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Upper Oligocene Sediments in the Ciscaucasus, Volga–Don, and Mangyshlak Regions (Central Part of the Eastern Paratethys): Communication 2. Facies–Paleogeographic Sedimentation Settings

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Abstract—Late Oligocene basins were very unusual in terms of sedimentation. The most remarkable example is the early Kalmykian basin that was characterized by the drastic morphological differentiation and deposition of substantially different lithofacies sediment types (shallow-water shelf to relatively deep-water facies in anoxic troughs). Slopes of the troughs and uncompensated areas are marked by the accumulation of thick sandy–silty–clayey (up to 1000 m) and thin calcareous–clayey (up to 100 m) sediments, respectively. The outer shelf zone with islands and shoals includes metalliferous fish bone detritus and iron sulfide deposits. This exotic feature of the Kalmykian basin has no genetic analogues among other formations of the world. This communication presents the first description of the late Kalmykian basin and its lithofacies map that demonstrates the abrupt transformation of the paleogeographic setting in the late Oligocene as a result of the general relative shoaling and basin bottom leveling. Consequently, metalliferous sediments ceased to accumulate in the northern shelf area, but bone–sulfide deposits could accumulate in the southern part of the basin along the Caucasian archipelago.

As was shown in (Stolyarov and Ivleva, 2004), Upper Oligocene sediments of the study region accumulated in a specific marine basin. Their substantial facies–paleogeographic differentiation was responsible for significant changes in thickness and facies features of sediments, the deposition of clinoform sandy–silty bodies in deep-sea areas, and the formation of exotic metalliferous fish bone detritus and iron sulfide (hereafter, bone–sulfide) deposits. These sedimentation features of the late Oligocene marine basin need a comprehensive facies–paleogeographic analysis of its sedimentation settings.

It should be noted that the lithofacies (facies–paleogeographic) map presented in our previous work characterized only an interval of the late Oligocene period corresponding to the Batalpashinsk and Miatly–Mutsidakal formations of the Ciscaucasus region and lower subformations of the Kalmyk and Karagie formations in the Volga–Don and Mangyshlak regions (Popov *et al.*, 1993; Stolyarov and Ivleva, 1995). A modified version of this map is presented in Fig. 1. Accumulation conditions of upper Kalmykian sediments (Zelenchuk and Assinsk formations) in Ciscaucasia and upper subformations of the Kalmyk and Karagie formations (Volga–Don and Mangyshlak regions) are shown in Fig. 2.

STRUCTURAL–FACIES ZONING

In terms of the tectonic structure, the central Eastern Paratethys represents a young (epi-Hercynian) Central Eurasian Platform consisting of the Scythian and Turan plates, which border the ancient East European (Russian) Platform in the north. The boundary between these large different-aged elements of the Earth's crust passes north of the Karpinskii Ridge, between the Karpinskii Ridge and structures of Donbas in the west, and further follows south of the Azov Uplift (Ukrainian Shield). The most prominent structural element in the Transcaspian region is the Mangyshlak fold system, which supplements the Karpinskii Ridge as a single tectonic lineament extending from Tien Shan to the Carpathians (Rezvoi, 1993).

The structure of the epi-Hercynian platform is governed by the development of large linear (almost latitudinal and meridional) elements. They played a significant role in the formation of Paleogene marine basins that controlled the distribution of main facies zones and development of their individual structural–facies elements.

The largest structural–facies and paleogeographic zones occupied the northwestern Ciscaucasus region and the lower course of the Don River, on the one hand, and vast areas of eastern and southern Ciscaucasia, on the other. The first (always elevated) area was connected with the Azov Uplift, Donbas structures of the

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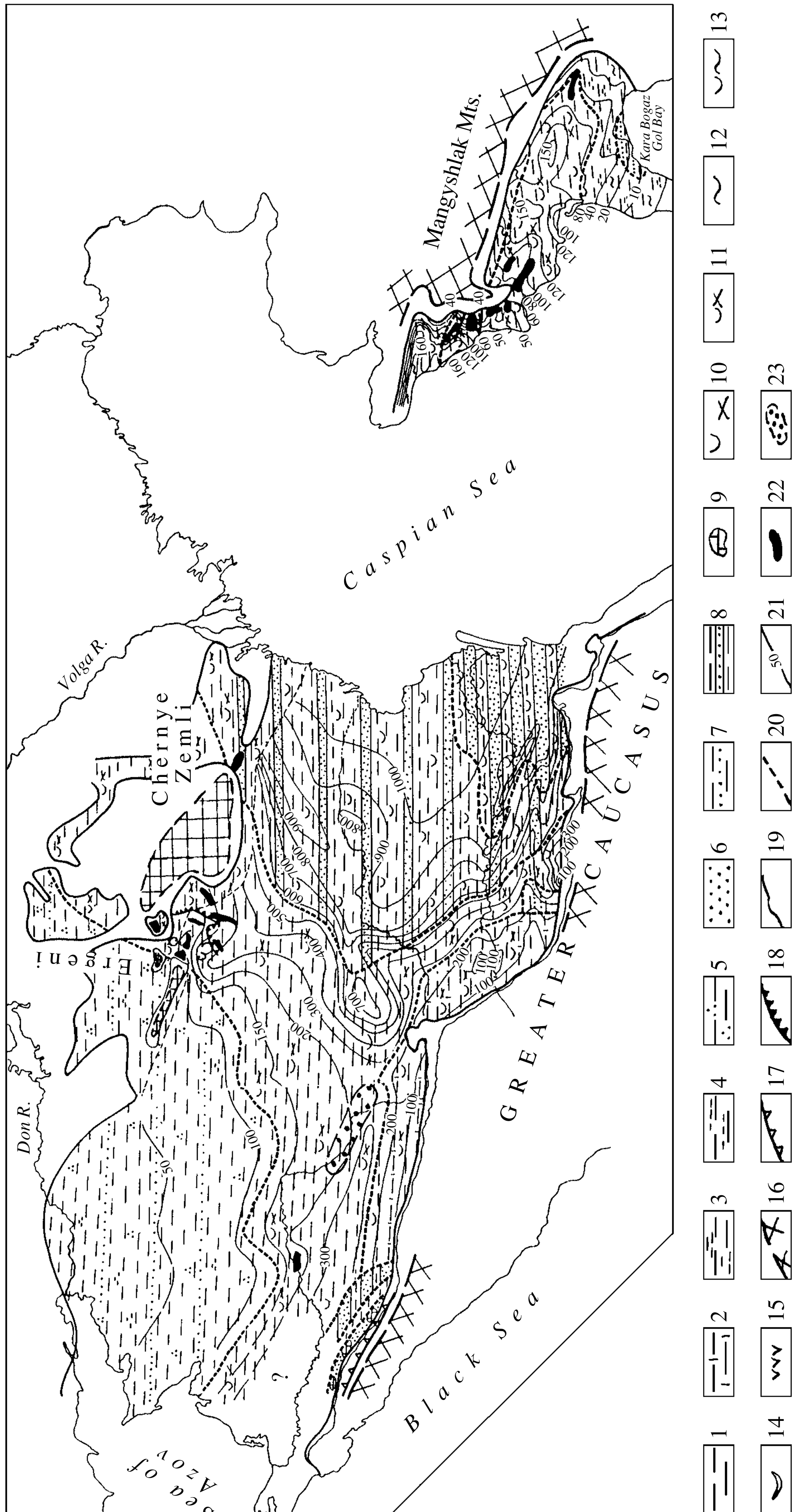

Fig. 1. Lithofacies map of the central Eastern Paratethys (early Kalmykian time). Sediment types: (1) clay, (2) calcareous clay, (3) silty clay, (4) clay with silty powder (5) sandy clay, (6) sand and silt, (7) clay with thin sand and silt interbeds, (8) clay with sand and silt members, (9) block inclusions (olistoliths); organic remains: (10) dispersed fish remains (scale and bones), (11) fish remains at bedding surfaces, (12) fucoids with iron sulfides, (13) alternating beds with fish remains and fucoids, (14) molluscan shells, (15) "algal" remains; paleogeographic elements: (16) assumed land, (17) high-amplitude steep scarps, (18) low-amplitude scarps controlling the formation of bone detritus deposits; (19) present-day distribution of sediments; (20) distribution areas of lithological complexes (lithofacies); (21) isopachs; (22) bone detritus deposits; (23) domains of thin bone detritus interbeds (ore occurrences).

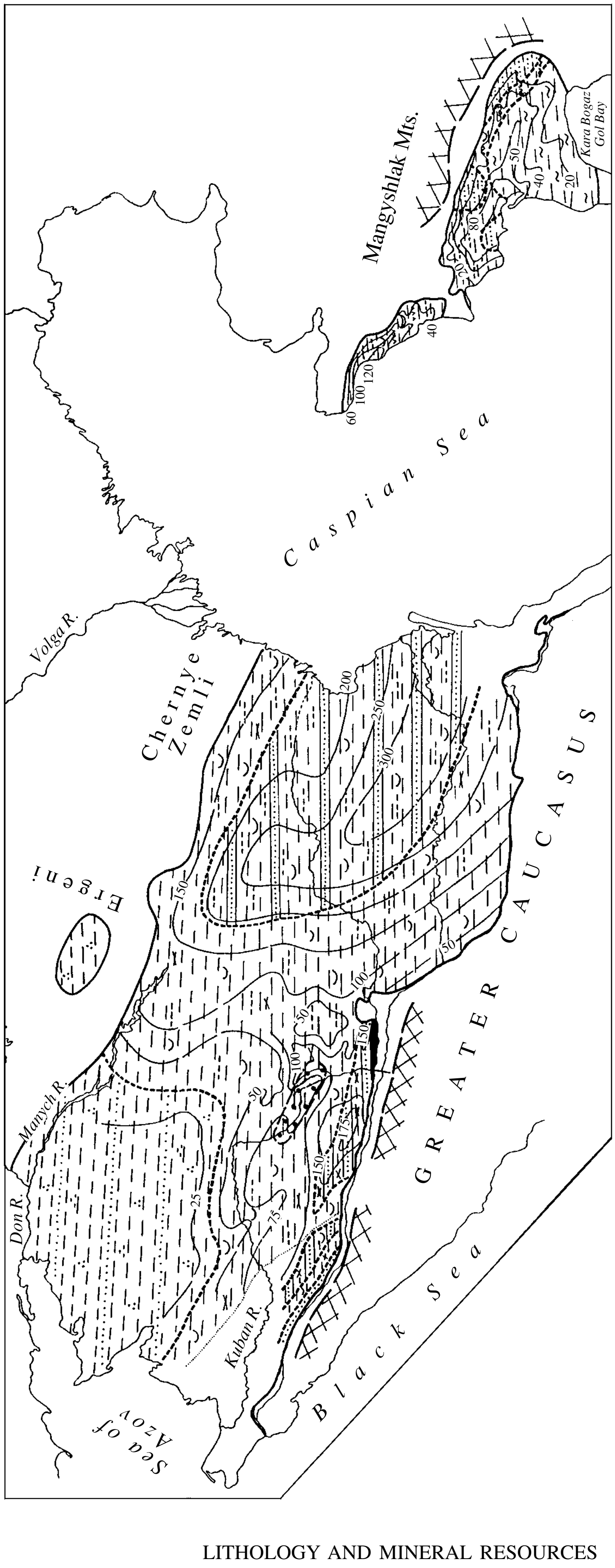

Fig. 2. Lithofacies map of the central Eastern Paratethys (late Kalmykian time).

Russian Platform, and northwestern part of the Karpinskii Ridge. Vast territories of the eastern and southwestern Ciscaucasus and Middle Caspian regions were subjected to steady subsidence.

These structural–facies zones were separated by the relatively narrow (approximately 100 km) arcuate structure. Its submeridional branch passes along the Volgograd Flexure (Ergeni Uplift), whereas the sublatitudinal branch extends to the western Ciscaucasus region (Timashev scarp) and further to the Sea of Azov (Shcherbakov, 1980). Both branches merged in the Stavropol Uplift area of the central Ciscaucasus region. The extended eastward-convex Ergeni–Stavropol–Timashev zone played a significant paleogeographic role as the outer shelf complicated by synsedimentary uplifts.

The sublatitudinal lineament (Karpinskii Ridge and Mangyshlak fold system) was another important structural–facies zone subdivided into several uplifts and troughs. They constituted an intricate system of islands and shoals that controlled the formation of bone–sulfide deposits (Stolyarov and Ivleva, 1995).

Thus, the Eastern Paratethys region incorporates the following structural–facies zones corresponding to certain facies–paleogeographic (morphological) elements of the Oligocene marine basin: (1) Azov–Volga–Don; (2) Ergeni–Stavropol–Timashev; (3) Karpinskii Ridge; and (4) Eastern Ciscaucasia and Mangyshlak. Unfortunately, structural–paleogeographic features of a relatively large territory located in the present-day Caspian Sea area are still insufficiently studied.

For a more complete understanding of the late Oligocene history of the eastern Paratethys, let us briefly characterize main features of the early Oligocene period of the Maikopian basin, which underwent two substantially different—Pshekhian (early) and Solenovian (late)—development stages (Stolyarov, 1991, 1999; Popov *et al.*, 1993; Stolyarov *et al.*, 1996; and others).

EARLY OLIGOCENE BASINS OF THE EASTERN PARATETHYS

Early Oligocene marine basins occupied the whole territory under study and inherited all spatial and biogeographic patterns of the early Eocene. However, the Eocene–Oligocene transition was marked by changes in tectonic movements from moderate uplifts to rapid high-amplitude subsidences and the consequence formation of a deep (1000 m) noncompensated trough in the eastern Ciscaucasus and Middle Caspian regions during the Pshekhian time (Stolyarov, 1991). One of the most characteristic hydrological features of the early Oligocene basin was the H_2S-contamination of bottom waters in its deepest part. This resulted in the accumulation of dissolved manganese and wide development of manganese mineralization in a vast area extending from Bulgaria to Mangyshlak (Stolyarov, 1993, 1996).

The sedimentation was relatively intense only in the southwestern part of the basin (Indol–Kuban Trough) and the Mangyshlak region. The Pshekhian sediments are 300–400 m thick in the first zone and characterized by a clinoform reduction from 500 m in the Kara Bogaz Gol area to 37 m near the Caspian Sea (Stolyarov, 1961, 1991; Stolyarov *et al.*, 1996).

The northwestern Ciscaucasus sector and lower reaches of the Don River make up a large shelf zone bounded by scarps of the Ergeni–Stavropol–Timashev zone in the east and south. The northern part of the basin was marked by a more contrast development of the sublatitudinal structure extending from Donbas via the Karpinskii Ridge to Mangyshlak and the Ustyurt Plateau. This structure is one of the major paleogeographic lineaments of Oligocene basins and includes a discontinuous system of low islands and shoals (banks) that complicated the outer shelf. The Chernye Zemli area of this zone accumulated bone–sulfide deposits with a significant admixture of glauconite and foraminifers (Stolyarov and Ivleva, 1989).

The terminal Pshekhian time was marked by a short-term uplift. However, the consequent shoaling and leveling of the basin floor did not significantly change paleogeographic patterns of the topography.

The terminal stage of early Oligocene was characterized by the formation of a different type of sedimentary basin corresponding to the Solenovian period of the Eastern Paratethys. The latter lost for the first time free communication with the World Ocean. The consequent drastic change in the hydrodynamic regime was expressed as freshening of waters and restoration of their normal aeration in the Eastern Paratethys (Popov *et al.*, 1993).

The general cycle of Solenovian basin development can be divided into two distinct stages (or substages), namely (1) early brackish-water stage with calcareous sedimentation and (2) late stage with noncalcareous clayey sedimentation and variable hydrological regime (Stolyarov, 1999). The early stage was characterized by the regressive trend in basin development with the gradual cessation of calcareous sedimentation and relative coarsening of sediments upward the section. The late Solenovian basin became relatively deep with H_2S-contaminated bottom waters in deep-sea areas where the water was characterized by a nearly normal salinity and its freshening was noted only in marginal parts of the basin.

The beginning of the late Oligocene was marked by the formation of specific calcareous sediments named as the *Virgulinella* Beds (Stolyarov, 2001). They reflect a lithologically and biologically anomalous phenomenon that characterizes a specific short-term stage in the Oligocene basin development. It was relatively rapid against the background of intense tectonic subsidences, resulting in the formation of a deep trough with steep slopes and slumping processes. However, the terrigenous material influx was still lacking and only fine clayey–calcareous material accumulated central part of the trough (Stolyarov, 2001).

Below, we consider lithofacies and paleogeographic accumulation conditions of sediments overlying the *Virgulinella* Beds at the lower and upper substages of the Kalmykian regional stage.

THE EARLY KALMYKIAN BASIN

Differentiated tectonic movements at the beginning of late Oligocene were characterized by sharp high-amplitude subsidences in troughs and stable position of uplifts at their margins, resulting in a contrast distribution of the major structural–facies and paleogeographic (morphological) elements of the marine basin (Fig. 1).

The Azov–Volga–Don region with relatively thin (50–100 m) sandy–silty–clayey sediments on the inner shelf remained uplifted. In the northwest, it was bordered by a relatively large Donbas archipelago that separated the basin from intrashelf seas of the Dnieper–Donets Depression (Popov *et al.*, 1993; Stolyarov and Ivleva, 1995).

Substantial facies changes occurred in the arcuate Ergeni–Stavropol–Timashev zone of the outer shelf where relatively deep-water fish-facies sediments (up to 200–300 m thick) accumulated. The sediments were subsequently transformed into bone–sulfide deposits. The shelf area merged via the steep slope zone with the eastern Ciscaucasian deep-sea basin, where the thickness of sediments increased to 500–700 m or more.

The sublatitudinal structural–facies elements of the Karpinskii Ridge and Mangyshlak, which bordered the deep eastern Ciscaucasus–Middle Caspian basin in the north and east, also played an important role in terms of the facies–paleographic setting. They formed a system of isolated low islands and shoals in the outer shelf that steeply graded into the central deep-sea area, where the majority of metalliferous deposits formed during the early Kalmykian time.

The junction of nearly latitudinal and meridional structural elements in the southern Ergeni area is most intricate. This was responsible for the morphological and compositional diversity of numerous metalliferous deposits and sharp facies changes of host sediments (Stolyarov and Ivleva, 1991).

The morphologically less differentiated environment was favorable for the formation of rare isolated bone–sulfide deposits or their dispersion over large areas. For example, the slope of the large Peschanyi Island in the eastern Karpinskii Ridge incorporates the sublatitudinal Chernye Zemli deposit 11×3 km in size. It includes two beds, 0.1 to 0.7 m thick, mainly composed of clayey–sulfide sediments (S_{pyr} up to 12%) with a subordinate admixture of bone detritus (P_2O_5 up to 2%).

The Nekrasov deposit in the Krasnodar Territory is the largest one in the outer shelf zone of the central and western Ciscaucasus region. It extends over 20 km in the shelf area complicated by the almost meridional Eisk–Berezan Swell and includes three beds (0.5–1.3 m) enriched in bone detritus ($P_2O_5 \sim 9\%$). Thin (0.1–0.3 m) clayey–sulfide (S_{pyr} up to 19%) interbeds are developed over the entire South Stavropol Swell (~100 km) on the eastern gentle seamount. They usually make up almost latitudinal zones, 6–8 km long and 3–4 km wide, mainly composed of clayey–sulfide sediments (S_{pyr} up to 12%) with an admixture of bone detritus (P_2O_5 up to 2%) (e.g., the Urakov–Bogoslov deposit).

Thus, the periphery of the fish-facies area on the outer shelf of the Ciscaucasus and Volga–Don regions with low islands and shoals accumulated metalliferous deposits over the >700-km-long zone extending from Chernye Zemli to the Azov region. The deposits are mainly composed of iron sulfides in the relatively deep-sea areas and bone detritus in shallower settings. The bone detritus concentration is related to the multiple intertidal reworking (Stolyarov and Ivleva, 1991).

Numerous large bone–sulfide deposits in the Transcaspian region accumulated in quite different structural–facies and paleogeographic settings. The region was a relatively elevated and differentiated zone that fringed the Middle Caspian Basin in the east.

The major structural elements of the region—the Mangyshlak fold system in the north and the Kara Bogaz Dome in the south—are separated by the sublatitudinal South Mangyshlak Trough. The smaller transverse uplifts (saddles)—the western Karagie Uplift and the eastern Karynzharyk Uplift—had an important paleogeographic significance in the formation of metalliferous deposits (Stolyarov, 1961; Stolyarov and Shlezinger, 1962).

The Mangyshlak Mountain of that time was a large island located in the outer shelf of the Aral and Ustyurt zone, the northern boundary of which remains unclear owing the erosion of sediments.

In the south, the island was complicated by peninsulas grading into shoals (banks). The largest bank was outlined by the Karagie Saddle that merged in the south with the Peschanyi Mys Uplift located offshore in the Caspian Sea. Precisely this elevated part of the basin controlled the formation of bone detritus deposits in the Mangyshlak area (Stolyarov and Ivleva, 1995; Stolyarov and Kochenov, 1995; Sharkov, 2000; and others).

Like in the southern Ergeni area, the bone–sulfide deposits in Mangyshlak differ in facies, composition, and morphology. In the arched area of the shoal, they include relatively shallow-water deposits of coarse bone materials in the form of stratabound–lenticular bodies with a variable (often low) sulfide content. In deeper slope zones, the deposits are less enriched in the fine-grained bone detritus and characterized by the seaward divergence ("fish tail" structure).

The upper Oligocene sediments are eroded in the eastern Karynzharyk Saddle that probably represented a large shoal with bone detritus deposits. This inference is supported by the presence of relatively small deposits (5–12 km long and a few kilometers wide) along its western slope. The deposits are composed of the dominant bone detritus (25–40%) and the subordinate sulfides (up to 12%), coalified plant remains, glauconite, and quartz.

Upper Oligocene sediments are eroded in the Ustyurt area. Therefore, we cannot reconstruct the sedimentation setting in this area.

Thus, metalliferous bone–sulfide deposits were developed in the northern framing of the ~1500-km-long Ciscaucasus–Middle Caspian deep-water basin extending from Ustyurt to the Azov region in the early Kalmykian (late Oligocene). These deposits occupy a distinct facies–paleogeographic position. All of them are confined to outer part of a spacious shelf (with islands and shoals), which generated and concentrated the fish bone detritus.

The paleogeographic position of the Karpinskii Ridge–Mangyshlak boundary zone flooded by waters of the Caspian Sea is least studied. In the late Oligocene, this area served as conduit for the transport of the main portion of terrigenous material that formed a clinoform sequence in the deepest part of the eastern Ciscaucasus–Middle Caspian basin. Probably, the clayey and sandy–silty material was mainly delivered from the Urals and Russian Platform.

The noncompensated character of sedimentary material input is evident from the absence of shallow-water features in the clinoform sedimentation zone of eastern Ciscaucasia dominated by sediments of the relatively deep-water fish facies with sandy–silty interbeds. These intricate clinoform bodies with gradual southwestward displacements presumably accumulated at depths of several hundreds of meters on a relatively steep slope with H_2S-contaminated waters.

The partly compensated character of sedimentation is indicated by the general pinchout of the clinoform sequence sharply reducing from 700–1000 m to 200–300 m and its replacement in the southern part of the central and western Ciscaucasus region by the deep-water fish-facies calcareous–clayey sediments (up to 100 m) thick with the planktonic foraminifer assemblage (Batalpashinsk Formation).

The zone of relatively thin and fine-grained calcareous–clayey sediments extends as a narrow (40–50 km) band over hundreds of kilometers along the North Caucasus anticline, indicating the existence of a linear deep and ~100-km-wide trough in this region during the Kalmykian time. In the south, the trough was bordered by islands or seamounts of the Greater Caucasus with steep slopes. Unfortunately, a more detailed paleogeographic reconstruction of the study region is impossible, because relevant sediments are mostly eroded.

Thus, the shelf zone is traced only in the northern part of the present-day area of lower Kalmykian sediments, whereas the southern Ciscaucasus region is mainly occupied by deep-water sediments.

The bone–sulfide deposits are confined to the northern outer shelf. Its position was determined on the basis of paleogeographic elements of the arcuate Ergeni–Stavropol–Timashev and the sublatitudinal Karpinskii Ridge–Mangyshlak structural–facies zones that are complicated by smaller structures. In terms of paleogeography, they represent differentiated archipelagoes of low islands and shoals that are likely favorable for the development of large fish populations, as well as the reworking and burial of bone detritus after their death.

This unavoidably brings up the question: What was the factor responsible for the mass death of fish communities in a certain zone of the basin during a relatively long geological time? This phenomenon was most probably related to fluctuations of the upper boundary of the H_2S-contaminated water zone, because the metalliferous deposits occur at margins of the fish-facies area, where penetration of H_2S-contaminated water to the inhabited part of the shelf is highly probable. However, the prolonged stability of this process suggests that the influence of other enigmatic processes cannot be ruled out.

Thus, the early Kalmykian basin was characterized by unusual facies–paleogeographic settings that promoted the large-scale formation of bone–sulfide deposits in the outer shelf. This process was accompanied by intense sedimentation in the central (deepest) part of the basin and the formation of numerous clinoform bodies on the slope. The largest metalliferous deposits in the Karpinskii Ridge–Mangyshlak region were separated by an approximately 300-km-wide subsidence zone, which served as conduit for the transport of a great quantity of terrigenous material from the north. The role of these powerful sedimentation processes in the simultaneous formation of bone detritus and sulfide deposits is unclear so far.

THE LATE KALMYKIAN BASIN

In terms of the composition and structure of sediments, the upper substage of the Kalmykian regional stage substantially differs from the lower substage. The upper Kalmykian clays almost universally contain an admixture of the powder-type silty material, algal remains, and interbeds with fucoids, whereas the distribution of typical fish-facies sediments is substantially decreased. All these features indicate a different facies–paleogeographic setting (Fig. 2).

Thin (up to 30 m) sandy–silty clay sequences without fish remains accumulated in the Azov–Volga–Don shelf area. Relatively thick (300 m or more) clays with sandy–silty interbeds continued to accumulate in the eastern Ciscaucasus Trough. However, the transition between these sedimentation zones was more gradual and lacked the scarp that previously rimmed the outer shelf, particularly in the northern part of the basin near the Karpinskii Ridge. This was probably responsible for cessation of the process of bone detritus accumulation at the previous bone–sulfide deposits.

In the late Kalmykian time, only the sublatitudinal (Timashev–Stavropol) branch complicated by uplifts in the South Stavropol Swell was prominent in the arcuate Ergeni–Stavropol–Timashev structural–facies zone that controlled the formation of rather contrast morphological structures of the outer shelf at the beginning of the late Oligocene. These structures probably represented a system of shoals (banks) that included thin (0.1–0.3 m) bone–sulfide interbeds of the Urakov–Bogoslov multistage deposit.

The southern part of the basin corresponding to the central North Caucasus anticline located west of the Caucasian Mineral Waters (CMW) was also marked by a substantially different facies–paleogeographic setting. The early Kalmykian deep-water trough was filled with shallower-water sandy–silty shales, implying the appearance of a new provenance with coarse-grained (sometimes gravel-sized) material. The sandy–silty shales previously accumulated only in the westernmost Neftegorsk area where they continued to accumulate in the late Kalmykian time as well (Fig. 1).

The rise of the Central Caucasian archipelago during the late Kalmykian time was restricted to specific areas. This process did not involve areas located east of the CMW area where one can see sediments of the fish-facies (50 m) in a deep trough.

The Caucasian archipelago provided an avalanche accumulation rate of sandy–silty material that drastically differs from host shales of the fish facies. The insular shelf terrace served as a favorable site for the formation of the 54-km-long Cherkessk bone–sulfide deposit in the lower part of the Zelenchuk Formation with a low content of the sandy–silty material. However, the ore-forming process was interrupted by intense tectonic uplifts and the avalanche influx of sandy–silty material to the basin.

West of the Caspian Sea, the late Kalmykian basin was morphologically differentiated only in its southern (Caucasian) part where isolated bone–sulfide deposits accumulated. The low abundance of bone–sulfide deposits in the southern part of the basin was related to the influx of sandy–silty material from the Caucasian land. The scarcity of such deposits in the northern (Azov) part of the shelf was caused by its insufficient morphological differentiation.

In Mangyshlak, the late Kalmykian basin substantially differed from the early Kalmykian counterpart by its relatively flat topography, the variation of sediment thickness from 20 to 100 m, and the absence of fish facies. However, the appearance of benthic organisms indicates the deposition of sediments in an open deep-water area adjacent to the Middle Caspian Basin (Merklin *et al.*, 1960).

Thus, the upper Kalmykian sediments accumulated during tectonic uplifts that resulted in the substantial flattening and shoaling of the basin floor. Therefore, areas with sediments of the fish facies and bone detritus deposits were significantly reduced in the entire northern part of the basin in the early Kalmykian time. At the same time, facies–paleogeographic settings favorable for the formation of bone–sulfide deposits appeared near the Caucasian archipelago for the first time in the Oligocene history. However, this short-term event was soon interrupted by an avalanche influx of sandy–silty material.

Thus, the latest Oligocene history of the central Eastern Paratethys was marked by uplifts and flattening of the basin floor. This process was also slightly developed in its deepest zone with noncompensated sedimentation. Consequently, conditions favorable for the formation of the Cherkessk bone–sulfide deposit appeared in the Caucasian segment of the basin.

It should be noted, however, that the environment in the central part of the basin with clinoform sedimentation during the early Kalmykian time remains yet insufficiently clear. This is primarily caused by difficulties in the recognition of stratigraphic analogues of upper Kalmykian sedimentary units, particularly based on the seismostratigraphic method. One can assume that regional uplifts and flattening of the basin floor was also typical of its central part, although this process presumably did not substantially change the general paleogeographic setting in the study area. This inference is supported by the existence of a deep basin east of the CMW area, suggesting the formation of clinoform sedimentary bodies in the latest Oligocene and early Miocene (Kosova, 1994; and others).

CONCLUSIONS

The late Oligocene basin in the central Eastern Paratethys was a specific structure in many aspects. Some of its features remain insufficiently understood so far. Its development began with the powerful tectonic subsidence that produced a deep trough in the eastern Ciscaucasus and North Caucasus monocline.

This spacious trough had an asymmetric structure characterized by a wide (gentle) northern limb and sharp flexure crowned with a narrow shelf terrace near the Caucasian archipelago. This terrace is recognizable only for sediments of the terminal Oligocene when the Cherkessk bone–sulfide deposit formed here.

The deep trough, which originated in a very short geological time, first accumulated thin clayey–calcareous sediments (*Virgulinella* Beds) with abundant underwater slump structures on the Caucasian slope (Stolyarov, 2001). In the subsequent early Kalmykian time, the sedimentation rate sharply increased because of the influx of large volumes of clayey and sandy–silty material from the northeast with the formation of an intricate system of clinoform bodies successively advancing in the southwestern direction. However, this thick (more than 1000 m) sequence only partly compensated the subsidence. Deep-water calcareous–clayey sediments of the Batalpashinsk Formation (approximately 100 m thick) continued to accumulate in the narrow trough located north of the Greater Caucasus archipelago.

Intense subsidence during the initial late Oligocene did not affect the northern part of the outer shelf. Here, the system of low islands and shoals, which separated the deep-water area from the intrashelf seas of the Azov, Dnieper–Donets, Caspian, and Aral region, was more prominent relative to the early Oligocene pattern. This discontinuous system of underwater and subaerial uplifts in the outer zone of the wide northern shelf controlled the formation of bone–sulfide deposits that are unique in terms of their geological nature and dimensions.

Within the present-day domain of upper Oligocene sediments, the zone of metalliferous deposits extends over approximately 1500 km from the Sea of Azov to the Transcaspian region. This region probably represented a stable zone favorable for the prolonged habitat of large fish populations dominated by herrings. It is difficult to decipher biological factors responsible for the confinement of fish community to this zone because of the following reason. Unlike areas with thick fish populations in the present-day upwelling zones, where well-aerated waters ascend from deep basin to the shelf, this zone adjoined a H_2S-contaminated deep-water area that could not supply nutrients (Kochenov *et al.*, 1970). In contrast, migration of H_2S-contaminated waters to the populated shelf could be responsible for the mass death of fish community.

The paleogeographic confinement of metalliferous deposits to the outer differentiated shelf, which steeply dips to H_2S-contaminated areas of the basin, is sufficiently undoubted. This conclusion is also supported by historical–geological features of the basin. For example, metalliferous deposits did not form on the northern shelf at the end of the Oligocene (late Kalmykian time) characterized by flattening of the basin floor and reduction of the H_2S-contaminated area. At the same time, conditions favorable for the formation of bone–sulfide deposits appeared on the shelf terrace of the southern area, although a hydrosulfuric zone was retained in the adjacent deep-water zone.

The wide development of sedimentary clinoform bodies is another specific feature of the late Oligocene basin. It remains unclear whether or not this feature is related to the formation of bone–sulfide deposits, because they developed in both proximal and distal zones relative to the clinoform bodies. Therefore, the temporal and, partly, spatial juxtaposition of different specific processes can be incidental as well.

In conclusion, let us once more emphasize that issue of the formation of bone–sulfide deposits requires a more detailed and purposeful consideration, because we do not know other examples of the burial of organic remains and their subsequent transformation into commercial metalliferous deposits in the course of dramatic biological and geological processes.

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