical radiolarians (*Cenoshpacra and Distiomicro*) (Sharafutdinov *et al.*, 1999).

The **Zuramakent Formation** corresponds to the uppermost layers of the Maikop Group in the eastern Ciscaucasia and represents an analogue of the Ritsa Formation in western areas. In terms of lithology, the Zuramakent Formation is relatively uniform and is distinguished from the underlying sediments by the prevalence of dark gray to almost black clays. The clays enclose various siderite structures ranging from the stratiform elongated-lenticular aggregates to the typical isolated very hard concretions. According to Uspenskaya (1936), siderite concretions are characterized by the high Mn content (up to 4.6%).

Clays of the Zuramakent Formation usually contain a dissemination (sometimes, abundant) of fish remains and rare *Saccammina zuramakensis*, the guide species for this part of the Maikop Group (Sharafutdinov *et al.*, 1999).

The uppermost part of the formation located adjacent to the Tarkhanian sediments is represented by paler clays (up to 30 m) with abundant *Amphisyle* remains (the *Amphisyle* Clay). V.V. Menner also determined *Clupeonello brevicauda* Meck. and *Steidachorella sculptata* Well. among fish remains (Sharafutdinov *et al.*, 1999).

The fine-dispersed laminated Zuramakent clays have the hydromica–beidellite composition with thin silt intercalations in some places. As compared with underlying clays of the Riki Formation, they are marked by a lower natural radioactivity (Sharafutdinov *et al.*, 1999).

The Zuramakent Formation is usually 150–170 to 230–290 m thick in Dagestan and northern Ossetia. In some areas of Dagestan, sediments of this formation transgressively overlie different-age sediments. In the unique Kichigamri River section, the upper Zuramakent beds (only 7 m thick) are sandwiched between the Maestrichtian eroded surface and the younger Tarkhanian marl (Sharafutdinov *et al.*, 1999). Low thicknesses and transgressive relationships of the Zuramakent Formation with the underlying Khadumian–Upper Cretaceous strata are also observed in southern Dagestan. In the major part of the eastern Ciscaucasia, the Zuramakent Formation has a conformable contact with the underlying sediments.

In northern (central) areas of the Terek–Kuma Trough, the Maikop sediments are recovered by numerous deep oil wells. However, they are insufficiently studied because of poor core recovery. Ter-Grigor'yants (1964, 1969) carried out their stratification based on microfossils.

Calcareous–dolomitic rocks of the Alkun Horizon in the Trans-Terek Plain section are overlain by a thick (up to 700 m) clayey sequence with thin sandy members that are most completely described in cores from the Ozek–Suat field. The gray to dark gray compact carbonate-free clays are characterized by the following monotonous foraminiferal assemblage: *Uvigerinella californica* Cushm., *Cibicides ornatus* Bogd., *Elphidium onerosum* Bogd., *Nonion polymorphus* Bogd., and *Haplophragmoides kjurendagensis* Moros. This sequence is probably an analogue of the Riki Formation (Assa and Sulak horizons).

The upper part of the Maikop Group (up to 450 m thick) corresponding to the Zuramakent Formation is composed of dark gray clays in all wells of the Ozek–Suat field and in wells Pravoberezhnaya R-3, Priozernaya R-5, and Pravokumskaya R-8. They contain the following agglutinated foraminifers: *Saccammina zuramakensis* Bogd., *S. bulla* Bogd., *Haplophragmoides latidorsatus* (Bornemann), *H.* aff. *kjurendagensis* Moros., and *Trochammina depressa* Subb.

Thus, the Oligocene–Miocene boundary is even more uncertain in central areas of the Terek–Kuma Trough because of the impossibility to subdivide the Riki Formation and identify analogues of the Assa Sequence (in particular, the probable counterpart of the Karadzhalgan regional stage).

THE SOUTHERN MANGYSHLAK AREA

At the beginning of the Middle Miocene, Maikop sediments developed east of the Caspian Sea were subjected to tectonic deformations and, as a consequence, to significant erosion. Therefore, their complete sections are missing from the entire Mangyshlak region and the overlying Middle Miocene sequences begin with different-age (occasionally, Chokrakian; most commonly, Karaganian or Konkian; and locally, Sarmatian) horizons.

In this connection, Lower Miocene strata were not defined in the Maikop sequence at all in the first subdivision (Stolyarov, 1958). Subsequently, when large (3–5 cm) shells of molluscan species *Tellina* sf. *planata* L., *Nucula kalmikensis* Liv., and *Corbula* sp. of the Early Miocene affinity were found in its uppermost sediments preserved in depressions (Merklin *et al.*, 1960), the lithological designation of this unit became necessary. As a result, Lower Miocene sediments were defined in the work mentioned above as the **Kashkarata Formation.** It should be noted, however, that its lower boundary is frequently arbitrary to a variable extent because of the gradual Oligocene–Miocene transition in many places of the southern Mangyshlak area and poor paleontological remains that are insufficient for tracing variations in biostratigraphic complexes.

The Kashkarata Formation was named after the eponymous ravine situated northwest of the Karagie Depression, where its paleontologically substantiated sediments were first recovered under Middle Miocene strata. In this area located near the Caspian Sea, the apparent thickness of the formation does not exceed 100 m.

In the stratotype section, laminated clays of the upper Karagie Subformation with silty coating and algal remains are gradually replaced by massive gray clays with conchoidal fracture of the Kashkarata Formation. They are characterized by a high irregular admixture of silty and fine-grained sandy material, which frequently contains a significant amount of glauconite grains that impart spotty greenish color to rocks.

The Kashkarata Formation in the Caspian area differs from the underlying Karagie Formation by a relatively diverse (both in quantitative and qualitative respects) foraminiferal assemblage. T.N. Bondareva, V.G. Morozova, and L.S. Ter-Grigor'yants found numerous species inherited from the upper Karagie Subformation, such as *Nonion* aff. *polymorphus*, *Bolivina mississipiensis* Cushm., *Elphidium* aff. *onerosum* Bogd., and *Uvigerinella californica* Cushm. In addition, the Kashkarata Formation includes new species, such as *Spiroplectammina* aff. *tereckensis* Bogd., *Bolivina* aff. *plicatella* Cushm., and others, as well as fragments of Ostracoda carapaces, echinoderm needles, pyrite casts of radiolarians, and spherical fish otoliths.

L.A. Kozyar (Kozyar and Stolyarov, 1962) carried out the palynological study of the entire Maikop section west of the Karagie Depression. She established the upper Maikopian (Lower Miocene) spores–pollen assemblage in sediments of the Kashkarata Formation, which characterizes more thermophilic vegetation as compared with that from the Karagie Formation.

East and south of the Karagie Depression, the more widespread Kashkarata Formation extends to the Ustyurt Plateau and Kara-Bogaz-Gol Bay. In this area, the Kashkarata Formation is characterized by a slightly different composition and structure. The sandy–silty admixture is abundant in clays. It is remarkable that its content is higher in the central part of the depression and the concentration increases toward the Caspian Sea. Near the Kendyrli Bay, the Kashkarata Formation was penetrated by boreholes at the interval of 96–221 m (Borehole 493). In the lower part (77 m), the Kashkarata Formation is composed of greenish gray silty clays with lenticular sandy–silty interbeds (up to 10–20 cm thick) and iron sulfide concretions developed after fucoids. Higher in the section (48 m), the clays are silty with lenses, nests, and pockets of sandy–silty material enclosing abundant glauconite grains and interbeds (2–4 m) of quartz–glauconite sand. The apparent thickness of the formation is 125 m.

In the eastern part of the South Mangyshlak Trough (Fig. 2, Section VII), the thickest (up to 150 m) sections of the Kashkarata Formation were drilled in the Kaundy and Zhaz-Gurly depressions. Its base is marked by beds with fish remains (Stolyarov and Ivleva, 2004). The sediments are represented by dark gray clays (up to 4 m thick) of the typical fish facies with bones and scales that locally form sulfide-free accumulations up to 1 cm thick at bedding surfaces. At the interval of 11 m, sediments of the fish facies are less developed and they enclose clay interbeds (up to 1–4 m thick) with fucoids.

The overlying sediments are lacking fish remains. The lower part of the section (30 m) consists of gray silt-free massive clays with fucoids. In some places, they include thin (2–3 cm) lenticular siderite aggregates (rudimentary concretions) typical of the Karadzhalga Formation of the Ciscaucasia.

Higher in the section (60 m), similar clays contain an irregular dissemination and lenticular accumulations of silty material and rare siderite concretions. In the uppermost part of the visible section (20 m), clays are characterized by the abundance of silty admixture and the presence of silty interbeds with glauconite.

Thus, Lower Miocene sediments of the Kashkarata Formation are developed in southern Mangyshlak in two areas separated by the Karagie Depression, where the sediments are missing. They are connected with underlying sediments of the Upper Oligocene (Karagie Formation) by gradual transition (a few meters). Only in the east, the base of the Kashkarata Formation is lithologically distinct owing to the presence of beds of the fish facies.

The lower Miocene clays contain a significant admixture of sandy–silty material and glauconite. They are also marked by massive structures with conchoidal fracture.

The Kashkarata Formation should undoubtedly be correlated with the Karadzhalga and Nugra formations of the Ciscaucasia and Volga–Don regions; i.e., it should be attributed to the Karadzhalgan regional stage. This inference is also supported by paleontological evidences.

The deposition of sediments of the Sakaraulian and Kotsakhurian regional stages (stratigraphic analogues of the Ol'ga and Ritsa formations of the Ciscaucasia) in Mangyshlak remains a debatable issue.

In conclusion, it should be noted that the overview of materials related to Lower Miocene sediments in central areas of the Eastern Paratethys primarily testify to different degrees of the completeness of their sections up to the point of their absence in some large areas. This is likely explained by an irregular development of erosional processes in the Neogene–Quaternary. At the same time, one cannot rule out that the uppermost layers of the Maikopian Group were not deposited in some areas. However, this important aspect has no confident interpretation. Therefore, analysis of the latest stages in the evolution of the Maikop Group remains a challenging task.

Similar uncertainty exists in the case of the upper boundary of the Maikop sequence even in some most complete sections, where transition to the Tarkhanian regional stage takes place via the intermediate Kuva Beds that are present in the Maikop carbonate-free clays but are characterized by the presence of Tarkhanian foraminifers (Krasheninnikov *et al.*, 2003).

Most of the researchers consider the central Ciscaucasia with its typical well-exposed and thoroughly studied sections as the reference one for the Maikop Group stratification. In this region, the Oligocene–Miocene boundary placed at the base of the Karadzhalgan regional stage is quite distinct. In many other regions, this boundary is ambiguous from the point of view of both lithology and biostratigraphy. This statement is also valid for different sections (relatively deep-water thick sequences or shallow-water varieties with a high admixture of coarse-grained siliciclastic material).Generally, the Zelenchuk–Karadzhalga sedimentary complex cannot be subdivided in such sections.

Identification and stratigraphic correlation of the Sakaraulian and Kotsakhurian regional stages corresponding to the Ol'ga (Sulak) and Ritsa (Zuramakent) formations, respectively, is an easier task. It should be noted, however, that the younger the Lower Miocene sediments, the smaller their domains. Nevertheless, it is possible to outline general trends of their formation in lithofacies maps (Figs. 3–5).

FACIES–PALEOGEOGRAPHIC SEDIMENTATION ENVIRONMENTS

Evolutionary–geological aspects of the Maikop Group formation have a great importance for understanding processes of the accumulation of the thick (up to 4–5 km) clayey sequence and the formation of unique (in scale and genesis) sedimentary manganese and uranium–rare metal deposits (Strakhov *et al.*, 1968; Stolyarov, 1993, 1996; and others). They reflect two grandiose (Early Oligocene manganese and Late Oligocene uranium–rare metal) ore epochs.

The issue of H_2S-contamination of bottom waters in the Maikop basins, one of the major ore-forming factors in the study region (Sapozhnikov, 1967, 1984; Stolyarov, 1993, 1996; Kochenov and Stolyarov, 1996; Varentsov *et al.*, 1997; and others), is considered from the geochemical standpoint in several works (Kholodov and Nedumov, 1991; Nedumov, 1998; and others).

The terminal (Early Miocene) stages in the formation of the Maikop Group were also accompanied by the concentration of manganese and rare metals, but the latter process was less intense (Kalinenko, 1990; Kochenov and Stolyarov, 1996; and others). Their consideration can shed light on evolutionary–geological and metallogenic peculiarities of the Maikop sedimentary basins.

We analyzed the characteristics of Oligocene basins in the central part of the eastern Paratethys in several papers (Stolyarov, 1991, 1999, 2001; Stolyarov and Ivleva, 2004; and others). Popov *et al.* (1993b) discussed the evolution of the Eastern Paratethys during the Late

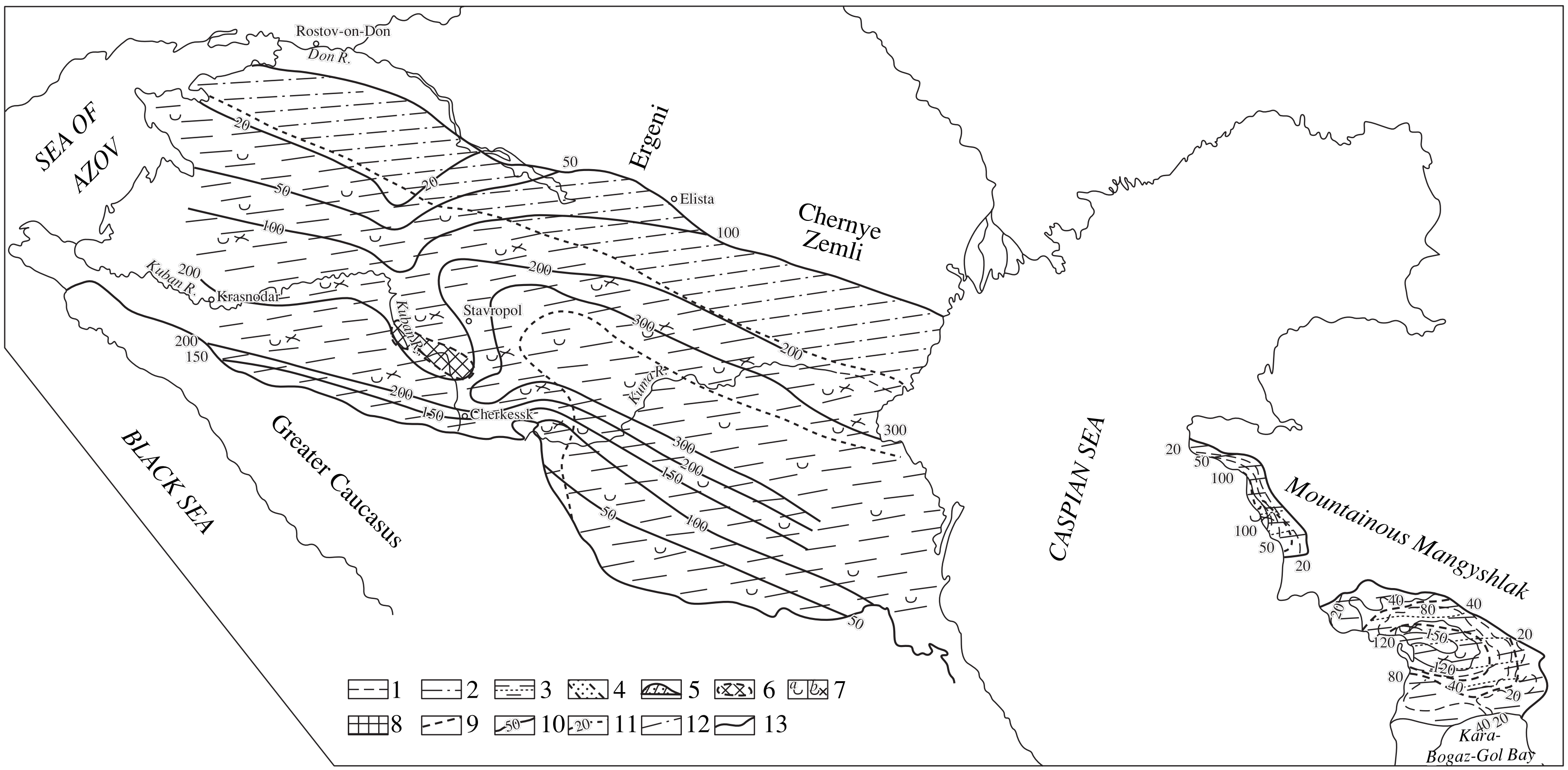

Fig. 3. Lithofacies map of the central Eastern Paratethys (Karadzhalgan time). (1) Clay; (2) silty clay; (3) clays with sandy and silty interbeds; (4) sediments of mudflows (gravitites and turbidites): sand and silt; (5) deltaic sediments; (6) areas with uranium–rare metal occurrences; (7) fish remains (scales and bones): (*a*) scattered, (*b*) accumulations; (8) assumed land; (9) boundaries of lithological complexes (lithofacies); (10) isopachs; (11) isopachs of incomplete sections; (12) domains of complete and incomplete sections; (13) present-day domain of Lower Miocene sediments.

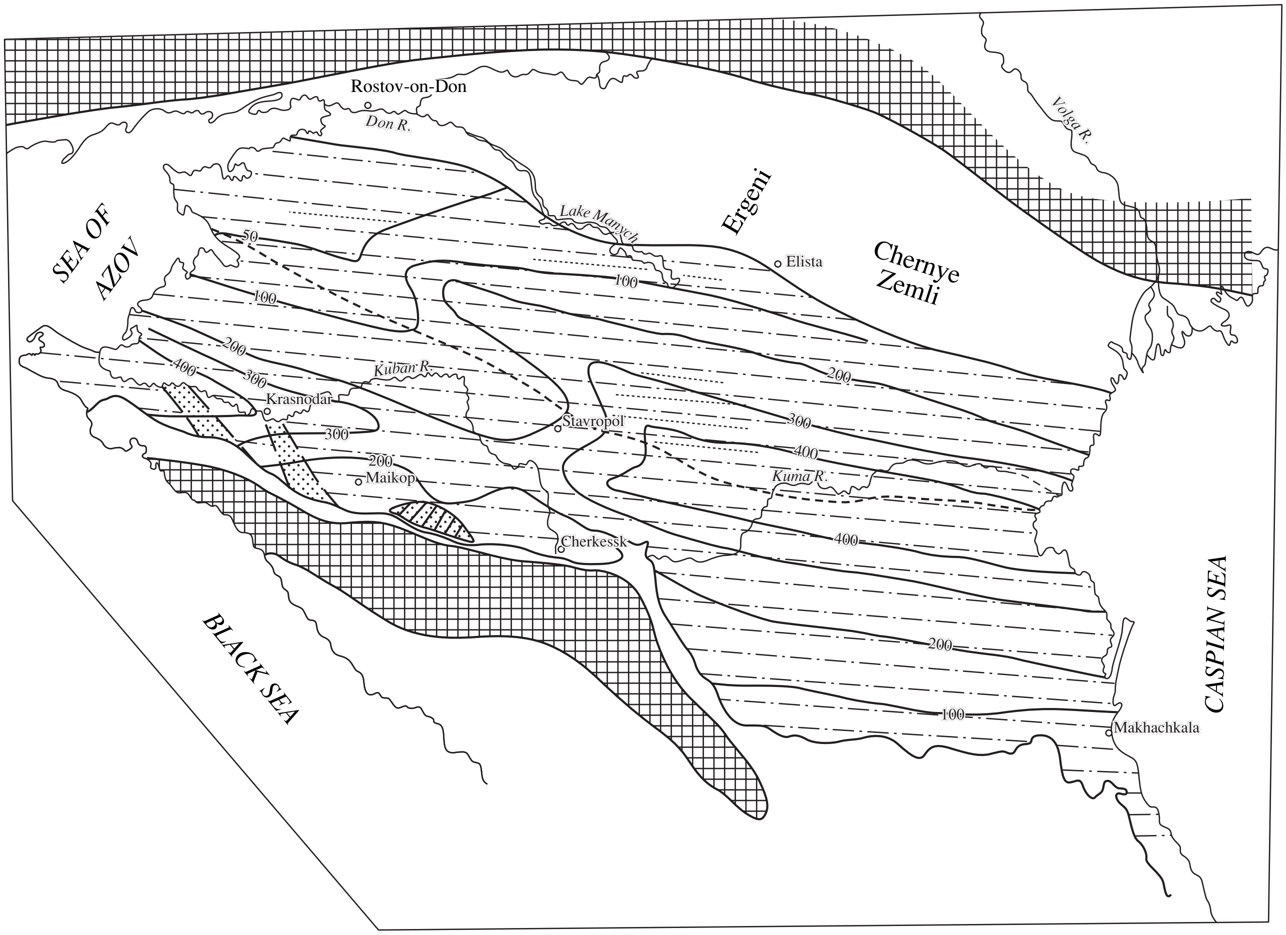

Fig. 4. Lithofacies map of the central Eastern Paratethys (Sakaraulian time). For legend, see Fig. 3.

Eocene–Early Miocene. They compiled the composite lithofacies map for the Karadzhalgan and Sakaraulian regional stages to illustrate the development of Early Miocene basins. Separate maps for these stages are given in the present communication (Figs. 3, 4). We have also attempted to illustrate the latest (Kotsakhurian) stage in the formation of the Maikop Group (Fig. 5).

With respect to tectonics, the central Eastern Paratethys represents the young (epi-Hercynian) Central Eurasian Platform consisting of the Scythian and Turan plates bordered by the ancient East European (Russian) Platform in the north. The boundary zone between them is marked by the sublatitudinal Karpinsky Ridge. Structural patterns of the Transcaspian region are determined by the Mangyshlak folded megastructure that forms, together with the Karpinsky Ridge, an extended tectonic lineament (Rezvoi, 1993).

The structure of the epi-Hercynian platform was controlled by the combination of linear sublatitudinal and submeridional structures that played an important role in the formation of Oligocene sea basins (Stolyarov and Ivleva, 2004). The central part of the Eastern Paratethys comprised the following major structural–facies zones: (1) Azov–Volga–Don; (2) Ergeni–Stavropol–Timashevskaya; (3) Karpinsky Ridge; and (4) eastern Ciscaucasia and Mangyshlak.

The largest opposite structural–facies and paleogeographic zones were located in the northwestern Ciscaucasia and lower course of the Don River, on the one hand, and in spacious regions of the eastern and southern Ciscaucasia, on the other. The Azov Uplift and Donbas structures of the East European Platform, as well as the western part of the Karpinsky Ridge, were always elevated. In contrast, areas of the eastern and southern Ciscaucasia were subjected to continuous subsidence. All these structural elements with different tectonic regimes were separated by the arcuate Ergeni–Stavropol–Timashevskaya zone that represented the spacious outer shelf of the northeastern Ciscaucasia basin complicated by contemporaneous uplifts.

The sublatitudinal lineament, which is composed of the Karpinsky Ridge and Mangyshlak structures and is divided into several uplifts and depressions, represented another major structural–facies zone of the Oligocene basin. These structures formed a complex system of islands and shoals that controlled the formation

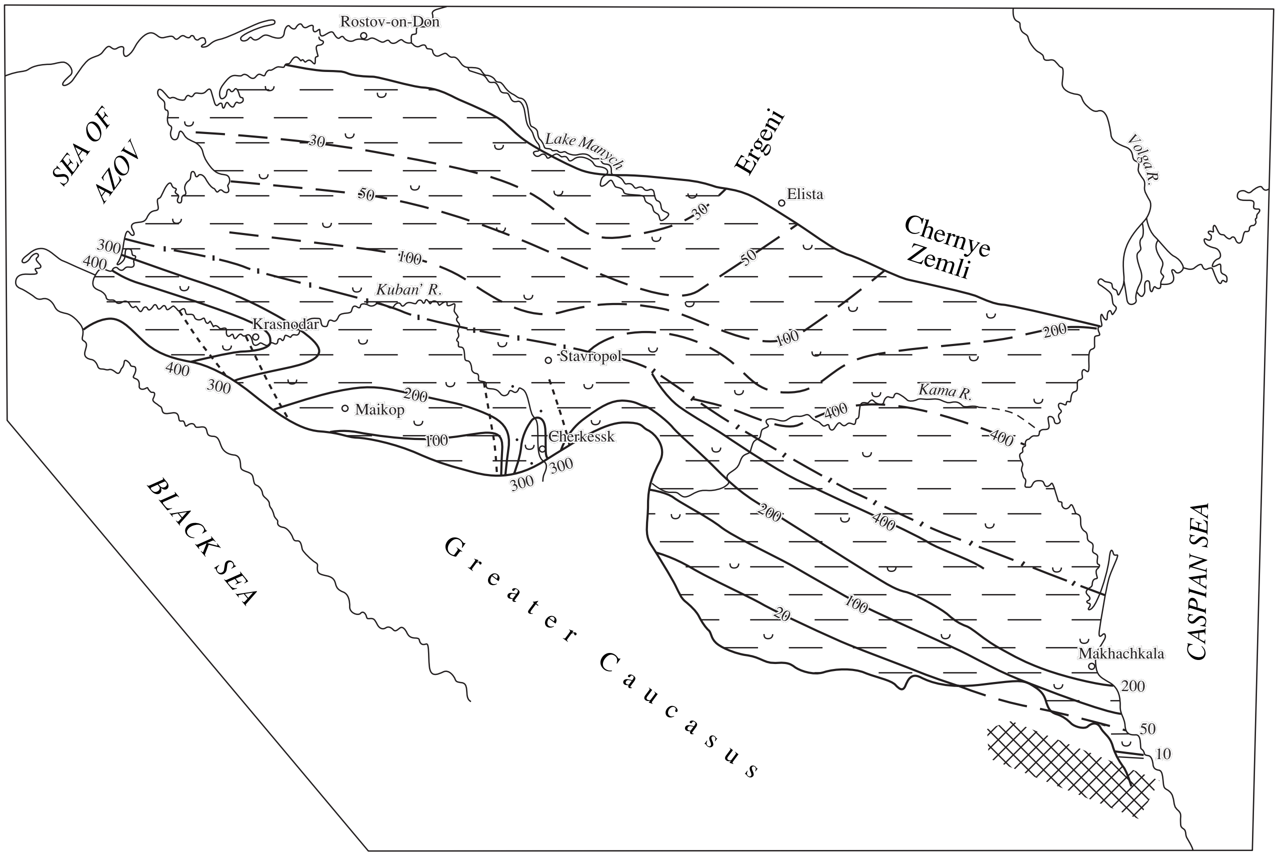

Fig. 5. Lithofacies map of the central Eastern Paratethys (Kotsakhurian time). For legend, see Fig. 3.

of all deposits of bone detritus and iron sulfides in the Ergeni and Mangyshlak regions during the Late Oligocene (Stolyarov and Ivleva, 2004).

The structural–facies zones mentioned above formed the outer shelf and represented the major metallogenic element of the Late Oligocene basin extending from the Azov Sea to Mangyshlak over approximately 1500 km. The shelf was everywhere separated by steep slopes of deep basins filled with H_2S-contaminated waters. At the end of the Oligocene (late Kalmykian–Zelenchuk time), the paleogeographic situation in the basin drastically changed owing to ascending tectonic movements. They resulted in relative leveling of the bottom relief and reduction of the H_2S-contaminated area. Consequently, the formation of metalliferous deposits almost completely ceased on the northern shelf. At the same time, sedimentation environments favorable for the accumulation of bone detritus and iron sulfides began to appear on the shelf in the southern Caucasian part of the basin, where deep-water H_2S-contaminated zone was preserved (Cherkessk deposit).

Thus, terminal stages of the Late Oligocene evolution of the central Eastern Paratethys was marked by ascending tectonic movements and general leveling of the seafloor. The growth of the Caucasian archipelago resulted in the slight shoaling of the adjacent deep uncompensated basin and the appearance of geological prerequisites for the formation of the Cherkessk deposit on its shelf. However, the ore formation process was complicated by the avalanche sedimentation of sandy–silty material transported from the Caucasus.

The ascending tectonic movements and growth of the Caucasian archipelago also resulted in convergence of the archipelago with the shelf zone of the northwestern Ciscaucasia. In the terminal Oligocene, this area was marked by the development of some morphological elements of the future South Stavropol Swell (e.g., banks and shoals) and the formation of thin (0.1–0.3 m) sulfide layers with fish bone detritus (Urakovo–Bogoslovskoe ore occurrence). The subordinate development of bone detritus and sulfide deposits in the uppermost Oligocene sediments was caused by unfavorable paleogeographic conditions.

In Mangyshlak, the Late Oligocene (late Karagie) basin was also characterized by the flattened bottom topography, absence of fish facies, and appearance of benthic communities (Merklin *et al.*, 1960). This resulted in termination of the ore-forming process that was most intense in the basin in the preceding early Karagie time.

The **Karadzhalga basin** (Fig. 3). The beginning of the Early Miocene was marked by a new pulse of descending tectonic movements that resulted in general deepening of basin and wider development of fish facies accumulated under H_2S-contaminated conditions. The Caucasian archipelago and adjacent southern part of the basin experienced the most intense subsidence. Consequently, the flux of relatively coarse-grained sandy–silty material from the Caucasus was exhausted and the H_2S contamination of waters became more widespread.

In the Stavropol and Azov uplifts, the northwestern shelf was most stable in terms of tectonics and was only subjected to low-amplitude subsidence. This area accumulated largely clayey sediments with fish remains that represented the more or less developed thin fish facies.

Like in the preceding Oligocene period, such tectonic regime governed the regional southeastern trend of lithofacies changes in Karadzhalga sediments. The major morphological element of the basin was represented by the outer shelf that incorporated the prominent South Stavropol Swell, where numerous thin (0.1–0.3 m) sulfide beds with fish bone detritus continued to accumulate. Such deposits are confined to lower parts of the Karadzhalga Formation (50 m) composed of the most typical fish facies. Upsection, they are replaced by clays without fish remains and sulfide interbeds.

In the southern part of the basin, uranium–rare metal mineralization was poorly developed because of the cessation of the influence of the Caucasian archipelago on sedimentation.

In the eastern South Mangyshlak Trough of the Transcaspian region, the basal part of the Lower Miocene (Kashkarata) section is composed of fish facies (10–20 m thick) with insignificant accumulations of bone detritus (Stolyarov and Ivleva, 2004). In this area, sediments accumulated mainly at shallower depths as clays without fish remains. Consequently, descending tectonic movements east of the Caspian Sea at the initial Miocene were relatively low-amplitude and shorter than in the Ciscaucasia. Such conditions prevented the development of uranium–rate metal mineralization in the Transcaspian region during the Early Miocene.

Thus, the Oligocene–Miocene boundary period in the central Eastern Paratethys corresponded to the pulse of descending tectonic movements. Subsidence was most intense in the Caucasian archipelago, as well as the Indol–Kuban and Terek–Kuma troughs, which accumulated clays of the deep-water fish facies and flyschoid sediments. The thickness of sediments decreases southward to 100–50 m, indicating uncompensated sedimentation in the Caucasian part of the basin.

In the shelf zone of the northwestern Ciscaucasia and in Mangyshlak, the amplitude of subsidence was lower. In these areas, sediments of the fish facies are relatively thin (20–100 m). They are completely replaced by silty–clayey sediments near the Karpinsky Ridge. It should be noted that subsidence in the Oligocene-Miocene boundary period was a relatively short-term episode and the evolutionary–geological development of the Karadzhalga Basin was characterized by a general regressive trend.

The **Sakaraulian basin** (Fig. 4). Sandy–silty–clayey sediments of the Ol'ga (Sulak) Formation, which apparently lack the fish facies, accumulated in a relatively shallow basin.

The Sakaraulian stage was characterized by differentiated tectonic movements. Against the background of continuing subsidence in Ciscaucasian troughs, the Caucasus region again experienced sharp uplift with the formation of an elevated archipelago that supplied the basin with coarse-grained material.

The major morphological elements of the northern and central parts of the basin were inherited from the preceding development stage. However, the outer shelf became more flattened. The South Stavropol Swell area was characterized by the disappearance of the shoal zone that controlled uranium–rare metal mineralization at the preceding stage.

The basin deepened progressively southeastward from the Azov Uplift to the Terek–Kuma Trough. The sediment thickness increased in the same direction from 30–50 m to more than 400 m. However, the thickness of the Ol'ga (Sulak) Formation in the southern part of the trough again reduced to 100 m, suggesting retention of the deepest zone of the basin with uncompensated sedimentation in this area.

A more drastic thickening of sediments is observed in the southern direction from the Azov Uplift toward the Indol–Kuban Trough, which underwent a more significant morphological differentiation owing to the formation of the Caucasian archipelago.

Paleogeographic and sedimentological changes (disappearance of the fish facies) in the Sakaraulian basin resulted in a substantial transformation of its metallogenic properties. Uranium–rare metal mineralization is absent on the outer shelf, but the ore-forming process resumed near the Caucasian archipelago. In contrast with the Late Oligocene (Zelenchuk time), when the Caucasian shelf was characterized by intense sulfidization and accumulation of bone detritus (Cherkessk deposit), the Sakaraulian time was marked by a relatively intense accumulation of manganese ores in the unique Laba deltaic complex of the Caucasus. However, the formation of gravitite branches in this area was not accompanied by Mn mineralization, and the gravitite branches are virtually sterile, probably, because of their substantially different formation conditions.

The coarse-grained sediments differ primarily by their spatial orientation in the sedimentation basin. Sediments of the paleo-Laba deltaic facies make up a 30-km-wide zone extending in the sublatitudinal direction along Caucasus Island over a distance of 100–110 km. In contrast, the gravitite (turbidite) branches, up to 100 km long and up to 30 km wide, extend in the meridional direction toward the central zone of the Indol–Kuban Trough. Let us consider the principal lithofacies properties of these anomalous features of the Sakaraulian basin.

Kalinenko (1990) scrutinized the composition and structure of the Laba paleodelta and identified the following facies in this area: (1) coastal and near-coastal sands and silts accumulated in the transitional zone between subaerial and subaqueous parts of the delta (thickness 5–10 m); (2) sands of the sallow-water deltaic platform (deltaic shoal) characterized by the multiple reworking of sediments and the removal of fine-grained fractions (thickness 10–25 m); and (3) unsorted clayey silts of the shelf-break zone or delta slope (thickness up to 50 m).

Thus, the shallow-water platform (the main part of the delta) was characterized by accumulation of the coarsest gravelly–sandy material because of the high-energy hydrodynamics and removal of manganiferous and other finer fractions. In contrast, the delta slope in the shelf-break zone was characterized by intense accumulation of the fine-grained Mn-bearing clayey–silty material.

However, manganese carbonate ores are confined to sands of the shallow-water deltaic platform. Therefore, Kalinenko assumed that their genesis is related to the development of postsedimentary elision processes, removal of Mn by ascending solutions, and its deposition in highly permeable sands of the deltaic platform with the formation of authigenic manganese carbonates.

Thus, manganese mineralization in the Laba deltaic complex proceeded in a closed ore-forming system. Accumulation of Mn-rich sediments along the periphery of the delta was one of the necessary conditions for this ore-preparatory process.

The main ore-forming process was realized through ascending solutions, which deposited the solid carbonate phase during their migration in line with geochemical stability of components of the hydrocarbonate system. Residual part of the solution produced Mn-siderite and several ferromanganese carbonates in silty sediments of the deltaic slope and only manganese carbonate (Ca-rhodochrosite) in sands of the delta platform (Kalinenko, 1990).

The largest up to 100-km-long gravitite branch was formed in the Neftegorsk area west of the Laba manganiferous delta (Gubkin, 1912; Grossgeim, 1960; Kalinenko, 1990). It is composed of anomalous sandy–silty members with the fine-grained sandy–clayey to coarse-grained sandy–gravelly material characterized by massive to cross-wavy structures that are typical of mudflows.

The formation of such large linear bodies with diverse sedimentary structures is presumably related to the intermittent influx of dense suspension flows associated with the underwater turbidite-forming slumping, from steep slopes of the Caucasus archipelago.

The Neftegorsk gravitite branch differs from the deltaic complex primarily by an irregular spatial alternation of compositionally different sediments. They lack manganese concentrations despite the proximity of the Laba deposit and wide distribution of other carbonates.

Calcite cement of sands is typically similar to that of calcite concretions in sands of the manganiferous sequence. Siderite frequently associated with calcite also makes up hard cement in sandstones and siltstones. It is worth noting that diagenetic carbonates are depleted in Mn ($MnCO_3$ 0.43–1.16%).

The clayey members enclosed in sandy–silty sequences also contain septarian calcite nodules that are absent in the manganiferous sequence (Kalinenko, 1990).

West of the Neftegorsk gravitite body, one can see another similar anomalous structure. Previously, it was considered a relatively small body (Popov *et al.*, 1993b), but now its continuation has been penetrated by a superdeep borehole drilled 50 km west of Krasnodar. In the basal part of the recovered Lower Miocene section (depth interval 3872–3961 m), the Ol'ga Formation is characterized by a high sand content and the presence of numerous sandy layers with cross-wavy and lenticular structures that indicate the high-energy hydrodynamics of sedimentation environments. Thus, the gravitite branch extended northwestward over more than 50 km as far as the central Indol–Kuban Trough.

Sandstones are largely observed as fine-grained quartzose rocks with clayey (locally, regenerated quartz) cement and subrounded (less commonly, angular) grains. The contents of the majority of chemical elements are at the clarke level or lower. Only Ni, Mo, Zn, and Fe concentrations are slightly increased (K_C = 2.8, 4.0, 1.5, and 1.2, respectively). Thus, sediments of the gravitite branch lack Mn. Manganese is absent in both sandy layers and enclosing clays. Consequently, Mn was not delivered to areas located west of the Laba paleodelta.

A substantially different Mn distribution is observed in marine sediments in eastern areas located beyond the deltaic complex. According to Kalinenko (1990), clays with anomalously high Mn concentrations (0.12–0.15%) make up an approximately 200-km-long and 50- to 60-km-wide band that extends along the axis of the East Kuban Depression from the Laba deposit to the western Terek–Kuma Trough. It is assumed that this band ("tongue") marks an ancient sea current that passed by the manganiferous delta.

The existence of currents in the western Terek–Kuma Trough is also supported by some sedimentation features observed in the Ol'ga Formation at the termination of the Mineral'nye Vody Uplift. In this area, silty accumulations frequently crosscut the horizontal bedding surface in clays at an angle of 45° or even fill vertical fissures. This indicates unstable sedimentation environments with periodically intensified bottom hydrodynamics.

In the southern deepest part of the eastern Terek–Kuma Trough, sedimentation environments were calm and thin lamination in sediments remained undistorted by hydrodynamics.

In the northern central part of the trough, where the Ol'ga (Sulak) Formation is thickest (up to 400 m), the clayey sequence contains a substantial quantity of sandy–silty material. Oil wells indicate the presence of a spacious sandstone bed (4–5 m thick) in this area. In addition, a sandy–silty member (30–35 m thick) is located at the northern termination of the Yankul Uplift. Sandy–silty sediments with clay interbeds are as thick as 70–80 m in the Blagodarnoe area.

It can be assumed that the sandy–silty bodies inside the clayey sequence of the Sakaraulian basin are elements of clinoform structures that are widespread in Late Oligocene basins (Stolyarov and Ivleva, 2004). According to seismostratigraphic data (Kunin *et al.*, 1989; Kosova, 1994, and others), the clinoform bodies are typical of the entire Cenozoic section in the eastern Ciscaucasia. Their formation was related to the intermittent influx of sandy–silty material from the East European Platform in the east.

It is noteworthy that separate sandy–silty interbeds (up to 5–6 m thick) also occur in the relatively shallow-water western areas of the basin, where thin (30–100 m) sequences of silty–clayey sediments accumulated in the Azov Uplift area.

Thus, the Sakaraulian basin of the Ciscaucasia was characterized by some local features, although the regional sedimentation environment was generally uniform. They were governed by proximity of the Caucasian archipelago that provided an intense influx of the relatively coarse sandy–silty material of clinoform bodies, on the one hand, and controlled metallogeny of the basin with the formation of anomalous sedimentary structures, such as the Laba Mn-bearing deltaic complex and gravitite branches, on the other hand.

The **Kotsakhurian basin** (Fig. 5). At the latest stages of the Maikop Group formation, the facies–paleogeographic sedimentation environment was again subjected to principal transformation. The general deepening of basin was accompanied by subsidence of the Caucasian archipelago, which already did not affect the sedimentation environment in the basin. Other areas of the Ciscaucasia inherited morphological features of the basin, and sedimentation in the western part of the basin was governed by the Azov and Stavropol uplifts with the Indol–Kuban Trough as the southern boundary. The Terek–Kuma Trough began to develop in the central and eastern Ciscaucasia.

In order to consider the main facies–paleogeographic features of the Kotsakhurian basin, we should first note that the Ritsa (Zuramakent) Formation section is reduced in a significant part of the Ciscaucasia because of its erosion to a variable extent in the Middle Miocene. It is impossible to assess confidently the degree of erosion.

In Fig. 5, we attempted to outline the domain of the complete Maikop section, i.e., to determine areas where they are conformably overlain by Tarkhanian sediments. These areas are sufficiently well outlined along the sublatitudinal direction approximately in the middle part of the Ciscaucasia. In the north, the Maikop sequence is unconformably overlain by Middle Miocene (Chokrakian–Karaganian and younger) sediments (Goncharova, 1991).

In the southern Ciscaucasia, sedimentation was most intense in the western part of the Indol–Kuban Trough, where the 442-m-thick Ritsa Formation was recovered by the Kuban superdeep Borehole SG-12000. This deep part of the basin accumulated clayey sediments with the dissemination of fish remains that represent the more or less developed fish facies. However, the initial sedimentation stage (210 m) in the Kotsakhurian basin was accompanied by a relatively intense influx of silty material, which is absent in the typical fish facies. The influx of silty material into the deep part of the basin probably represented a repercussion of the preceding Sakaraulian development stage. Subsequently, the influx of silty material decreased and formed only coating at bedding surfaces in laminated clayey sediments. Fish remains are virtually absent in the uppermost (50 m) layer of almost black clays at the contact with Tarkhanian sediments.

Deep-water environment was relatively stable in eastern areas of the Indol–Kuban Trough, which accumulated uniform clayey sediments with fish remains. Their thickness decreases to 70–100 m in the southern direction (Laba and Urup rivers).

The spacious Terek–Kuma Trough was also characterized by a uniform sedimentation environment that was favorable for the universal accumulation of typical fish facies in areas of both their maximal thickness (up to 400 m) in the central part of the trough and in the southern zone of uncompensated sedimentation, where these sediments are only 50–100 m thick.

The easternmost areas (Dagestan) demonstrate locally transgressive contact between the Zuramakent sediments and underlying different-age Paleogene and Cretaceous strata. In one of the localities, thin (7 m) upper layers of the formation overlain by the Tarkhanian marl rest upon an eroded surface of the Maestrichtian sequence (Sharafutdinov *et al.*, 1999).

Thus, terminal stages in the formation of the Maikop Group in the Ciscaucasia correspond to general deepening of the basin and leveling of sedimentation environments. This was accompanied by subsidence of the entire Caucasus orogen that is locally overlain by upper Maikop sediments. The fine-grained clayey material was completely derived from the East European Platform and distributed in the basin according to the scenario inherited from preceding stages with the formation of the thickest sections in troughs and their reduction on uplifts and zones of uncompensated sedimentation.

In contrast to preceding stages, waters of the Kotsakhurian basin experienced substantial freshening. Therefore, mainly endemic brackish-water fauna was developed in this basin (Popov *et al.*, 1993b).

CONCLUSIONS

The first overview of data on the composition and structure of Lower Miocene Maikop Group in the central part of the Eastern Paratethys provided insights into its terminal formation stages. The initial Miocene was marked by vigorous tectonic subsidences and the consequent significant subsidence of the Late Oligocene Caucasian archipelago and the Indol–Kuban and Terek–Kuma troughs. These motions promoted a stable regional sedimentation environment and the dominant accumulation of clayey sediments with fish remains (fish facies) of H_2S-contaminated basins. In the Karadzhalgan time, the accumulation of sediments of the fish facies was accompanied by the development of uranium–rare metal mineralization in some areas of the outer shelf (Urakovo–Bogoslovskoe ore occurrence).

Subsidence in the Oligocene–Miocene boundary period was a relatively short episode and development of the Karadzhalgan basin was characterized by a general regressive trend.

During the remarkable Sakaraulian stage of basin evolution, the fish facies gave way to the accumulation of silty–clayey sediments locally complicated by sandy clinoforms composed of a relatively coarse-grained material that was intensely transported from the East European Platform.

This stage was characterized by not only tectonic activation in the northern periphery of the basin, but also intense ascending tectonic movements in the Caucasus region and the formation of the elevated archipelago. Probably, this structure had a differentiated morphology that was favorable for the formation of isolated deltaic complexes and gravitite branches. Thus, the Sakaraulian stage can be considered a period of maximal tectonic activation in the Eastern Paratethys during the Early Miocene.

In the Kotsakhurian basin, sedimentation environment was again stabilized and the Caucasus experienced substantial subsidence, which continued in the Tarkhanian time. The northern part of the Ciscaucasia, where Tarkhanian sediments are absent, represented a plain gently dipping southward. Pre-Chokrakian erosion of the uppermost Maikop Group in this area was likely insignificant.

Existence of the post-Maikopian hiatus raises the issue of the stratigraphic range of Lower Miocene sediments in Mangyshlak, where only analogues of the Karadzhalga Formation are reliably known so far. The question as to whether the Sakaraulian and Kotsakhurian sediments accumulated in this region or they were eroded in the Middle Miocene remains still unanswered.

The Sakaraulian basin was unique with respect to metallogeny. It was remarkable for the accumulation of a single deltaic complex and an intense influx of suspended manganese into the basin. Manganese was accumulated in the prodelta environment and was transported by currents to the deep part of the basin with the formation of high Mn concentrations (up to 0.15%) in clays. During this short period, Mn was delivered to the Sakaraulian basin from the Caucasian archipelago. This fact is important for solving the issue of sedimentary manganese ore formation.

It should be noted, however, that the Mn influx to the basin continued in the subsequent Kotsakhurian time, when the Caucasian archipelago experienced subsidence and its role in sedimentation was virtually negligible. This is evident from high Mn concentrations (0.2–0.8%) in siderite concretions of the Ritsa Formation in the Indol–Kuban Trough. Moreover, the Mn content increases to 4.6% in similar concretions of the Zuramakent Formation in the eastern Ciscaucasia. In this case, the source of Mn remains unknown, although, strictly speaking, such situation is typical of manganese ore formation in general (Stolyarov, 1993, 1996; and others). In this respect, the Laba deltaic complex is a unique phenomenon in the development of sedimentary manganese ore formation.

Materials on Early Miocene basins of the central Eastern Paratethys discussed in the present paper made it possible to characterize terminal stages in the formation of the Maikop clayey sequence. The data obtained will make it possible to elaborate the general evolutionary–geological model of these unique (with respect to geology and metallogeny) sediments.

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