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Upper Oligocene Sediments of the Ciscaucasus, Volga–Don, and Mangyshlak Regions (Central Eastern Paratethys): Communication 1. Main Compositional and Structural Features

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Abstract—Upper Oligocene sediments of the Eastern Paratethys are distinguished in the Maikop Group owing to several characteristic features. They form a thick (1000–1200 m) sequence with specific composition and structure in different structural–facies zones of the basin. The development of "fish facies" is the most remarkable feature. It includes unique sediments composed of fish bone detritus (FBD) and iron sulfides with high contents of REE, U, Sc, Re, Ni, Co, Mo, and other elements. These elements form commercial uranium–base metal deposits so far unknown in other formations of the Earth. The structure of thick rock sequences in the deepest part of the Eastern Paratethys is also characterized by specific features. Deep-sea clayey fish-facies sediments intercalate with beds of fine-grained sandy and silty material. Their influx into the central part of the basin was responsible for the clinoform structure of the rock sequence revealed by seismostratigraphic studies.
This communication presents new data on the distribution of bone detritus deposits, composition and structure of sediments, and summary characteristics of Upper Oligocene sediments that are essential for the further analysis of facies–paleogeographic sedimentation conditions in the central Eastern Paratethys.

Upper Oligocene sediments of the Eastern Paratethys are distinguished in the Kalmykian regional stage (Popov *et al.*, 1993b). Its basal layers are composed of calcareous clays with characteristic foraminifers of the genus *Virgulinella* (*Virgulinella* Bed) described in (Stolyarov, 2001). The overlying Upper Oligocene sequence is observed as the Batalpashinsk (including Septarian beds) and Zelenchuk formations in the central Ciscaucasus region, the Kalmyk Formation (divided into two subformations) in the Volga–Don region, and the Karagie Formation (also divided into two subformations) in Mangyshlak. In the northern Ustyurt, northern Aral, and northern Black Sea regions, the Kalmykian regional stage corresponds to the Karatomak, Chagrai, and Askaniya formations, respectively (Popov *et al.*, 1993b).

The fish beds (stratiform FBD accumulations), which include unique sulfide–phosphorus deposits enriched in uranium and rare metals, are the most characteristic feature of Upper Oligocene sediments (Kochenov and Stolyarov, 1996; Stolyarov and Ivleva, 1995; and others). Metalliferous deposits occur mainly within lower subformations of the Karagie and Kalmyk formations that are stratigraphic analogues of the Batalpashinsk Formation in the Ciscaucasus region, where ore deposits are located in the younger Zelenchuk Formation.

Upper Oligocene sections have been scrutinized in hundreds of boreholes drilled in the Mangyshlak, Ergeni, and central Ciscaucasus ore regions located in marginal parts of the basin. The deepest part of the basin (Terek–Kuma Trough) has a remarkable structure. It includes the thickest sandy–clayey sequence (over 1000 m) with an intricate clinoform structure investigated on the basis of seismostratigraphic materials (Kunin *et al.*, 1988).

Upper Oligocene sediments of the central Eastern Paratethys are characterized by highly specific sedimentation and ore-generating features. Main lithostructural features of ore deposits and host rocks in such regions have been discussed in numerous publications. At present, there is a necessity for the comprehensive analysis of sedimentary process evolution in the Late Oligocene sea basin and regional trends in the formation of stratiform fish bone and iron sulfide deposits enriched in uranium and rare metals (hereafter, complex uranium–rare metal deposits).

MAIN COMPOSITIONAL AND STRUCTURAL FEATURES

Upper Oligocene sediments form a relatively uniform clayey sequence characterized by the development of fish beds (or fish facies) with FBD accumulations. The specific distribution of fish remains (FR) in clayey sediments requires a comprehensive lithostratigraphic mapping.

Fish remains are irregularly distributed in the studied territory. They are virtually missing in vast areas of the northwestern Ciscaucasus, Volga–Don, and north-

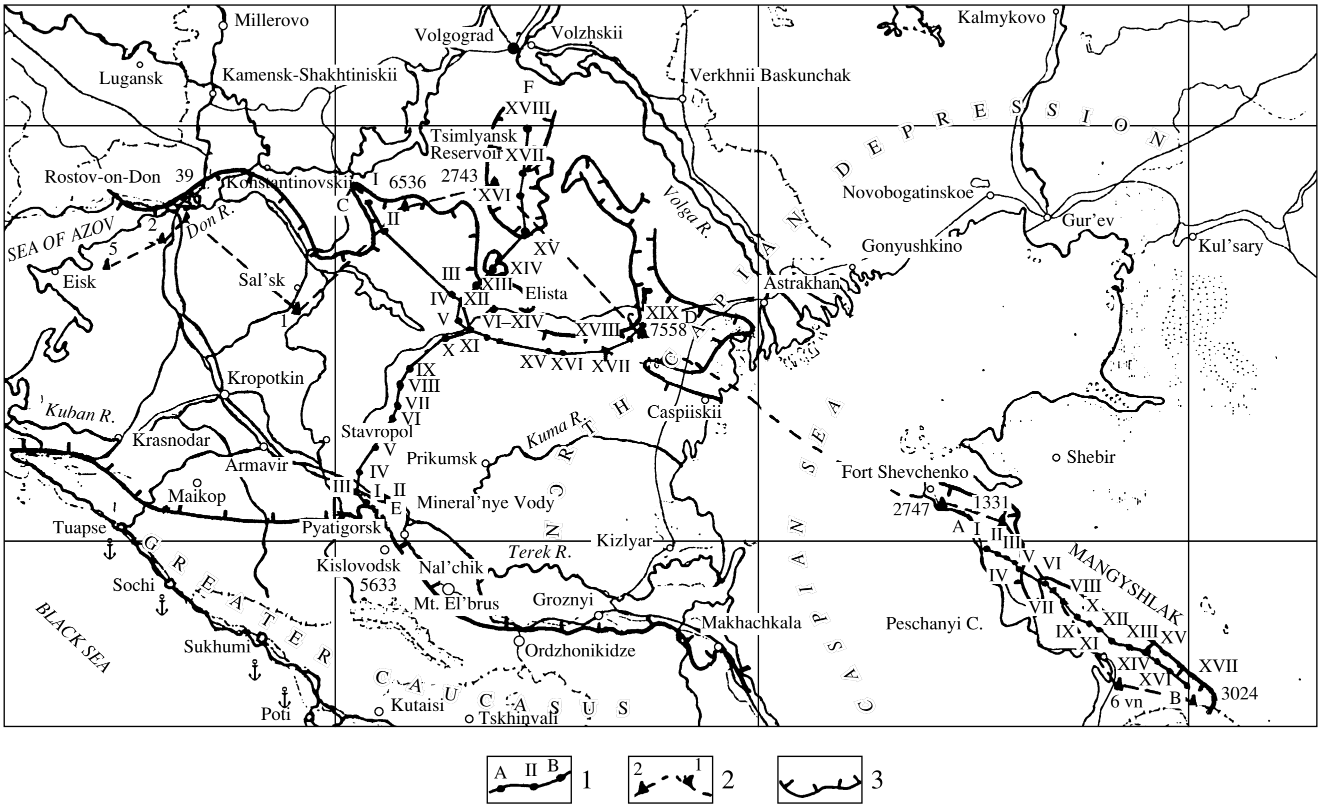

Fig. 1. Location of reference sections in regional profiles. (1) Regional A–B, C–D, and E–F profiles; (Roman numbers designate reference sections); (2) correlation lines of borehole sections and their numbers; (3) contour of the present-day domain of Upper Oligocene sediments (primes are oriented toward the domain of sediments).

ern Ergeni regions. In terms of stratigraphy, fish beds are confined to the lower part of the Upper Oligocene section that encloses main FBD accumulations.

This communication presents detailed lithological characteristics of Upper Oligocene sediments for individual areas of the Eastern Paratethys supplemented with lithofacies cross sections and correlation schemes of some reference sections (Fig. 1).

SOUTHERN MANGYSHLAK

Upper Oligocene sediments in Mangyshlak are defined as the Karagie Formation divided into the lower (fish) and upper subformations (Merklin *et al.*, 1960; Stolyarov, 1958; and others). The lower subformation includes the following three units: *Virgulinella* (carbonate clay) beds, Zhazgurly (subore) beds, and Segendyk (fish bone detritus) beds (Sharkov, 1963, 2000; Stolyarov, 1961; Stolyarov and Kochenov, 1995; Stolyarov and Sharkov, 1976; and others).

The approximately 300-km-long longitudinal profile across the South Mangyshlak Trough demonstrates main compositional and structural features of the Karagie Formation in the central zone of the trough (Fig. 2). In contrast to previous data (Mstislavskii *et al.*, 1996), this profile shows the detailed structure of fish facies, including FBD accumulations. It outlines the FR distribution in the eastern part of the South Mangyshlak Trough on the western slope of the Karynzharyk Uplift (Fig. 2, sections XV, XVI).

Lower Subformation

The Zhazgurly (subore) Unit is most complete (up to 150–160 m thick) in the central South Mangyshlak Trough. It is composed of uniform dark gray striated clays with FR dissemination (mainly, scales) and layers of light gray clays with thin fucoids up to 0.5 m long. Alternating light gray and fish-facies clays form intermittent beds up to 20–30 m thick (Fig. 2, sections VII, X, XI, XIV).Their thickness is reduced (locally, up to the point of pinching out) in the North Caspian Depression.

The Segendyk Beds are ore-bearing sediments. Main deposits of the study region have been considered in previous works (Sharkov, 2000; Stolyarov and Ivleva, 1995; Stolyarov and Kochenov, 1995). Therefore, only some lithostructural characteristics of ore-bearing sediments of the region are given below. We also present first data on the isolated Unerin deposit located in the eastern part of Mangyshlak.

The thickness of ore-bearing sediments is not more than 50–60 m in the most part of southern Mangyshlak

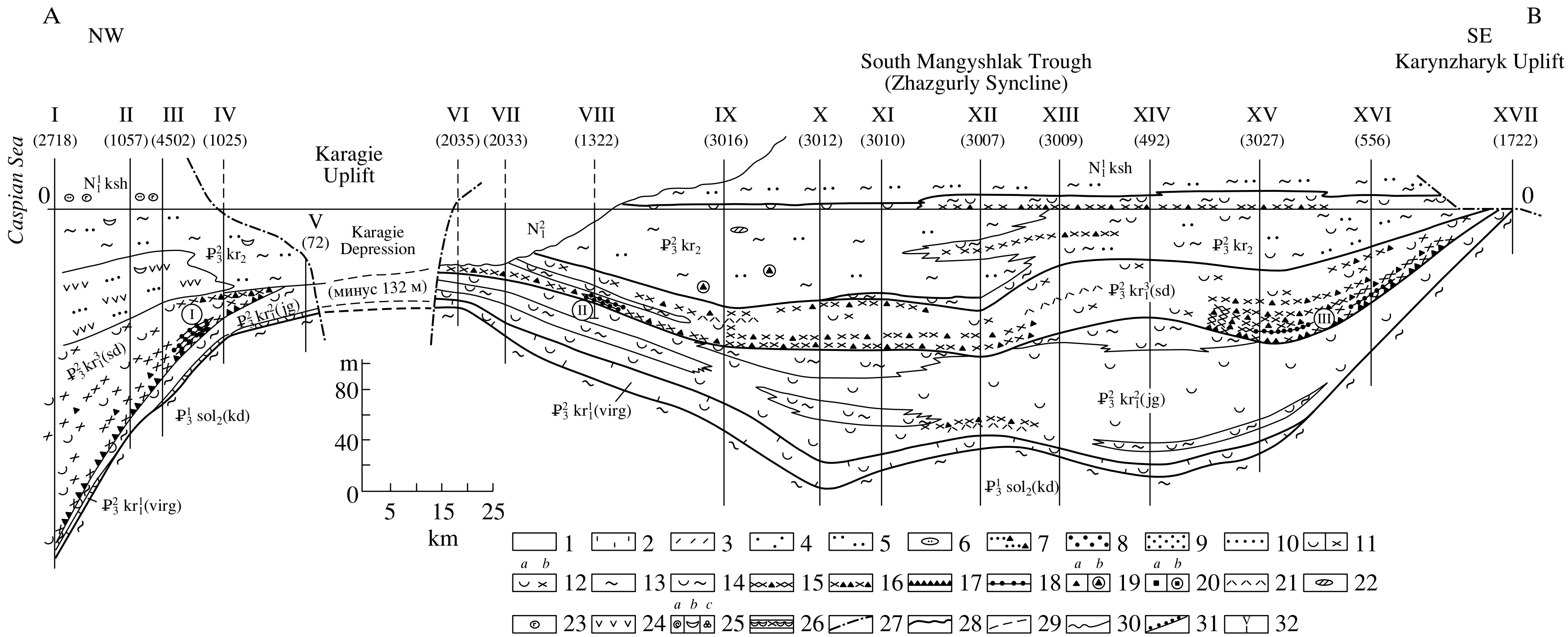

Fig. 2. Lithofacies section of South Mangyshlak along the A–B profile (see Fig. 1 for location). (1) Clay; (2) calcareous clay; (3) marly clay; (4) clay with a low silt admixture; (5) silty clay; (6) clay with silty lenses and patches; (7) clay with silt and sulfide accumulations at bedding surfaces; (8) sands and sandstones (silty sandstones); (9) fine-grained sands, siltstones; (10) siltstone layers in clays; (11) fish remains dispersed in clay: (a) scales, (b) bone detritus; (12) FR accumulations in clays; (13) clay with fucoids; (14) alternating clayey beds with fish remains and fucoids; (15) FBD layers with subordinate iron sulfides; (16) layers of iron sulfides with subordinate FBD; (17) sulfide layers; (18) bone detritus deposits: (I) Melovoe, (II) Taibagar, (III) Unerin; (19) sooty pyrite: (a) fine-dispersed, (b) patchy; (20) crystalline pyrite: (*a*) fine-crystalline, (*b*) patchy; (21) tuffite layers in clays; (22) siderite concretions; (23) glauconite; (24) algae-type remains; (25) shells: (*a*) *Planorbella*, (*b*) mollusks, (c) foraminifers; (26) accumulations of molluscan shells with fish bone detritus; (27) present-day erosion level; (28) Neogene erosion level; (29) arbitrary correlation boundary of sediments; (30) sediment roiling zone; (31) unconformable boundary with the basal sandstone layer; (32) reference borehole sections and their numbers (in parentheses).

Local stratigraphic units. *Underlying sediments*: Solenovian sediments: (₽$_3^1$–sol$_2$) (kd)) Kaunda Beds, (₽$_3^1$ sol$_2$(ik)) Ikiburul Beds; Upper Oligocene sediments: (₽$_3^2$ kl) Kalmyk Formation; *Virgulinella* Beds: ₽$_3^2$ kr$_1^1$ (virg) (at the base of the Karagie Formation) and ₽$_3^2$ kl$_1$ (virg) (at the base of the Kalmyk Formation); (₽$_3^2$ kl$_1$) lower Kalmyk Subformation; (₽$_3^2$ kr$_1^2$ (jr)) lower Karagie Subformation, Zhazgurly Horizon; (₽$_3^2$ kr$_1^3$ (sd)) lower Karagie Subformation, Segendyk Horizon; (₽$_3^2$ kl$_{1-2}$) nondifferentiated Kalmyk Formation; (₽$_3^2$ bt) Batalpashinsk Formation; (₽$_3^2$ kr$_2$) upper Karagie Subformation; (₽$_3^2$ kl$_2$) upper Kalmyk Subformation. *Overlying sediments*: (N$_1^1$ ksh) Kashkarata Formation; (N$_1^1$ kr) Karadzhalga Formation; (N$_1^1$ ng) Nugra Formation.

and reaches 150–160 m only in the North Caspian Depression (Fig. 2 section I). They have a dark color owing to high content of sulfide dissemination in clays (up to 3%; 1.5–2.0% in subore sediments). The bulk Fe content is up to 6–8% (4–5% in subore clays).

Relative to ambient layers, the ore-bearing sediments are characterized by a higher content of dispersed fish remains (mainly bone detritus) that make up wide dispersion haloes beyond the FBD beds and layers (up to 0.1 m in thickness and tens of kilometers in length) with iron sulfides.

The content of FR dissemination usually does not exceed 1.0–1.5% in clays and varies from a few percents to 20–25% in the FBD beds and layers (P_2O_5 up to 8.5%).

The fish-facies clays usually include organic matter (OM) of animal origin. In the form of brown scales that impart the striated (or microstriated) appearance to rocks. The C_{org} content usually does not exceed 1.0–1.5% in ore-hosting clays and 0.5–0.7% in subore clays.

Main FBD accumulations are confined to the Karagie Uplift zone in the western part of the South Mangyshlak Trough (Stolyarov and Kochenov, 1995. Another area of their concentration is the Karynzharyk Uplift bordering the trough in the east (Stolyarov and Shlezinger, 1962). Here, the FBD accumulations are confined to the Karynzharyk ore field (30 × 40 km), which is much smaller than the Karagie ore field (120 × 50 km).

The Karynzharyk ore field comprises several isolated sublatitudinal beds 5–12 km long and a few kilometers wide. The Unerin deposit includes the largest (Western and Eastern) lodes of this ore field (Fig. 2, Sections XV, XVI).

Based on reconnaissance prospecting of the deposit carried out by the Kol'tsov Industrial–Geological Association, the average mineral composition of ores is as follows (%): bone detritus 26.2 (P_2O_5 9.44), iron sulfides 11.9 (S_{pyr} 7.56), carbonates 16.8, and clayey material 45. The admixture (up to 1%) includes coalified plant remains, barite, phosphate nodules, glauconite, and quartz.

The distribution of bone remains in beds is irregular and reaches 40% in some layers. The sulfide component is observed as pyrite dispersion or less common nodules up to 1 cm across. Marcasite forms intergrowths with pyrite. Clay minerals are represented by the muscovite-type hydromica with an admixture of smectite.

Carbonates are observed as dolomite and the subordinate calcite and siderite. The dark brown scaly OM is mainly confined to clayey layers.

On the whole, ores from the Unerin deposit are characterized by the elevated FBD content and lowered sulfide concentrations. For comparison, ores of the Melovoe deposit, the major commercial object in Mangyshlak, contain 4.32% P_2O_5 and 11.1% S_{pyr} (Stolyarov and Ivleva, 1995). The U and REE contents (0.1 and 0.7%, respectively) in the bone phosphate from the Unerin deposit are lower than those in the Melovoe ore (0.3 and 1.3%, respectively). These data are consistent with the general distribution trend of main useful elements in the Mangyshlak-type deposits, where their contents are higher in low-phosphorus beds (Stolyarov *et al.*, 1991).

Thus, we have outlined a new metalliferous FBD zone in the eastern part of the South Mangyshlak Trough. This discovery widens the scope of unique mineralization in ore-bearing sediments of Mangyshlak.

Upper Subformation

The upper part of the Karagie Formation is composed of greenish gray clays with an admixture of silty material. The clays are mainly represented by massive varieties with silt patches and fucoids. Some sections in the North Caspian Depression enclose thin-bedded clays with silty layers and algal remains (Fig. 2, sections I–III). The thickness of the upper subformation is maximal in this region (up to 100 m).

In the eastern part of the South Mangyshlak Trough, the thickness of the upper subformation decreases to 10–50 m. It encloses numerous layers of dark gray clays (from 0.1–0.2 to 2–3 m thick) with fish remains (fish facies) and thin (up to 0.1 m) laminae of bone detritus (Fig, 2, sections XII, XIII). Thus, the Karagie section in this area is characterized by the presence of beds with fish remains.

We studied the mineralogy and geochemistry of the Karagie section in the Melovoe quarry located west of the Karagie Depression (Fig. 2). Analysis of the clay composition using the IR spectroscopic and X-ray diffraction methods showed that clays from the lower and upper subformations are rather similar.

The IR-spectroscopic data show that the clays include hydromuscovite (up to 70%), kaolinite (10–30%), and smectite. The X-ray diffraction study revealed hydromicas, chlorite, and smectites in fraction <0.001 mm. The quantitative proportions of these minerals are highly variable. On the whole, hydromicas and chlorite–kaolinite aggregates prevail, whereas smectites are subordinate.

Since clays from the lower and upper subformations are almost similar in chemical composition, let us present only average contents of the major components for the Karagie Formation (%): Na_2O 1.61, MgO 2.72, Al_2O_3 18.7, SiO_2 53.2, P_2O_5 0.14, K_2O 3.0, CaO 0.82, TiO_2 0.91, MnO 0.058, Fe_2O_3 8.22, CO_2 1.38, H_2O^- 3.50, and H_2O^+ 5.61. Notable differences are registered only for the contents of FeS_2 (1.26% in the lower subformation and 4.84% in the upper subformation) and S_{tot} (0.63 and 2.42%, respectively).

In section IV (Fig. 2), the silt content in massive silty clays from the upper subformation varies from

2.24 to 10.96% (in lenticular accumulations). Its average mineral composition is as follows, %: quartz 58.3, albite 30.5, potassic feldspar 9.9, and glauconite 3.85. The composition of the heavy fraction (1–2%) is as follows, %: epidote–zoisite group minerals (mainly, clinozoisite) 43.9, titanomagnetite 20.9, anatase 11.3, leucoxene 2.6, zircon 6.6, sphene 1.4, rutile 1.6, tourmaline 3.6, garnet 3.2, apatite 1.7, and chlorite 1.7. Biotite, muscovite, staurolite, kyanite, amphibole and chromite are rare.

Clays of the fish subformation in the Karagie Depression and eastern areas (Fig. 2, section XIII) enclose thin (1–5 cm) violet-gray tuffogenic layers of uniform pelitomorphic smectites with microscopic acicular clasts of volcanic glass typical of volcanic ash. Quartz, feldspars, fragments of coalified plant remains, zircon, and biotite are present as single grains. The composition of this rock is as follows, %: SiO_2 47.8, Al_2O_3 18.8, Fe_2O_3 3.41, TiO_2 0.05, CaO 0.65, and MgO 2.72.

The fish facies of the Karagie Formation is developed in the central South Mangyshlak Trough. In marginal parts of the trough, beds with fish remains are subordinate (or absent) and the Karagie Formation cannot be subdivided. For instance, Figure 3 shows that the 100- to 120-m-thick Karagie Formation in the Kara Bogaz area (sections 6vn, 3024) is composed of greenish gray massive clays with fucoids and less common silt “flour” (section 6vn). Sections in the eastern Kara Bogaz area (section 3024) enclose subordinate layers with fish remains.

In the northwestern Mangyshlak area (sections 2747, 1331), the Karagie Formation is thicker (160–220 m) and more intricate. The sequence consists of irregularly alternating packages of bedded and massive silty clays up to 30–40 m thick. These packages also include dark clay beds (up to 10–15 m thick) with fish remains and a thin sulfide layer (up to 0.1 m) traceable over a large area at the section base (Stolyarov, 2001 and others).

The content of silty aggregates varies from 3–4 to 9% (sometimes, up to 17.4%). They are mainly composed of quartz (34–67%), albite (10–33%), potassic feldspar (4–16%), biotite and muscovite (up to 2%), and occasional glauconitic. The heavy fraction consists of minerals of the epidote–zoisite group (50–70%), titanomagnetite, ilmenite, leucoxene, rutile, zircon, tourmaline, garnet, apatite, staurolite, kyanite, and andalusite.

The distribution of organic remains in the Karagie Formation shows a distinct antagonism between the conchilio- and ichtyofaunas. For example, the conchiliofauna do not occur *in situ* in sediments of the fish facies. Finds of fish remains include intact skeletons of carnivorous fishes of the genus *Tetrapturus* from the family Ystioforidae (determinations by P.G. Danil’chenko) as well as tuna vertebrae (Merklin *et al.*, 1960).

L.S. Glikman and A.S. Stolyarov took a large collection of shark teeth (over 1000 specimens) from outcrops of bone detritus in the Karagie Depression. This collection includes *Jaekelotodus karagiensis* (Gluck., *Lamiostoma stolarovi* Gluck. et Zhel. (in litt.), and *Odontaspis* ex gr. *Dubia* (Ag.) (determinations by L.S. Glikman and V.I. Zhelezko). These forms correspond with the *Lamiostoma stolarovi* (E 19) Zone of the Chattian Stage (Zhelezko, 1995; Zhelezko and Kozlov, 1999). Noteworthy are also finds of cetacean mammal skeletons (Dubrovo and Sharkov, 1971).

The foraminiferal assemblage from the Karagie Formation is characterized by an impoverished taxonomic composition and dwarfish appearance. Small dimensions of tests, presence of rounded specimens, poor preservation, and uniform species composition of foraminifers imply environments unfavorable for their development.

The foraminiferal tests in subore sediments of the lower subformation occur in light-colored FR-free clay layers with occasional globigerinids and redeposited rounded tests of *Nonion* aff. *granosus* Orb., *Cibicides* sp., *Globigerina* sp., *G.* aff. *officinalis* Subb., *Elphidium* sp., and spherical fish otoliths (Mikhailova, 1968).

The upper subformation is remarkable for the appearance of new foraminiferal assemblages. In its lower part exposed in the Karagie Depression, L.S. Ter-Grigor’yants found benthic foraminifers *Uvigerinella californica* Cushm., *Miliolina* ex gr. *enoplastoma* (Reuss), *Bolivina* sp., *Elphidium* sp., *Rotalia beccarii* (L.), and fish otoliths.

The upper part of the subformation in sections of the Caspian Sea coast contains a more diverse foraminiferal assemblage: *Uvigerinella californica* Cushm., *Spiroplectammina* aff. *terekensis* Bogd., *Bolivina* aff. *plicatella* Cushm., *Eponides propinquus* H.B. Brady, *Pseudoparella* aff. *kiliani* Andreae, *Rotalia beccarii* (L.), *Sphaeroidina variabilis* Orb., *Polymorphina* sp. *Miliolina* sp., and *Elphidium* sp. Other organic remains are characterized by echinoderm needles, pyritic casts of radiolarians, and spheroid fish otoliths (Mikhailova, 1968).

In addition to foraminifers, these sediments yield common shells of molluscan species *Leda gracilis* Desh., *L. varians* Wolf., *L.* ex gr. *deshaesiana* Dush., *Yoldia glaberrima* Münst., *Thyasira* ex gr. *obtusa* (Beyr.), and *Astarte* aff. *demissa* Wolf. (Merklin *et al.,* 1960). Shells are thin-walled and usually contain joint valves, indicating an open sea environment.

Northwest of the Karagie Depression, the Segendyk Beds of the lower subformation enclose diatomaceous clays (Kochenov *et al.*, 1960). It forms a thick package (8–20 m) extending in the sublatitudinal direction over 15 km as a narrow band (up to 1 km wide). Among other sediments, these clays are distinguished by light color and low specific weight. According to A.P. Jousé, the *Stephanopixis–Stephanogonia* diatom assemblage

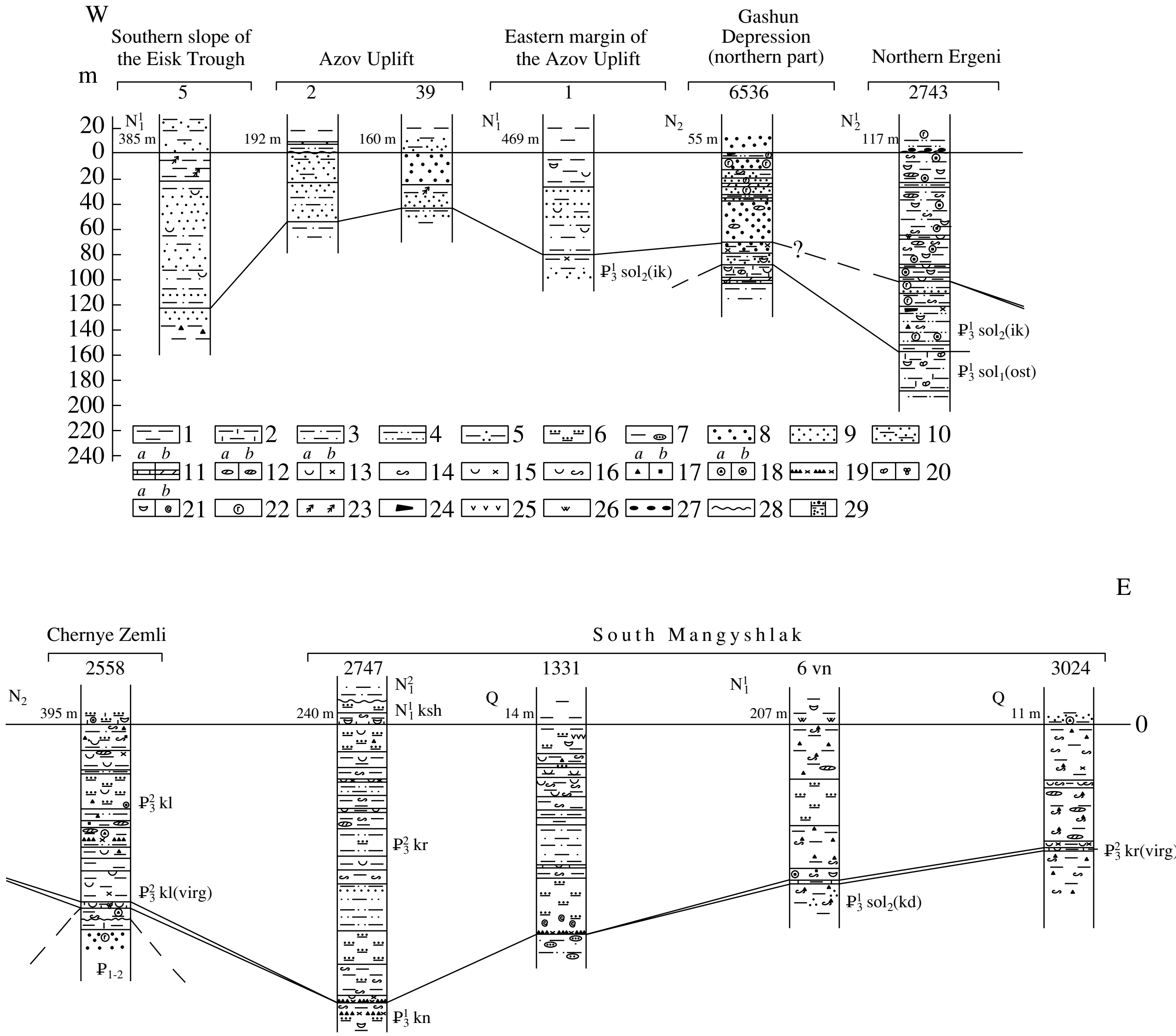

Fig. 3. Correlation of reference sections along the profile extending from the Volga–Don region to South Mangyshlak (see Fig. 1 for location). (1) Clay; (2) calcareous clay; (3) clay with low silt admixture; (4) silty clay; (5) sandy clay; (6) clay with silty laminae and powder; (7) clay with silty lenses and patches; (8) sand and sandstone; (9) siltstone and fine-grained sand; (10) siltstone and clayey sand; (11) carbonate layers: (*a*) calcareous rocks, (*b*) marl; (12) concretions: (*a*) marly, (*b*) siderite; (13) dispersed fish remains: (*a*) scales, (*b*) bone detritus; (14) fucoids; (15) FR accumulations in clays; (16) alternating clayey beds with fish remains and fucoids; (15) FBD layers with subordinate iron sulfides; (17) pyrite: (*a*) fine-dispersed, (*b*) fine-crystalline; (18) pyrite patches: (*a*) fine-dispersed, (*b*) fine-crystalline; (19) iron sulfide layers with subordinate bone detritus; (20) small organic remains: (2a) ostracods, (*b*) foraminifers; (21) shells: (*a*) mollusks, (*b*) *Planorbella*; (22) glauconite; (23) plant remains; (24) admixture of organic (humic and bituminous) matter; (25) algae-type remains; (26) gypsum; (27) phosphorite pebbles; (28) unconformable boundaries; (29) reference sections and relevant borehole numbers.

Local stratigraphic units. *Underlying sediments*: (₽$_3^1$ kn) Kendzhala Formation; Solenovian sediments: (₽$_3^1$ sol$_1$) (ost)) lower Solenovian (Ostracod) Beds, (₽$_3^1$ sol$_2$) (kd)) Kaunda Beds, (₽$_3^1$ sol$_2$) (ik)) Ikiburul Beds; Upper Oligocene sediments: (₽$_3^2$ kr) Karagie Formation, (₽$_3^2$ kl) Kalmyk Formation; *Virgulinella* Beds: (₽$_3^2$ kr (virg)) at the base of the Karagie Formation, (₽$_3^2$ kl (virg)) at the base of the Kalmyk Formation. *Overlying sediments*: (N$_1^1$ ksh) Kashkarata Formation.

includes dominant *Stephanopixis* cf. *supera St. ferox* Grev., and *St. turris* var. *cylindris* Ralfs.

Diatoms are supplemented with silicoflagellate algae, scarce radiolarians, and sponge spicules.

The diatom assemblage mainly consists of planktonic species. According to Jousé, the prevalence of spores suggests sedimentation in the sea basin with normal salinity at a depth of 5–200 m.

Thus, Upper Oligocene sediments of the fish facies in southern Mangyshlak (Karagie Formation) are divided into two subformations. The lower subformation contains abundant fish remains, whereas the upper subformation is marked by their subordinate development or absence. The lower subformation includes the Zhazgurly (subore) and Segendyk (ore-bearing) units. The Segendyk Unit incorporates all accumulations of metalliferous FBD and iron sulfides. The sulfides confined to a relatively narrow stratigraphic interval reflect a specific ore epoch.

THE VOLGA–DON REGION

The >350-km-long sublatitudinal lithofacies profile demonstrates principal lithostructural features of the Upper Oligocene and overlying Lower Miocene sediments (Fig. 4). The profile extends from the Chernye Zemli area to southern Ergeni and the Gashun Depression of the Sal'sk–Manych interfluve. Thus, it crosses the entire fish-facies region with metalliferous FBD and iron sulfide deposits and marginal (relatively shallow-water) facies in the northwestern part of the region, where fish remains are subordinate or missing.

Upper Oligocene sediments in the studied region correspond to the Kalmyk Formation. Like the Karagie Formation in southern Mangyshlak, it is divided into the lower (fish) and upper subformations. Ore accumulations are confined to the Mangyshlak-type fish subformation. However, their stratigraphic distribution in the section is substantially different. This is responsible for structural differences between fish subformations of the Mangyshlak and Volga–Don regions.

In contrast to the Mangyshlak region, the Volga–Don region is characterized by the confinement of FBD accumulations to several closely spaced stratigraphic levels (ore horizons) in the lower part of the fish subformation (Stolyarov and Ivleva, 1991).

The FBD distribution is extremely irregular. Some deposits are surrounded by large FBD haloes, whereas other deposits lack them. Therefore, the fish subformation has a very complicated structure.

Within the Chernye Zemli area in the east, the Kalmyk Formation is reduced as a result of substantial erosion in the Neogene and observed as a part of its lower subformation (Fig. 4, sections XVII–XIX). This area is marked by the local development of a significant stratigraphic unconformity. In such sectors, the fish subformation rests upon Eocene glauconite sandstones and its base contains a thin (up to 5 cm) layer of redeposited glauconitic sandstone with inclusions of dark green clays, rounded or angular phosphorite pebbles, and brown decomposed fish bone remains. Higher in the section (0.4 m), clays with rare fish remains and pyrite nodules enclose thin (1–3 cm) layers with glauconite grains and coprolite inclusions.

The overlying section of the lower subformation (30 m) is composed of typical fish-facies sediments with thin (up to 0.1 m) sulfide layers. This zone hosts the previously unknown Chernye Zemli FBD deposit (Stolyarov and Ivleva, 1991, 1995) (Fig. 4, section XVII). It is located on the eastern slope of the Peschanoe Uplift, up to 3 km wide, and extends in the sublatitudinal direction over 11 km. The deposit consists of two closely spaced (3–10 m) relatively thin (0.13–0.72 m) clayey–sulfide (S_{pyr} = 11.8%) beds with minor contents of bone detritus (P_2O_5 = 2.11%), U (0.016%), and REE (0.06%). The U and REE concentrations in the bone phosphate are 0.23 and 0.85%, respectively, which are typical of low-phosphorus deposits (Stolyarov *et al.*, 1991).

In the Chernye Zemli area, the upper part of the lower subformation is composed of practically FR-free clays with a fine silty flour on bedding surfaces. In the remote western area (Fig. 4, sections XIV–XVI), the two-member structure of the lower subformation is characterized by relatively low FR contents (mainly, scales).

The maximal thickness of the lower subformation (up to 130 m) is recorded in the South Ergeni area with numerous FBD deposits beds (Stolyarov and Ivleva, 1991, 1995). They are concentrated at several stratigraphic levels (ore horizons) in the lower part of the subformation. The Stepnov deposit, one of the largest FBD deposits in the Ergeni ore district, overlies the *Virgulinella* Beds at the Kalmyk Formation base (Fig. 4, sections V–VIII; Fig. 5, section XI).

In paleogeographic terms, the Stepnov deposit is located in the deepest zone of the ore district and controlled by the morphological scarp, along which it pinches out (Stolyarov and Ivleva, 1991). The deposit displays the "herring tail" structure and divergence in the southeastern direction in the form of 6- to 8-m-thick layers with large FBD dispersion haloes. The deposit is few kilometers wide, over 20 km long, and dips toward the Manych Trough. The deposit is characterized by a high sulfide content (S_{pyr} = 16–25%) and the lowest FBD concentrations (P_2O_5 = 1.5–6.0%, average 4.8%) probably owing to relatively deep sedimentation settings. At the same time, the phosphate material of bones in such environments is characterized by the maximal average contents of REE and U (1.44 and 0.31%, respectively).

The morphology and composition of ore beds are substantially changed in the western marginal zone of the fish-facies area with a significantly lower content of dispersed fish remains and the presence of silty material and clays with worm trails. The largest stratiform-lenticular Shargadyk–Bogorodsk deposit is more than 30 km long and 0.25–1.23 m thick. It extends in the sublatitudinal direction with a gap of 3 km and occupies the highest stratigraphic position (Fig. 4, sections III, IV). Some lithostructural features of stratiform bodies are remarkable.

The Shargadyk (western) deposit is largely composed of brownish bone detritus (P_2O_5 20–25%) that

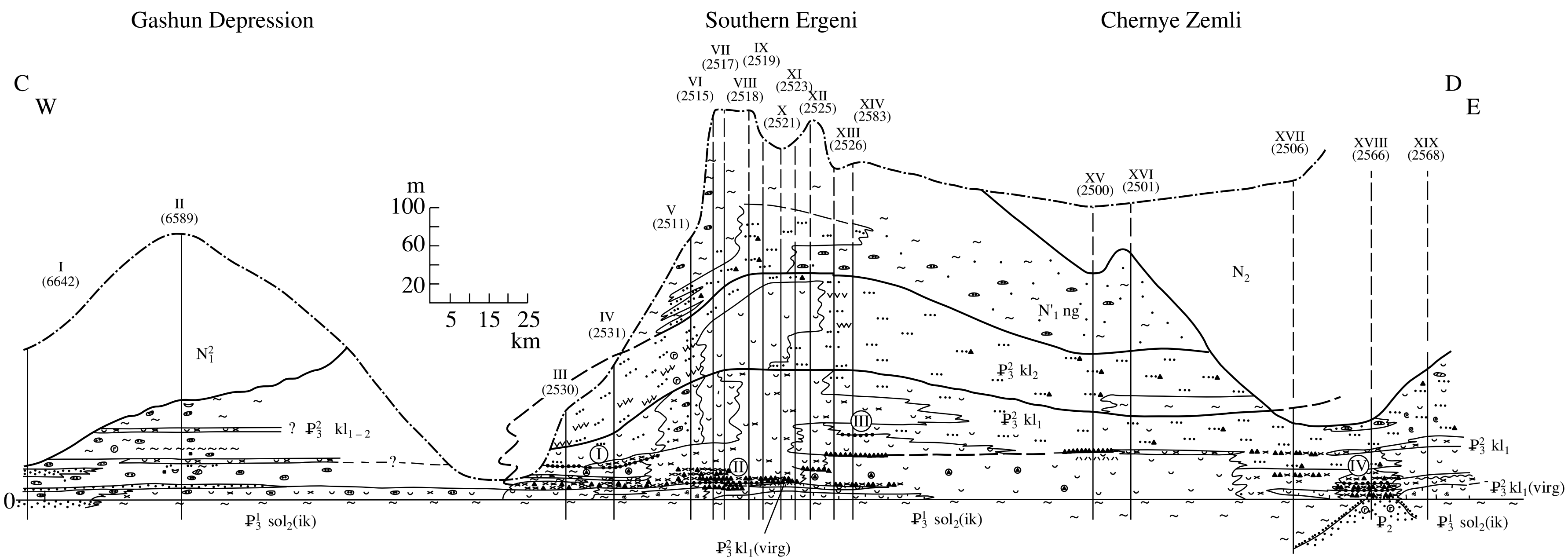

Fig. 4. Lithofacies profile C–D across lower reaches of the Don River, southern Ergeni, and Chernye Zemli (see Fig. 1 for location). Deposits of bone detritus and iron sulfides: (I) Shargadyk–Bogorodsk, (II) Stepnov, (III) Nugra, (IV) Chernye Zemli. Other symbols as in Fig. 2.

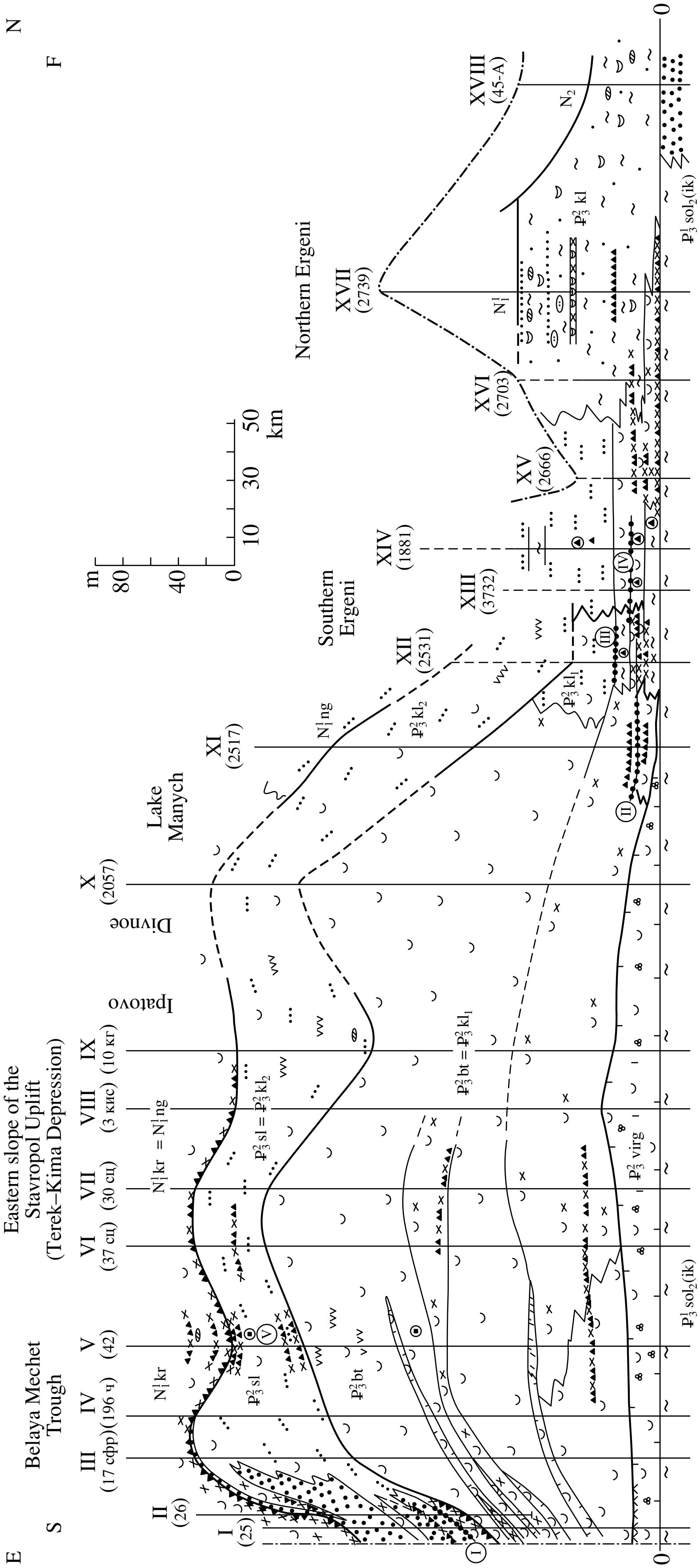

Fig. 5. Lithofacies profile E–F across northern Ergeni, central Ciscaucasus, and North Caucasian monocline (see Fig. 1 for location). Deposits of bone detritus and iron sulfides: (I) Cherkessk; (II) Stepnov, (III) Shargadyk, (IV) Yashkul, (V) Urakov–Bogoslov. Other symbols as in Fig. 2.

represents a reworked (loose) lenticular-bedded natural bone concentrate with the subordinate quantity of iron sulfides (S_{pyr} 5–10%), clayey material (Al_2O_3 1–4%), and carbonates (CO_2 2–5%). The roof of the deposit (0.2–0.4 m) is black-colored owing to a very high content of iron sulfides (S_{pyr} 20–30%). The FR content is substantially lower (P_2O_5 3–7%).

Based on the phase X-ray diffraction data, clayey layers of the ore deposit are composed of the major hydromica and the subordinate kaolinite, chlorite, and smectites. The chemical composition of clayey material in fraction <0.01 mm is as follows (%): SiO_2 57.0, Al_2O_3 19.5, MgO 2.6, K_2O 3.1, Na_2O 0.9, H_2O^+ 11.8, H_2O^- 5.1, and Sc 0.0031. These data indicate a substantial hydration of clayey material and high Sc content.

The Bogorodsk (eastern) deposit is also characterized by contrasting types of FBD concentrations. However, relative to the Shargadyk deposit, it is characterized by a substantially different FBD distribution pattern and the presence of local scours up to 0.1 × (0.3–0.5) km in size and up to 1.5–3.0 m in depth. The lower sedimentary sequence is enriched in bone detritus (P_2O_5 up to 21–23%) but depleted in iron sulfides (S_{pyr} up to 10%) and clayey material (Al_2O_3 1–3%). Zones located upsection and beyond the scours show a sharp decrease of the FBD content (P_2O_5 5–7%) and increase of the sulfide concentration (S_{pyr} up to 23%).

Bone phosphate from deposits in the marginal fish-facies zone is generally characterized by low REE and U contents (0.84–1.06 and 0.1–0.16%, respectively).

It should be noted that facies types similar to those in the Stepnov and Shargadyk–Bogorodsk deposits are also developed in other areas of southern Ergeni (Stolyarov and Ivleva, 1991). This implies relatively sharp changes in the marginal fish-facies zone.

The upper Kalmyk Subformation is composed of rather uniform greenish gray clays with obscure thin bedding emphasized by fine silty material and accumulations of algae-type organic remains. They are locally replaced by the fish-facies clays only in the southern Ergeni area (Fig. 4, sections VII–XII). The upper subformation is up to 115 m thick.

Sediments of the fish facies are poorly developed or missing in the western and northern parts of the Volga–Don region. Therefore, the Kalmyk Formation is divided into subformations based on biostratigraphic criteria rather than lithological properties.

In the Gashun Depression located westward, the Kalmyk Formation is composed of greenish gray massive clays with fucoids and silty material lenses and sandy–silty layers (Fig. 4, sections I, II). Beds (up to 2 m thick) with fish remains are rare. The base of the Kalmyk Formation occasionally includes up to 10-m-thick bone detritus beds.

The Kalmyk Formation in the northern Ergeni and Volgograd regions is also composed of similar greenish gray massive silty clays with fucoids (Fig. 5, sections XVI–XVIII). The X-ray diffraction study revealed that rocks in section XVIII are composed of quartz, smectites, hydromica, kaolinite, and subordinate feldspars and pyrite. Fraction <0.001 mm is composed of smectites with the subordinate kaolinite, chlorite, and rare quartz.

Their chemical composition is as follows (average of three samples, %): Na_2O 0.69, MgO 2.83, Al_2O_3 18.06, SiO_2 53.11, P_2O_5 0.08, K_2O 3.12, CaO 0.94, TiO_2 0.80, MnO 0.1, Fe_2O_3 7.91, and L.O.I. 11.85. Some samples additionally yielded the following components, %: H_2O^+ 8.34, FeO 1.92, S_{tot} 1.4, SO_3 <0.25, CO_2 0.82, and C_{org} 0.24.

The distribution of organic remains in the Kalmyk Formation is highly irregular and depends on facies features of sediments (Semenov and Stolyarov, 1988; Voronina *et al.*, 1988). Clays of the fish facies usually lack benthic foraminifers and mollusks. Planktonic fossils are also poorly preserved in carbonate-free sediments.

Benthic foraminifers appear in marginal parts of the fish facies in the southern Ergeni area, where they are confined to clayey sequences without fish remains. The foraminiferal assemblage includes *Haplophragmoides karadjalgensis* Ter-Grig., *H. kjurendagensis* Ter-Grig., *H. rotundidorsatus* (Hant), and *Trochammina depressa* Subb.

The foraminiferal assemblages are composed of agglutinated or secretory benthic species dominated by *Uvigerinella californica* Cushm. Sections of the Chernye Zemli area includes the following similar assemblage of foraminiferal species with agglutinated tests: *Trochamminoides rotaeformis* Subb., *Trochammina depressa* Subb., and *Haplophragmoides kjurendagensis* Ter-Grig.

Stratigraphic analogues of the lower subformation in the northern Ergeni area contain the following *Spiroplectammina terekensis* Zone assemblage: *Spiroplectammina terekensis* Bogd., *Uvigerinella californica* Cushm., *Pseudoparella caucasica* Bogd., *Caucasina schischkinskayae* Sam., *Cibicides nefestus* Nikit., and others. First two species are dominant in this assemblage.

The shallow-water sandy–silty clays of the northern Ergeni and Volga–Don regions yield relatively diverse molluscan assemblage dominated by bivalves *Nucula comta, Nuculana gracilis* Desh., *N. karaschokiensis, N.* cf. *nana* (Koen.), *Portlandia (Yoldiella)* sp., *Chlamys* sp.; *Lentipecten corneus* (Sow.), *Anomalina* sp. *Astarte gracilis* Goldf., *Parvicardiun nikolaevae* Merkl., *Plagiocardium abundans* (Liv.), *Cerastoderma* cf. *prigorovskii* (Bogd.) (=*C. helmerseni* and *C. levinae*), *Arctica rotundata* (Br.), *Cultellus* sp., *Corbula (Varicorbula) gibba* (Ol.), *Thracia ventricosa* Phil., and *Natica* achatensis, *Dentalium* cf. *transiens* (Stein.) (Voronina *et al.*, 1988).

The presence of relatively polyhaline forms in this assemblage suggests an almost normal salinity of the Kalmykian sea basin.

Recently, Zaporozhets (1998) studied the taxonomic composition of Eocene and Oligocene spores, pollen, and organic-walled phytoplankton in section XIII of the northern Ergeni area (Fig. 5). Clayey sediments of the Kalmyk Formation enclose the phytoplankton assemblage with dominant *Chiropteridium pertispinatum, Deflandrea spinulosa*, and subordinate *Homotryblium tenuispinosum*, and *Pentadinium laticinctum.*

The spectra of the Kalmyk palynological assemblage contain dominant Gymnospermae (80–85%) accompanied by pollen of Taxodiaceae, conifers, and Betulaceae (particularly *Alnus*). The decrease in the content of small pollen belonging to the *Quercus* genus usually associated with its evergreen forms is noted. According to Zaporozhets, the above assemblage is typical of Upper Oligocene sediments, and water column of the Kalmykian basin was characterized by normal salinity but distinct stratification.

The upper Kalmyk Subformation of the southern Ergeni and Chernye Zemli areas composed of relatively deepwater sediments usually lack molluscan remains. Foraminifers are represented by the *Cibicides ornatus* Zone assemblage with neogenic *Perfectononion polymorphus* Bogd., *Elphidium onerosum* Bogd., and still existing *Uvigerinella californica* Cushm. The similar foraminiferal assemblage is typical of relatively shallow-water upper Kalmyk sediments in the northwestern part of the studied region, where the impoverished molluscan assemblage includes large relatively euryhaline *Cerastoderma prigorovskii.*

The brief description of Upper Oligocene sediments in the Volga–Don region shows that they are general similar with their counterparts from Southern Mangyshlak. However, one can also note certain differences related to some regional variations in the lithofacies composition and distribution of FBD deposits. The FBD deposits are localized at different stratigraphic levels of the fish subformation. Hence, the FBD deposits of the studied region are older relative to those in other areas; i.e., the process of fish bone accumulation was asynchronous in the central part of the Eastern Paratethys.

It should also be noted that sediments of the fish facies of the Mangyshlak and Volga–Don regions characterize marginal parts of their vast domain in depressions of the Middle Caspian–eastern Ciscaucasus region (Stolyarov and Ivleva, 1995). They are confined to the central South Mangyshlak Trough in Mangyshlak. The Volga–Don region demonstrates regional transition from the relatively deep fish-facies to shallow-water sediments without fish remains. These processes probably governed lithostructural differences of FBD deposits in their two large domains.

THE CENTRAL AND WESTERN CISCAUCASUS

In this area including the most part of the Ciscaucasus region, Upper Oligocene sediments are developed continuously from lower reaches of the Don River to the North Caucasian monocline. Like the Volga–Don region, this territory can be divided into two facies zones with different lithostructural types of sediments. Sediments of the fish facies are widespread in the central Ciscaucasus, Stavropol Uplift, western Terek–Kuma Trough, southern areas of the western Ciscaucasus, and Indol–Kuban Trough. Shallow-water FR-free sediments are developed in the northwestern Ciscaucasus, including the Azov Uplift and adjacent areas (Popov *et al.*, 1993b).

In the fish-facies domain, Upper Oligocene sediments are divided into the Batalpashinsk (with Septarian and Alkun beds) and Zelenchuk formations that stratigraphically correspond to the lower and upper Kalmyk subformations. Both formations enclose FBD and iron sulfide deposits. However, stratigraphic interval of their distribution is wider and includes the Zelenchuk Formation as well (Kochenov and Stolyarov, 1996).

Figure 5 (sections VI–XI) demonstrates the structure of the Batalpashinsk Formation and lower Kalmyk Subformation in the central Ciscaucasus region. In the western part of the Terek–Kuma Trough, they are composed of typical fish-facies sediments (up to 300 m or more). The lower part of the section (50–80 m) is characterized by a high content of fish remains that form an extended dispersion halo south of the Ergeni ore district. Higher in the section, dark clays usually contain only fish scale.

In the southern area (North Caucasian monocline and Indol–Kuban Trough), the thickness of the Batalpashinsk Formation sharply decreases to 100 m and clays enclose calcareous rock packages (up to 10 m) with local marl layers up to 0.2 m thick (Fig. 5, sections I–V).[1] These sections characterize the deepest fish facies of the Upper Oligocene sequence. The $CaCO_3$ content varies from 6.0 to 18.4% (CO_2 2.64–8.12%) in clays and equals to 71% (CO_2 31.3%) in compact marl layers.

Sediments of the fish facies are replaced by relatively shallow-water sediments in the northwestern direction. Their marginal zone extending from the southern Ergeni area to the Sea of Azov changes the strike from the submeridional to sublatitudinal direction at the northern flank of the Indol–Kuban Trough (Popov *et al.*, 1993b). This area also contains FBD deposits, but they are substantially smaller than the southern Ergeni deposit.

The Nekrasov deposit located 15 km southeast of Ust-Laba (Krasnodar Territory) is the largest object in the central and western Caucasus region (Kochenov and Stolyarov, 1996). The deposit has been drilled to a depth of 1420–1780 m and traced over more than 20 km

[1] Calcareous clay layers were initially established in the uppermost part of the Batalpashinsk Formation and defined as the Alkun Horizon (Somov, 1967; Ter-Grigor'yants, 1969).

(the boundary has not been outlined). It is confined to the lower part of the Batalpashinsk Formation (up to 150 m) and stratigraphically correlated with deposits of the southern Ergeni area.

The Nekrasov deposit comprises one to three sulfide–bone beds (0.15–1.3 m) with the following components (%): P_2O_5 9.25, U 0.046, Ce 0.1, J 0.06, and La 0.03% (based on a few determinations).

East of the Nekrasov deposit, the marginal fish-facies zone embraces a substantial part of the Stavropol Uplift. In this area, clayey sediments of the Batalpashinsk Formation (150–200 m) contain abundant fish remains that form centimeter-scale FBD layers. They usually extend in the sublatitudinal direction along the entire South Stavropol Swell over 6–8 km (width 3–4 km). For example, the lower bed of the multilevel Urakov–Bogoslov deposit (Fig. 5, section V) exposed in the Kuban River valley is 0.93 m thick and consists of three layers (16, 26, and 15 cm thick) separated by clay layers. These layers are enriched in sulfides (S_{pyr} 15–19%) and depleted in fish remains (P_2O_5 1–2%). The FR content increases only in the upper layer (P_2O_5 5%, U 0.22%).

Thus, bone–sulfide sediments are rather widespread in the peripheral fish-facies zone of the Batalpashinsk Formation in the central and western Ciscaucasus region, although they usually form thin FBD-poor sulfide beds. Only the Nekrasov deposit can be qualified as a large object with a relatively high FBD concentration (up to 18%).

The overlying Zelenchuk Formation, an analogue of the upper Kalmyk Subformation, is composed of gray clays with silty flour and algae accumulations in the most part of the central Ciscaucasus region. They contain scarce fish remains mainly represented by scales (Fig. 4, sections VII–XI). In the South Stavropol Swell, clays enclose thin (up to 0.1 m) sulfide layers with subordinate bone detritus sometimes up to 2–3 cm in size. These layers constitute the upper part of the Urakov–Bogoslov deposit (Fig. 5, sections V, VI).

Another type of the Zelenchuk section with bone–sulfide beds is developed in the North Caucasian monocline west of the Caucasian Mineral'nye Vody (CMV) area. Here, the Zelenchuk Formation is approximately 100 m thick and consists of alternating members (2–9 m thick) of dark gray fish-facies clays and sandy–silty sediments in the lower part (up to 60 m). The upper part is largely composed of sandy–silty rocks with rare gravelite layers. Sandy rocks are characterized by irregular (less common sinuous-lenticular) structures. The contact between clays and silty sandstones is sharp with erosion signs, indicating substantial changes in the hydrodynamic regime of the sedimentation basin.

The sandy–silty material is mainly composed of quartz (up to 84%) and subordinate feldspars (up to 10%), glauconite (up to 5%), and micas (2–4%). The heavy fraction includes garnet, tourmaline, zircon, apatite, ilmenite, leucoxene, and magnetite.

The bone–sulfide beds are confined to fish facies in the lower part of the Zelenchuk Formation. They make up the giant Cherkessk deposit almost continuously extending from the CMV area to Cherkessk, where they are exposed in the Kuban River valley. The deposit is 54 km long, few kilometers wide, and from 0.1 to 3.0 m thick. Its thickness reaches 7–8 m in the east, where the deposit is split into several beds.

The Cherkessk deposit (S_{pyr} up to 27%) is composed of cryptocrystalline pyrite in the form of microglobules or pisoliths within the clayey matrix. The FBD content varies from 1.5 to 7.8% (P_2O_5 0.5–2.6) and bone clasts are usually 0.1 mm or more in size. The deposit contains hard fragments of black OM with a weak luster and conchoidal fracture (brown coal, based on the IR diffraction data).

The Cherkessk deposit has the erosional southern boundary. The eroded part of the deposits located closer to the Caucasian Archipelago was probably enriched in the FBD. The preserved northern part of the deposit presumably formed in a relatively deep-water environment, which was responsible for its anomalous sulfide composition typical of deposits in deep zones of the basin. The Cherkessk deposit formed in an specific sedimentation environment characterized by sharp changes in the hydrodynamic regime and avalanche accumulation of coarser material that interrupted the formation of fish-facies sediments and bone–sulfide deposits.

The Zelenchuk and underlying sediments enclose sandy offsets and lack bone–sulfide beds west of the Cherkessk deposit (Kalinenko, 1990; Stolyarov, 2001).

Thus, the uppermost Oligocene section of the central and southwestern Ciscaucasus substantially differs from the underlying Batalpashinsk sequence. The fish facies is generally less manifested and enriched in silty material. Like ore districts of the Ergeni and Mangyshlak areas, the central and southwestern Ciscaucasus region lacks FBD deposits. At the same time, bone–sulfide deposits were accumulated in the North Caucasian monocline. These deposits contain a relatively coarse-grained sandy–silty material, which is atypical of the fish facies.

The vast territory of the northwestern Ciscaucasus, Sea of Azov, and Lower Don River regions is characterized by the development of more or less uniform sandy–silty–clayey sediments with occasional fish remains. These sediments, however, cannot be referred to the fish facies. The main structural–facies zone in this region is the large Azov Uplift bordered by the Tuzla–Manych Trough in the north, Cis-Sal'sk Trough in the east, and Eisk Trough in the south (Nikitina, 1962).

The Upper Oligocene and underlying sediments in this region are yet insufficiently studied. They are mainly discussed in works of Nikitina (1958, 1962, 1963). Their general lithostructural features are shown in sections compiled after this author (Fig. 3).

In the uppermost part of the Azov Uplift (sections 2, 39), the Upper Oligocene sequence (40–50 m) is composed of brown sands and silts with subordinate clay layers. The rocks lack characteristic fossils and only locally contain plant remains. The thickness increases to 120 m in the southern Eisk Trough area (section 5). Its 20-m-thick lower section (gray clays with silt layers) includes benthic foraminifer *Caucasina* aff. *bulimінoides* Bogd., Pinacea pollen, and abundant fern remains in local sectors. The overlying 80-m-thick section (grayish green silt, with clay layers) contains small radiolarians and scarce fish remains. The uppermost brown clay layer (20 m) includes plant remains and foraminiferal species *Bolivina goudkoffi caucasica* Bogd.

At the eastern margin of the Azov Uplift (Cis-Sal'sk Trough), sediments are very fine-grained, which is typical of the central Ciscaucasus (section I). The gray to dark gray silty clay section (105 m) contains FR dissemination and small radiolarians. The uppermost 5-m-thick layer of greenish gray clay yields the foraminiferal species *Cibicides ornatus* Bogd., which correlates with the upper Kalmyk Subformation of the Volga–Don region.

In the eastern Stavropol structural–facies zone, stratigraphic analogues of the Batalpashinsk Formation (or lower Kalmyk Subformation) are composed of greenish gray to dark gray clays (55–165 m) with fish remains. Ter-Grigor'yants united these sediments into the *Haplophragmoides kjurendagensis* Subzone with the impoverished foraminiferal assemblage of *Ammodiscus tenuiculus* Subb., *Trochammina depressa* Subb., *Rotalia propinqua* Reuss, and *Porosononion dendriticus* Chal.

Stratigraphic analogues of the Zelenchuk Formation (up to 40 m) are referred to the *Bolivina goudkoffi caucasica* Zone (Ter-Grigor'yants, 1969).

Foraminifers are rather rare in deepest-water sediments of the Batalpashinsk Formation of the North Caucasian monocline. According to Ter-Grigor'yants, the lower section of the Kuban sequence includes *Virgulinella* ex gr. *pertusa* (Reuss), *Cibicides* aff. *amphisilensis* (Andr.), small *Haplophragmoides* sp. and *Ammodiscus tenuiculus*, as well diatoms and rare radiolarians. Calcareous clay layers in the upper section (Alkun Horizon) yield more diverse and abundant foraminifers, such as *Virgulinella neobulimiformis* Kusnez., *V. poiliensis* Kusnez., *Bolivina* ex gr. *plicatella* Cushm., and *Uvigerinella californica parva* Kl.

Despite the sandy composition, the Zelenchuk Formation contains abundant and diverse foraminifers, such as *Cibicides ornatus* Bogd., *Porosononion dendriticus* Chal., *Rotalia propinqua* Reuss, *Ammodiscus tenuiculus* Subb., *Trochammina* sp., and *Haplophragmoides* sp.

Thus, like the Volga–Don region, the central and western Ciscaucasus region is composed of Upper Oligocene sediments of substantially different types, such as relatively deep-water sediments with the fish facies and bone–sulfide deposits and shallow-water sandy–silty–clayey sediments with rare fish remains. The relatively deep-water sections are characterized by the well-sustained two-member structure, while the subdivision of shallow-water sections is only possible based on the locally manifested paleontological zonation.

This territory is characterized by an additional section type with deepest-water calcareous–clayey sediments (Batalpashinsk Formation) grading into sandy–silty–clayey sediments (Zelenchuk Formation) in the upper part of the Oligocene sequence. The giant Cherkessk bone–sulfide deposit occupies an anomalous stratigraphic position in the central Eastern Paratethys.

THE EASTERN CISCAUCASUS

This Ciscaucasus territory represents a specific structure–facies zone that was governed by the stable development of the Terek–Kuma (Terek–Caspian) Trough uncompensated by sediments for a long time in the Paleogene. Therefore, the Paleocene, Eocene, and Oligocene sequence in the trough has a total thickness of only 150–200 m (Shutskaya, 1970; Stolyarov, 1991, 1999; Popov *et al.*, 1993b).

In the Terek–Kuma Trough, intense sedimentation commenced in the Late Oligocene and the sedimentary sequence is more than 1000 m thick. Another specific feature of this trough is the abundance of coarser sandy–silty material and local submarine-slump blocks within the clayey fish facies. The blocks started to slump at the early–late Oligocene boundary and became widespread in the *Virgulinella* Bed of the Upper Oligocene basal section in the southern part of the trough (Somov, 1967; Stolyarov, 2001).

The Upper Oligocene sequence in the central part of the trough is insufficiently studied because of a poor core recovery from deep oil wells. Therefore, its structure is reconstructed based on the available seismostratigraphic materials.

It should be emphasized that the stratigraphic volume of the Upper Oligocene in the eastern Ciscaucasus region remains ambiguous so far, because stratigraphic analogues of the Zelenchuk and Karadzhalgie formations, the boundary between which corresponds with the top of the Upper Oligocene Kalmykian regional stage, are unknown (Popov *et al.*, 1993b). The Upper Oligocene in the study region is mainly composed of the Miatly–Mutsidakal Formation (Sequence) defined in the Sulak area of Daghestan (Shatsky, 1929). It represents a stratigraphic analogue of the Batalpashinsk Formation (Somov, 1965, 1967) and is overlain by the stratigraphically ambiguous Alkun Beds.

The undifferentiated Assa Formation is considered a stratigraphic analogue of the Zelenchuk and Karadzhlagie formations (Popov *et al.*, 1993b). Consequently, the Oligocene–lower Miocene boundary remains arbitrary so far. It is occasionally drawn at the base of the Assa Formation or even Alkun Beds (Somov, 1965, 1967).

One of the most complete Upper Oligocene sections in the monocline of eastern Ciscaucasus is the Argun River section in Chechnya. Here, the thin (4.5 m) Roshna (*Virgulinella*) Bed composed of calcareous clays and sandstones (Stolyarov, 2001) are overlain by gray to dark gray noncalcareous clays with FR dissemination, including bluish scales replaced by silica. These sediments (approximately 40 m thick) are typical deep-water fish facies (lower clayey beds of the Miatly–Mutsidakal Formation).

Upward the section, the fish-facies clays enclose subordinate (up to 1–2 m thick) FR-free beds and thin (0.2–0.5 m) layers of gray massive or obscurely bedded (banded) fine-grained sandstones. The uppermost part of this clayey sequence hosts a thin (5–7 cm) sulfide layer with brown ferruginous coating, abundant fish scales, gagate lenticles, and high radioactivity (up to 10 μR/h).

The overlying clay member (15–20 m) with fish scale dissemination encloses isolated thin lenses (0.1–0.2 m) of compact siltstone. Some clayey layers are brecciated with the development of Liesegang rings around clasts.

The second clay member (12 m) is composed of alternating clay and sandstone layers from 0.1 to 0.7 m thick. The gray, usually uniform or silty, clays locally reveal signs of roiling and cementation of clasts by sandy–silty material. Sandstones are observed as hard (compact), fine-grained (locally grading into siltstones), massive or laminated, and sometimes sinuous-lenticular micaceous–quartzose rocks locally enriched in micaceous minerals or glauconite grains.

The next member (25–30 m) is mostly composed of gray uniform clays with rare layers of dark fish-facies clays and lenticular silty laminae in the upper part.

The overlying compact bed (2 m) consists of fine-grained massive, locally banded, micaceous–quartzose sandstone. It is overlain by gray clays (25–30 m) with siltstone and siderite pellets. The next member (approximately 80 m thick) is also composed of gray clays with subordinate fish-facies layers and frequent thin (up to 0.1 m) silty sandstone lenticles and siderite concretions.

The upper part of the Miatly–Mutsidakal Formation (70–80 m) is composed of relatively uniform clayey sediments of the typical fish facies with the radioactivity up to 40 μr/h (Argun Bed, according to N.S. Zolotnitskii). The clays are dark gray and striated owing to the presence of scaly OM. Fish remains are mostly represented by scales and subordinate bone detritus. Only the upper part of the section encloses silty sandstone laminae and dolomitic concretions. The FR content is decreased.

The overlying clay member (15–20 m) defined as the Alkun Beds is marked by the presence of several (usually more than three) relatively sustained lenticular dolomitic and marly layers (0.2–0.3 m). Concretions of the similar composition are also present in the enclosing clays. The Alkun Beds are overlain by gray to dark gray clays with FR dissemination (Assa Formation). The Assa Formation is marked by the presence of silty sandstone lenticles with glauconite grains standing out as crusts and lumps. The thickness of the Assa Formation in the Argun River valley approximates 170 m.

The upper Oligocene sediments in this section are dominated by the fish-facies clays accumulated in relatively deep-water settings. However, this process was complicated by the intermittent influx of fine-grained sandy and silty material (mica–feldspar–quartz).The thickness of this section is estimated at ~450 m, because its upper boundary is arbitrary.

The relatively complete section along the Argun River valley presents a general lithostructural image of the Upper Oligocene succession in the Terek–Caspian Trough of the eastern Ciscaucasus region. The presence of sandy–silty layers extending northward up to the Astrakhan region in deep-water clayey sediments of the fish facies is among the debatable issues in the study region.

The CMP studies revealed numerous inclined sandy beds surrounded by clayey sediments within the Maikop Group (Kunin *et al.*, 1988). The Upper Oligocene–Lower Miocene Maikop clinoform complex is developed practically throughout the entire study region. According to recent data (Kosova, 1994), one can distinguish 16 clinoform seismic facies from the northeast to southwest. They form arcuate bodies 90–300 km long, 40–50 km wide, and 250–400 m thick. Each clinoform body (seismic facies) is characterized by a sigmoid cross section and bedding dip of 1°–2°.

Comparison of seismic materials with the drilling data on both sides of the Kuma River shows that clinoforms are largely composed of sandy–silty–clayey sediments characterized by the prevalence of clays and occasional presence of relatively well-sorted sands. The lower clinoform pinchouts ("fondoforms") usually consist of dark clayey rocks with sandy layers (Kosova, 1994). Boreholes usually recover three to eight clinoform seismic facies (Kunin *et al.*, 1988).

Most of the sandstones are in fact siltstones with a subordinate (up to a few percents) admixture of fine-grained sandy material (0.25–0.1 mm). Therefore, petroleum geologists arbitrarily identify these rocks as sandstones and indicate that the content of fraction >0.1 mm therein usually varies from 0.*n* to 1–2% (occasionally, 30–40%). The elevated content of sandy fraction is usually noted in western areas of the eastern Ciscaucasus (Ossetia) located closer to the Caucasian provenance.

Results of the mineralogical analysis of terrigenous Maikop sediments are scrutinized in (Grossgeim, 1961). In the Chernye Gory terrigenous mineralogical province (TMP) of the eastern Caucasian monocline, the Upper Oligocene siltstone sequence is characterized the diversity of mineral associations. The light fraction has a polymictic composition (volcanic glass and altered volcanic ash). The heavy fraction is characterized by the presence of relatively unstable minerals, abundance of leucoxene, and the development of sillimanite, andalusite, monazite, perovskite, micas, garnet, kyanite, and staurolite.

In the central Terek–Kuma Trough (Ciscaucasian TMP), the light fraction of sandy–silty sediments has a polymictic (mostly quartzose) composition, whereas the heavy fraction has a normal composition. The sequence often contains a minor amount of metamorphic minerals and amphiboles and high contents of epidote and micas. Kyanite and staurolite are widespread. Their contents increase to the north.

Both polymictic and quartzose (or feldspathic) light fractions are typical of sandy–silty sediments in the northern Terek–Kuma Trough (Northeastern TMP). The heavy fraction of this area is marked by the abundance of epidote and Ti-bearing minerals and the presence of metamorphic minerals.

Ter-Grigor'yants performed the micropaleontological study of cores from wells that penetrated the Upper Oligocene sequence of the Terek–Kuma Trough and found that the dark gray to black carbonate-free fish-facies clays of the Miatly–Mutsidakal Formation (approximately 300 m thick) lack foraminifers.

The foraminifer assemblage is relatively diverse in the overlying Assa sequence (700–750 m). The basal (mostly clayey) section in the Ozek–Suat area yields rare *Uvigerinella* ex gr. *californica* Cushm., *Cibicides ornatus* Bogd., *Elphidium onerosum* Bogd., and *Haplophragmoides* aff. *kjurendagensis* Moros.

The overlying sequence of alternating gray to dark gray clays and siltstones is most complete in the Maksimokum area. The sediments contain abundant *Uvigerinella californica* Cushm., *Cibicides ornatus* Bogd., *Nonion polymorphus* Bogd., *Eponides propinqua* (Reuss), *Elphidium onerosum* Bogd., *Haplophragmoides* aff. *kjurendagensis* Moros., *Proteonina difflugiformis* (H. Brady), and others.

Greenish gray silty clays from the uppermost part of the Assa Formation (wells Pravoberezhnaya R-3 and Andrei-Kurgan R-1) are characterized by *Bolivina goudkoffi* Rankin subsp. *caucasica* Bogd., abundant *Uvigerinella californica* Cushm., *Caucasina buliminoides* Bogd., *Globulina gibba* Orb., *Verneuilina rasilis* Subb. (msc)., *Haplophragmoides kjurendagensis* Moros., *Circus rotaeformis* Subb., *Saccammina grzybowski* Bogd., *Hyperammina caucasica*, and others.

CONCLUSIONS

The Upper Oligocene sequence in the central Eastern Paratethys is an intricate geological body with different lithofacies relationships and thickness variation from a few tens of meters to more than 1000 m. The rock sequence is characterized by abundance of the clayey fish facies in troughs of the eastern Ciscaucasus and Mangyshlak. They make up the Batalpashinsk Formation (central Ciscaucasus) and the lower Kalmyk and Karagie subformations (Volga–Don and Mangyshlak regions), which enclose the main deposits of metalliferous FBD and iron sulfides. Sediments of the fish facies are less typical of the Upper Oligocene sequence, although they also contain bone–sulfide accumulations.

The Upper Oligocene sequence with the thickest fish-facies section (1000–1200 m) in the eastern Ciscaucasus is characterized by the abundance of clinoform sandy–silty layers, which significantly differ from the fine-grained clayey rocks. The southwestern area located beyond the thick clinoform sequence (Central Caucasian monocline) is occupied by thin (100–200 m) deepest-water fish-facies sediments with carbonate layers (Batalpashinsk Formation) but without bone–sulfide accumulations. The bone–sulfide accumulations are developed in the overlying Zelenchuk Formation (Cherkessk deposit), where sediments of the fish facies associate with sandy–silty layers.

Thus, Upper Oligocene sediments of the fish-facies domain (the southwestern, central, and eastern Ciscaucasus regions and southern Mangyshlak) can be divided into the following types:

(1) deep-water sediments with carbonate beds and bone–sulfide deposits in the upper part of the section (central Ciscaucasian type);

(2) deep-water sediments with abundant clinoform sandy–silty beds (eastern Ciscaucasian type); and

(3) relatively deep-water sediments of marginal fish-facies zones with abundant FBD and iron sulfide deposits (Mangyshlak–Ergeni type).

Beyond the fish-facies domain, relatively shallow-water thin (tens of meters) sandy–silty clays are most widespread in the northwestern Ciscaucasus and Volga–Don regions.

The presence of substantially different lithofacies complexes in the Upper Oligocene sequence suggests a significant facies–paleogeographic differentiation of the sedimentation basin. The formation setting of metalliferous FBD and iron sulfide deposits is the most important issue. The formation of the thick clinoform sequence is also an interesting problem. The synchronous development of bone–sulfide accumulations and clinoform bodies brings up the natural question as to whether their spatiotemporal relationships are regular or incidental.

It should also be noted that not only facies–paleogeographic environments are important for solving the problem of the origin of FBD deposits. One should also consider purely biological aspects, such as causes responsible for the prolonged existence of mass fish populations in certain zones of the sea basin, their periodical mass death, and so on.

However, factors controlling the concentration of metalliferous bone detritus and intense sulfide formation are the most important issue. Fish remains concentrate all rare earth elements (except promethium), uranium, and scandium. Scandium is also widespread in clayey sediments (Stolyarov *et al.*, 1991). The sulfide component of ore bodies includes Fe, Ni, Co, Mo, Zn, Pb, and Rh. Sources of these elements and conditions of their concentration in sediments are also undoubtedly essential issues.

It is obvious that metallogeny of the Upper Oligocene sequence and its relationship with regional facies–paleogeographic sedimentation environments need special consideration. These issues will be highlighted in the forthcoming communications.

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