Lithology and Mineral Resources, Vol. 36, No. 2, 2001, pp. 134–140. Translated from Litologiya i Poleznye Iskopaemye, No. 2, 2001, pp. 155–163.

Lithological–Facies Features and Formation Conditions of Paleogene Zeolite-Bearing Complexes of the Eastern Ciscaucasus

A. E. Khardikov

Rostov State University, ul. Bol'shaya Sadovaya 105, Rostov-on-Don, 344006 Russia

Received January 19, 2000

Abstract—Paleocene and Eocene terrigenous–siliceous complexes of the Eastern Ciscaucasus contain 18–92% zeolites represented by clinoptilolite. The studied complexes are the stratified subplatformal shallow-water subaqueous deposits with abundant authigenic silica as skeletal remains, cryptocrystalline substance, and pyroclastic material. Clinoptilolite in Paleocene–Eocene terrigenous–siliceous sediments formed from the mud solutions mainly at the expense of the labile pyroclastic material and biogenic silica. Variations in the zeolite abundance are explained by different contents of the pyroclastic material and SiO_2 in the primary sediment.

INTRODUCTION

Previous investigations revealed that Paleocene and Eocene terrigenous–siliceous rocks of Southern Russia locally contain 18–92% zeolites mainly represented by clinoptilolite (Khardikov *et al.*, 1992, 1997, 1999). Zeolite-bearing terrigenous–siliceous rocks are highly valuable mineral resources and may be used as raw material to obtain: (a) nontraditional light fillers; (b) synthetic wollastonite and facing ceramics; (c) complex, ecologically pure, meliorative materials (especially, for irrigated lands); (d) sorbents for various environment protection purposes (elimination of the radioactive pollution, refinement of sewage and smoke of heat electropower station, and others); (e) mineral dust and others.

Zeolite-bearing terrigenous–siliceous complexes are abundant within the Eastern Ciscaucasus. Zeolites were found in rocks of the Upper Paleocene Abazinka Formation and Lower–Middle Eocene Green Marl Formation. Taking into account the practical significance of this raw material and based on the detailed petrography, mineralogy, granulometry, and geochemistry of the exposed Paleocene and Eocene complexes and core materials, we attempted to decipher the tectonomagmatic prerequisites, lithofacies features, and formation conditions of these deposits within the Eastern Ciscaucasus.

RESULTS AND DISCUSSION

The study area includes the southeastern flank of the Epihercynian Scythian Plate and eastern segment of the northern slope of the Greater Caucasus Meganticlinorium (Fig. 1). The considered part of the Scythian Plate consists of the southern part of the Stavropol Uplift, Terek–Kuma Depression, Terek–Caspian Foredeep, and eastern part of the Northern Caucasus marginal massif (Lunev and Serezhenko, 1972). The latter consists of the Prealpian folded basement and the Mesozoic–Cenozoic sedimentary cover. The Alpian cover is composed of the Lower–Middle Jurassic lower stage (Laba–Malka Zone) and Upper Jurassic–Eocene upper stage (North Caucasian Monocline). The eastern segment of the northern slope of the Greater Caucasus includes the Central Meganticlinorium Zone, Agvala oblique folded terrace, and Beibulak Synclinorium, which are composed of Lower–Middle Jurassic rocks, as well as the Calcareous Dagestan Zone and Ulluchai Anticlinroium (Romanov, 1968), which are composed of Upper Jurassic–Eocene rocks.

Paleocene and Eocene rocks occur over the entire studied area. Their outcrops are traced as an E–W-trending band within the North Caucasian Monocline and Calcareous Dagestan, as well as in folded structures of the Calcareous Dagestan and Ulluchai Anticlinorium. In addition, Paleocene and Eocene rocks were recovered by numerous boreholes the prospecting areas located within the Stavropol Uplift, Terek–Kuma Depression, and Terek–Caspian Foredeep.

Paleocene and Eocene rocks reveal strong variations in composition and thickness within the Eastern Ciscaucasus and Eastern Caucasus. The Stavropol, Nal'chik, Chernogorsk–North Dagestan, and South Dagestan structural-facies zones are recognized here. The Stavropol Zone includes the Stavropol Uplift and western part of the Terek–Kuma Depression. The Nal'chik Zone includes the eastern part of the North Caucasian Monocline (east of Mineral'nye Vody in Caucasia) and the western limb of the Terek–Caspian Foredeep. The Chernogorsk–North Dagestan Zone comprises eastern parts of the Terek–Kuma Depression and Terek–Caspian Foredeep, along with the Calcare-

0024-4902/01/3602-0134$25.00 © 2001 MAIK "Nauka / Interperiodica"

ous Dagestan Zone. The South Dagestan Zone is confined to the Ulluchai Anticlinorium.

Upper Paleocene rocks (Kacha Stage) of the Stavropol structural-facies zone are represented by the Goryachii Klyuch and Abazinka formations. The lower part of the Upper Paleocene section (Goryachii Klyuch Formation) consists of gray and dark gray clayey–sandy, occasionally, calcareous siltstones (20–25 m). The siltstones contain up to 1-m-thick interbeds of clayey and organogenic (oyster) limestones. The overlying Abazinka Formation consists of gray (silty, quartzose, and noncalcareous) sandstones with a variable massive structure. The sandstone thickness is 25–30 m.

The Lower–Middle Eocene rocks (Bakhchisarai and Simferopol stages) are represented by the Georgievsk and Cherkessk formations. The Georgievsk Formation (8–15 m thick) consists of greensih gray calcareous clays and pink pelitic limestones. The Cherkessk Formation (20–30 m thick) is composed of greenish gray and brown, medium-bedded, fine-grained, sandy and clayey limestones.

The Kacha Stage of the Nal'chik structural-facies zone contains zeolite-bearing terrigenous–siliceous rocks. The most complete Kacha section was found along the Kheu River (Cherek River basin, Kabardino–Balkaria), where it conformably rests on the Inkerman Stage and consists of the following rocks:

(1) Olive-green, vaguely bedded, massive, silty and calcareous clays with 1.5- to 4-m-thick more compact interbeds. Fucoid spots are distributed throughout the entire layer. Thickness 46 m.

(2) Intercalation of dark gray, massive, noncalcareous, siliceous, zeolite-bearing clays (1–3 m) and greenish, massive, zeolite-bearing opoka (0.3–0.4 m). Thickness 16 m.

(3) Dark gray, massive, zeolitic and siliceous clays with a greenish tint. Thickness 3 m.

The total thickness of the section is 65 m.

Bed 1 corresponds to the Goryachii Klyuch Formation, while beds 2 and 3 compose the Abazinka Formation. Such a structure is typical of the structural-facies zone except for its southeastern part (Cherek–Terek watershed) where bluish gray, vaguely bedded, pelitic limestones (8–15 m thick) with dark gray fucoid spots are spread. The thickness of the Kacha sediments ranges within 8–65 m, reaching the maximum within the Terek–Caspian Foredeep.

The Eocene, lower Bakhchisarai Substage corresponds to the Georgievsk Formation consisting of the greensih gray calcareous clays and pink pelitic limestones. The thickness of the formation is 4–6 m. The upper Bakhchisarai Substage and Simferopol Stage in the Nal'chik Zone correspond to the Cherkessk Formation, which is represented by greenish-gray and brown, medium-bedded, fine-grained, sandy and clayey limestones. The thickness ranges within 15–27 m.

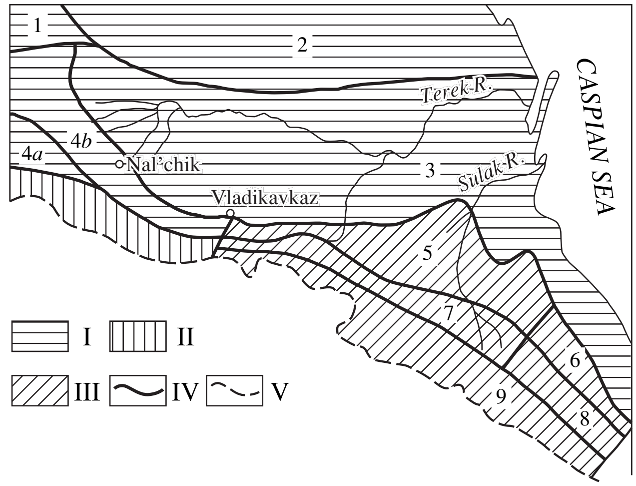

Fig. 1. Tectonic sketch of the Eastern Ciscaucasus and Eastern Caucasus. (I) Epihercynian Scythian Plate: (1) Stavropol Uplift, (2) Terek–Kuma Depression, (3) Terek–Caspian Foredeep, (4) North Caucasian marginal massif ((*a*) Laba–Malka zone, (*b*) North Caucasian Monocline), (II) Central Caucasus; (III) Eastern Caucasus: (5) Calcareous Dagestan, (6) Ulluchai Anticlinorium, (7) Agvala oblique terrace, (8) Beibulak Synclinorium, (9) Central Eastern Caucasus; (IV) tectonic zone boundaries; (V) State boundary.

Upper Paleocene rocks (Kacha Stage) of the Chernogorsk–North Dagestan structural-facies zone are represented by the upper part of the Variegated Formation, which disconformably rests on the Danian Stage rocks and consists of a sometimes vague intercalation (a) greenish calcareous clay (1.5–2 m), (b) greenish gray, pelitomorphic, medium-bedded, clayey and pelitic limestones, and (c) reddish cherry and reddish brown, medium-bedded, clayey limestones. The lower and middle parts of the Variegated Formation in the Calcareous Dagestan area locally contain interbeds of the fine to medium grained quartzose, calcareous sandstones (0.5–0.8 m) and conglomerates (1.5–2.5 m), as well as blocks and coarse-grained rubble of the Upper Cretaceous limestone. The thickness of the formation varies between 9 and 80 m owing to a variably eroded lower part of the sequence. The highest thickness is typical of the Terek–Caspian Foredeep.

Rocks of the Eocene Bakhchisarai and Simferopol stages in the Chernogorsk–North Dagestan structural-facies zone form the Green Marl Formation, which conformably rests on the underlying rocks. In the northern part of the structural-facies zone (eastern part of the Terek–Kuma Depression and northeastern part of the Terek–Caspian Foredeep), boreholes recovered the sandy clays and clayey sandstones with subordinate interbeds of sandy and silty limestones. The thickness of the Green Marl Formation here is 25–33 m.

The Bakhchisarai and Simferopol stages within the southern flank of the Terek–Caspian Foredeep and the northern part of the Calcareous Dagestan area are represented by greenish gray and light gray medium-bedded, pelitomorphic, clayey and pelitic limestones (40–60 m). South of the Calcareous Dagestan area (basins of the Dzhengutai-Ozen, Gerga, Khalagork, and Gamri-Ozen rivers), the Green Marl Formation is represented by an alternation of (a) light gray, medium-bedded (0.2–0.3 m), brecciated and conglomeratic, very massive, sandy–calcareous–zeolitic spongolites (0.25–3 m), (b) light gray, vaguely bedded and brecciated, very massive, fine-grained calcareous–sandy–zeolitic–silicilithic chlidolites (0.5–10 m), (c) light gray to white, massive and pseudobedded, calcareous zeolitites (1.2- to 10-m-thick interbeds and lenses). The thickness of the sequence is 48–66 m.

Upper Paleocene rocks of the South Dagestan structural-facies zone are represented by the upper part of the Gray Formation, which disconformably rests on the underlying rocks and corresponds to the Kacha Stage. It crops out in the Ulluchai–Rubaschai watershed. In the northwestern part of the zone, the formation is represented by a 50- to 60-m-thick intercalation of (a) light gray and greenish, medium- to thick-bedded, massive, fine-grained, sandy, glauconite-bearing limestones (4–10 m) with flint lenses (up to 10 cm) and (b) gray and greenish gray thick-bedded, massive, medium-grained, glauconite–quartzose and calcareous sandstones (7–8 m). In the southeastern part of the South Dagestan Zone, the base of the Gray Formation consists of calcareous–sandy clays (70 m) with blocks and fragments of 5- to 6-m-thick beds of the light gray, medium-bedded, massive, fine-grained calcareous sandstone. Upward, they grade into the gray calcareous sandstone (50 m).

The Bakhchisarai–Simferopol rocks (Green Marl Formation) conformably rest on the underlying rocks and only crop out in the Ulluchai–Rubaschai watershed. In the Ulluchai River basin, the Green Marl Formation is represented by the intercalation of (a) light gray, medium-bedded (0.2–0.3 m thick), very massive, sandy–calcareous–zeolitic spongolites (0.5–3 m) and (b) light gray, vaguely bedded, brecciated, very massive, fine-grained, calcareous–sandy–zeolitic–silicilithic chlidolites (0.5–4 m). The sequence thickness is 30–35 m.

The section in the Rubaschai River basin is different. From the bottom to top, it consists of clayey–silty limestones (60 m) and clayey limestones (60 m) with siliceous limestone interbeds (1–2 m).

Previous investigations (Agarkov *et al.*, 1987, 1991; Grossgeim, 1960, 1972; Machabeli, 1987; Tokmakova, 1978; Sedletskii *et al.*, 1990; Khardikov *et al.*, 1992, 1999) showed that Late Paleocene and Lower–Middle Eocene zeolite-bearing complexes consist of carbonates, terrigenous and pyroclastic materials, allothigenic and authigenic clayey particles, zeolites, and authigenic silica.

The carbonates account for 5–15% and are represented by structureless organic detritus and skeleton of globigerine, textulariidae, and lenticulides.

The sand-, silt, and clay-size terrigenous component accounts for 5–20% and is represented by subrounded quartz, rounded glauconite, acicular mica, platy chlorite, elongated amphibole, and irregular plagioclase.

The pyroclastic material accounts for 8–15% or more. It is represented by silt- and sand-size fragments of volcanic glass. The fine-grained (“hidden”) pyroclastic particles are deciphered based on rock geochemistry. During diagenesis, the volcanic glass was replaced by montmorillonite and zeolites. Montmorillonite (15–40%) has fine-grained, pelitic, colloform, reticulate, straticulate textures, indicating a primary vitroclastic structure of the sediment.

The zeolites are represented by fine clinoptilolite crystals. They associate with flaky montmorillonite and microglobular aggregates of opal and cristobalite.

The authigenic silica (30–60%) occurs as skeletal remains of sponges, diatom, and radiolaria, as well as flaky opal-A and cryptocrystalline and globular opal-CT.

The observed gradual transition of rocks in the studied area makes it possible to divide Upper Paleocene rocks into the following lithofacies complexes (Fig. 2):

(1) Coastal shallow-water deposits represented by two subcomplexes. Complex 1 is located northwest of the area and consists of clayey–sandy siltstones and silty sandstones. Complex 2 is located southeast of the area and consists of sandy limestones and calcareous sandstones with conglomerate interbeds and landslide-related horizons (Upper Cretaceous limestone blocks and large rubble).

(2) Shallow-water shelf deposits represented by zeolitic opokas and clays.

(3) Deep-water shelf deposits composed of calcareous clays and clayey–pelitic limestones.

The tectonic reconstruction and related transgression at the terminal Danian resulted in the redistribution of source areas. The marine basin covered the entire Ciscaucasus and northern slope of the Greater Caucasus. The facies composition of the Kacha stage rocks indicates shallow and moderate depths of the Paleocene sea within the Eastern Ciscaucasus. Sandstones and siltstones with clay interbeds within the Stavropol Uplift suggest a proximal provenance located to the northwest. This area was characterized by an coastal shallow-water sedimentation setting.

The significant amount of sandy and coarse-clastic materials in the southeastern Calcareous Dagestan area and the Ulluchai anticlinorium also suggests an coastal shallow-water setting. Evidently, the land was represented by an island archipelago in the Main Caucasus Range. Judging from exposed Paleogene sediments, these islands had a low, insignificantly rugged relief, except for the southeastern part of the archipelago, which supplied a large amount of clastic material. In addition, a small low-relief island existed in the Khalagork–Ulluchai watershed area. It consisted of

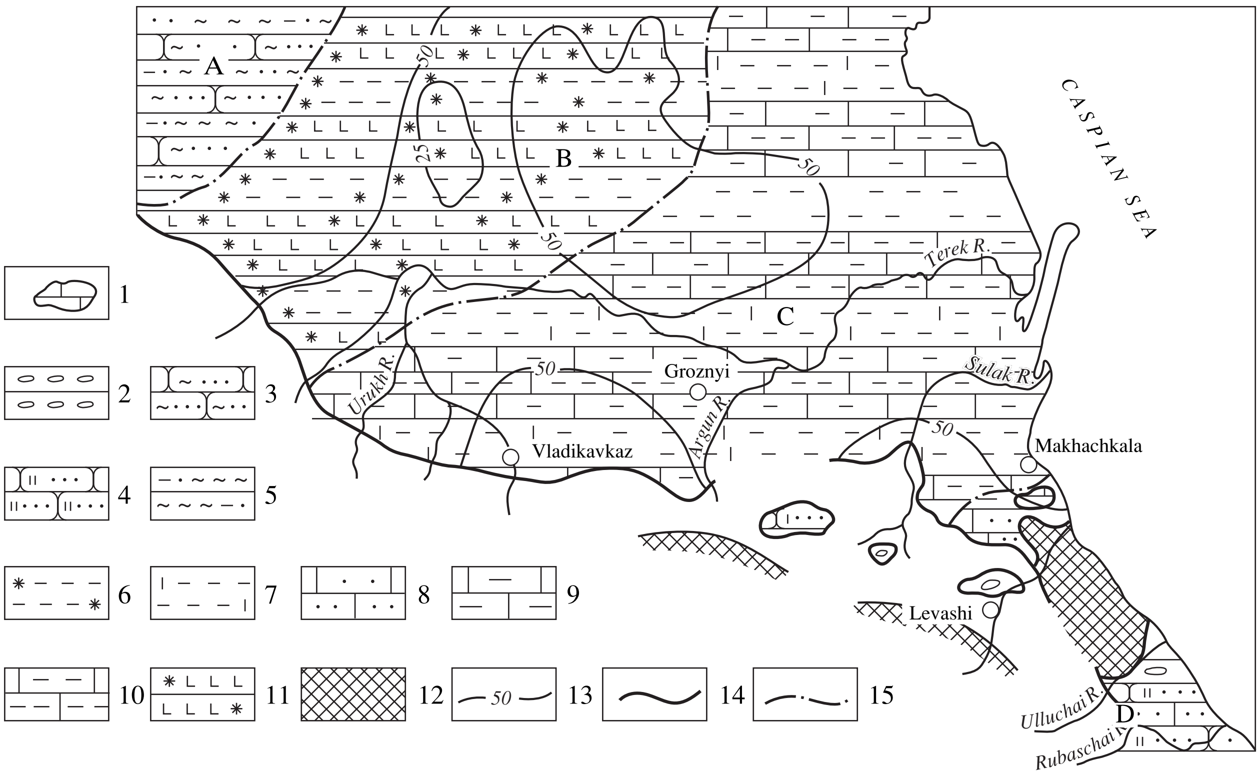

Fig. 2. Late Paleocene lithology and paleogeography. (1) Seismic lanslide horizon; (2) conglomerate; (3) silty sandstone; (4) calcareous sandstone; (5) clayey–sandy siltstone; (6) zeolitic clay; (7) calcareous clay; (8) sandy limestone; (9) clayey limestone; (10) pelitic limestone; (11) zeolitic opoka; (12) ancient provenance; (13) isopach lines; (14) boundaries of Neogene and Quaternary erosions; (15) boundaries of lithofacies complexes; Lithofacies complexes: (A) coastal shallow-water sediments; (B) shallow-water shelf sediments; (C) deep-water shelf sediments.

Upper Cretaceous carbonate rocks and did not supply any significant quantity of the terrigenous material.

To the southeast, within the western Terek–Caspian Foredeep and North Caucasian Monocline (west of the modern Cherek River basin), sandy–silty sediments grade into the deeper water zeolite-bearing siliceous–clayey sediments with pyroclastic admixture. During this time, the sedimentation basin bottom underwent a relative subsidence and became the deep-water shelf area extending from the modern Cherek River basin in the west to the Dzhengutai-Ozen River in the east and included eastern zones of the Terek–Caspian Foredeep and Terek–Kuma Depression. Clayey–carbonate sediments, which were later transformed into clayey and pelitic limestones, along with calcareous clays of the Variegated Formation, were precipitated here during the Kacha Stage.

The Kacha marine basin represented a part of the large South Russian sea. The presence of Pelecypoda bivalves indicates that the warm seawater with a normal salinity and annual average temperature of 20–23°C (Yasamanov, 1977, 1978, 1980) within the Eastern Ciscaucasus was linked with outer larger basins. The presence of the *Solomonia* and *Lucina* pelecypods supports an coastal shallow-water setting in separate parts of the basin. The presence of the gastropodas (*Natica*, *Cyclina*) in the western area suggests a water depth of 50–150 m. The foraminifera was the most abundant fauna in Paleocene. The presence of benthic *Cibicides Lectus* and *Cicicides incognitue* forms in sediments of the Eastern Ciscaucasus indicates a shallow-water setting. The presence of the planktonic *Cloboratalia ehgulata* and *Globoratalia aequa* forms in sediments of the North Caucasian Monocline and Calcareous Dagestan area and radiolaria in opokas of the Abazinka Formation indicates sedimentation in an open sea, which was deeper than the East Ciscaucasian basin.

Lower–Middle Eocene rocks can be divided into the following lithofacies complexes (Fig. 3):

(1) Coastal shallow-water deposits represented by sandy clays and clayey sandstones with subordinate interbeds of sandy and silty limestones.

(2) Shallow-water shelf deposits consisting of two subcomplexes. Complex 1 is represented by sandy, clayey, occasionally pelitic limestones and calcareous clays. Complex 2 is represented by intercalated sandy–calcareous–zeolitic spongolites and calcareous–sandy–zeolitic–silicilithic chlidolites.

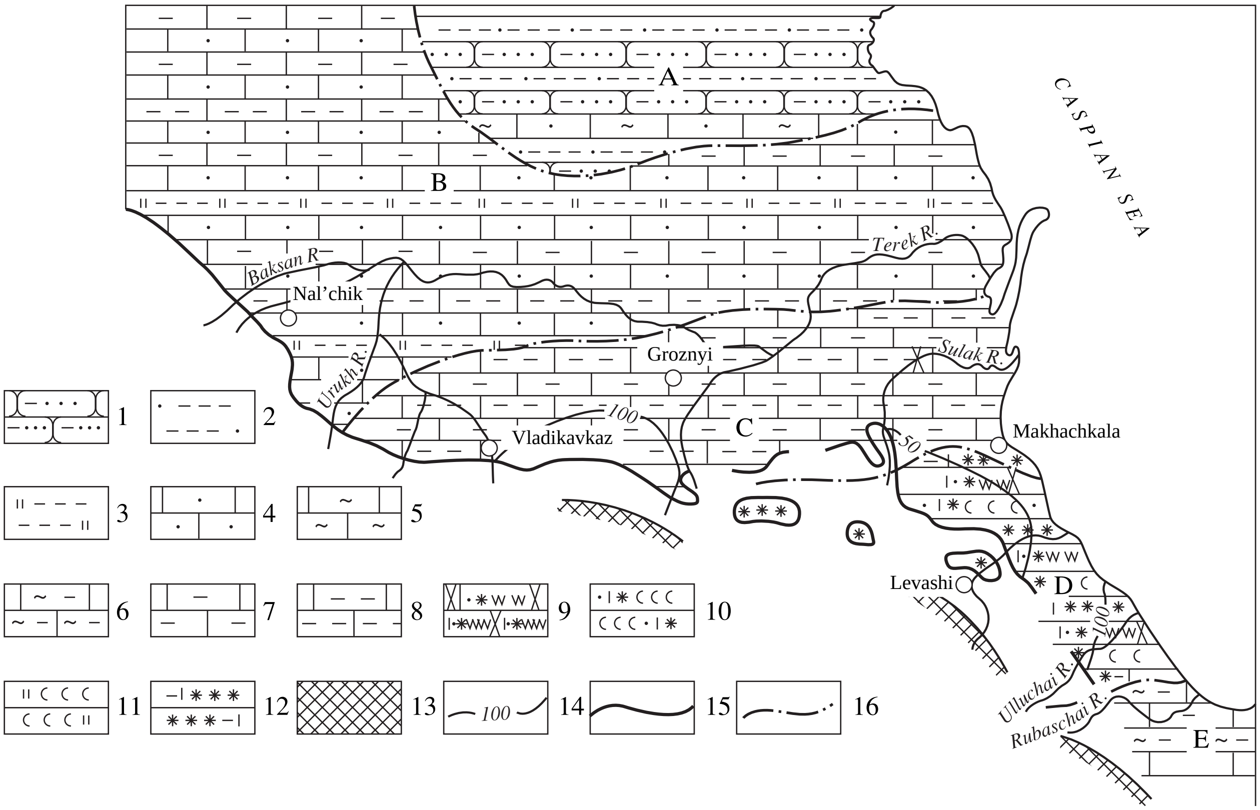

Fig. 3. Lithological and paleogeographic sketch of the timing of the Green Marl Formation. (1) Clayey sandstone; (2) sandy clay; (3) calcareous clay; (4) sandy limestone; (5) silty limestone; (6) silty–clayey limestone; (7) clayey limestone; (8) pelitic limestone; (9) calcareous–zeolitic–silicilithic chlidolite; (10) sandy–calcareous–zeolitic spongolite; (11) calcareous spongolite; (12) clayey–calcareous zeolites; (13) ancient provenance; (14) isopach lines; (15) boundaries of Neogene and Quaternary erosions; (16) boundaries of lithofacies complexes. Lithofacies complexes: (A) coastal shallow-water sediments; (B) shallow-water shelf sediments; (C) deep-water shelf sediments.

(3) Deep-water shelf deposits consisting of two complexes. One complex consists of intercalated clayey and pelitic limestones, while another complex consists of silty–clayey and clayey limestones with scarce interbeds of the calcareous spongolite.

The transgression began in the Inkerman and Kacha ages and continued in the Early and Middle Eocene. During that time, the Eastern Ciscaucasus and northern slope of the Greater Caucasus were occupied by a single basin extending far beyond this area. The coastal shallow-water setting existed in the eastern Terek–Kuma Depression and the northeastern Terek–Caspian Foredeep. A shallow-water shelf with clayey–carbonate sediments and terrigenous admixture existed within the spacious area including the western flank of the Terek–Kuma Depression, the central Terek–Caspian Foredeep, and a part of the North Caucasian Monocline within the Baksan–Urukh watershed area. The southeastern termination of the North Caucasian Monocline and the southern flank of the Terek–Caspian Foredeep represented a deep-water shelf. The rock lithology indicates that this part of the basin was deeper than the Ciscaucasus area and represents a distal environment. In the Early–Middle Eocene, the present Dzhengutai–Ozen–Rubaschai watershed was characterized by the shallow-water shelf setting and the accumulation of terrigenous–siliceous sediments with a significant volcanogenic admixture. The significant amount of terrigenous admixture indicates a proximal source area.

In Early–Middle Eocene, the land, which existed northwest of the studied area, in addition to the Caucasian Islands, underwent strong erosion, and the clastic material was transported into the sea, in particular, the Terek–Caspian Foredeep.

The Early–Middle Eocene sea was open and linked with large basins of West Europe, as indicated by Eocene fauna. The *Cyprina*, *Gastrochaena*, and *Arca*, bivalves are very similar to those of the West European pelecypods. The presence of the *Pecten* genus also supports an open basin environment.

The Eocene sea was warm (annual average temperature 26–28°C) and had a normal salinity. Warm water conditions are indicated by the presence of thermophilic *Lucina*, *Cyprina*, and *Natica* pelecypods. The normal salinity is suggested by the presence of the *Cardita* and *Nucula* pelecypods, articulate brachiopods, and radiolaria (Nassellina and Spumellina).

The shallow-water setting within the eastern segment of the northern slope of the Greater Caucasus Meganticlinorium and Eastern Ciscaucasus is confirmed by the presence of pelecypods inhabiting depths no more than 200 m, gastropods of the *Turitella* and *Natica* genera typical of depths of 50–160 m, articulate brachiopods typical of the shallow-water shelf, and Mediterranean *Natica* and *Pteurotoma* living at depths of no more than 100 m, though their individual forms may occur at greater depths. The presence of sponge spicules and diatom valves in Early–Middle Eocene sediments also marks shallow-water conditions.

The universal presence of different amounts of the terrigenous, volcanogenic, and authigenic siliceous materials in zeolite-bearing complexes indicates that the Late Paleocene and Early–Middle Eocene sedimentation within the Eastern Ciscaucasus was continuously affected by (a) land erosion, (b) volcanic activity, and (c) vital activity of organisms. Terrigenous mineral assemblages, including clay minerals, and relatively fresh clastic components suggest that the source area lacked a mature weathering crust. The terrigenous sedimentation was not dominant and did not suppress the accumulation of volcanogenic and biogenic products.

The Paleogene magmatism of the Caucasus was diverse and significantly activated in the Late Paleocene and Eocene (Borsuk, 1979; Milanovskii and Khain, 1963). In the Paleocene, volcanism was developed only at the Lesser Caucasus located south of the studied area. It was mainly represented by andesitic lavas with subordinate rhyolites and dacites. The Early–Middle Eocene volcanism was represented by mafic–intermediate lavas in the Lesser Caucasus and Transcaucasus median massif. Upper Paleocene and Early–Middle Eocene rocks of the Eastern Ciscaucasus bear no evidence of the subaqueous volcanism but record a significant contribution of subaerial volcanic products (fine ash). Because volcanic centers were located relatively far away, the coarse clastic material is subordinate.

Volcanic activity during the Late Paleocene and Early–Middle Eocene was discontinuous. This fact, coupled with different distances from eruption centers and changes in wind directions and strength, explain the irregular supply of loose products of the subaerial volcanic activity in different parts of the basin. Volcanism, in addition, served as a source of silica and other components necessary for the bios activity.

The biogenic sedimentation during the formation of zeolite-bearing complexes of the Eastern Ciscaucasus was provided by the activity of carbonate- and Si-bearing living organisms. The carbonate precipitatation was ubiquitous. The carbonate-rich complexes were mainly formed on a deep-water shelf and did not affect the zeolite formation. The localization of siliciliths was characterized by the following specific features. First, Paleocene and Eocene siliceous rocks of the Eastern Ciscaucasus were formed during transgressions and subsidences of the sedimentation basin. Second, silica was intensely deposited on a shallow-water shelf. Third, the silica deposition was not governed by basin temperature ranging within 20–28°C. Fourth, siliceous sediments precipitated in open basins with a normal salinity.

During transgressions, the basin within the Eastern Ciscaucasus represented a sea connected with the Tethys and large seas of the Russian Platform. Tectonic movements were responsible for periodical subsidences of the cordillera located in the axial part of the Greater Caucasus Meganticlinorium. Transgressions facilitated the supply of deep silica-rich waters into the sedimentation basin, thus stimulating a vigorous activity of Si-bearing organisms. Hence, silica was derived from seawater, and the total SiO_2 content in the seawater was replenished by volcanic activity. The land erosion did not play a considerable role as silica source, because large source areas were located at a significant distance, while the terrigenous contribution of small Caucasian Islands was not appreciable. A was mentioned above, the source area lacked a mature weathering crust. The clastic material, which was transported to the sea, diluted volcanogenic–siliceous sediments. The carbonate accumulation also played the role of a diluent.

The primary sedimentary material of Lower Paleocene and Lower–Middle Eocene volcanogenic–siliceous complexes experienced postsedimentary alterations. The strongest alterations of major rock-forming minerals occurred during the late diagenesis. This resulted in a complete or partial disappearance of the biomorphic texture of siliceous sediments with a gradual recrystallization of the authigenic silica. The fine pyroclastic material was replaced by montmorillonite and zeolites. The significant content of the mobile biogenic silica and other active components in sediments was responsible for the formation of high-Si zeolite (clinoptilolite). Variations in the clinoptilolite content is explained by an irregular distribution of pyroclastic material and different SiO_2 contents in the rock. The increase in terrigenous and carbonate materials diluted labile components in the sediments and consequently suppressed the diagenetic zeolite formation up to the point of complete cessation.

CONCLUSIONS

Based on formation conditions of Upper Paleocene and Lower–Middle Eocene zeolite-bearing terrigenous–siliceous complexes of the Eastern Ciscaucasus, we can draw the following conclusions:

(1) The initial material was formed during the tectonic activation and related to transgression and subsidence of the sedimentation basin floor.

(2) The Late Paleocene and Early–Middle Eocene sedimentation within the Eastern Ciscaucasus was

affected by (a) land erosion, (b) volcanic activity, and (c) vital activity of organisms.

(3) The contribution of terrigenous material from the land was not a leading factor of sedimentation and did not suppress the precipitation of volcanogenic and biogenic products.

(4) The primary sedimentary material accumulated simultaneously with volcanic eruptions in the adjacent areas, and the volcanism had an impulsive character.

(5) The carbonate accumulation did not affect the formation of zeolite-bearing complexes.

(6) The silica accumulated on a shallow-water shelf owing to the accumulation of skeletal remains of sponges, diatom algae, and radiolaria. The silica was derived by living organisms from seawater and supplied by volcanic activity.

(7) The primary sedimentary material was accumulated in open marine basins with a normal salinity. The water temperature ranged within 20–28°C.

(8) Zeolites were developed during the late diagenesis. The fine pyroclastic material was replaced by montmorillonite and clinoptilolite, which formed owing to high content of the labile biogenic silica in sediments.

(9) Variations in the clinoptilolite content in rocks are explained by an irregular distribution of pyroclastic material and different SiO_2 contents in sediments.

REFERENCES

Agarkov, Yu.V., Ryshkov, M.M., and Sedletskii, V.I., Alpine Silica Accumulation in the Major Caucasus, *Proiskhozhdenie i prakticheskoe ispol'zovanie kremnistykh porod* (Origin and Implication of Siliceous Rocks), Moscow: Nauka, 1987, pp. 96–110.

Agarkov, Yu.V., Sedletskii, V.I., and Boiko, N.I., *Kremnistye porody Severnogo Kavkaza* (Siliceous Rocks of the Northern Caucasus), Rostov-on-Don: Rostov. Gos. Univ., 1991.

Borsuk, A.M., *Mezozoiskie i kainozoiskie magmaticheskie formatsii Bol'shogo Kavkaza* (Mesozoic and Cenozoic Magmatic Formations of the Greater Caucasus), Moscow: Nauka, 1979.

Grossgeim, V.A., Paleogene of the Northern Caucasus, *Tr. Krasnodarskogo f-la VNII* (Proc. Krasnodar Branch, All-Russia Research Inst.), 1960, issue 4, pp. 3–190.

Grossgeim, V.A., *Terrigennoe osadkonakoplenie v mezozoe i kainozoe Evropeiskoi chasti SSSR* (Terrigenous Accumulation in the Mesozoic and Cenozoic within the European Part of the Soviet Union), Leningrad: Nedra, 1972.

Khardikov, A.E., Boiko, N.I., and Agarkov, Yu.V., Zeolites of the Eastern Ciscaucasus and Prospect of Their Practical Utilization, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1992, no. 6, pp. 25–37.

Khardikov, A.E., Boiko, N.I., and Talpa, B.V., Zeolites of the Southern Russian Platform and Prospect of Their Practical Utilization, *Izv. Vyssh Uchebn. Zaved., Geol. Razved.*, 1997, no. 3, pp. 121–126.

Khardikov, A.E., Boiko, N.I., and Agarkov, Yu.V., Zeolites of Southern Russia, *Litol. Polezn. Iskop.*, 1999, no. 4, pp. 389–399.

Lunev, A.L. and Serezhenko, V.A., Problem of Tectonic Zonation of the Northern Caucasus, *Tr. po geologii i poleznym iskopaemym Severnogo Kavkaza* (Proc. Geology and Minerals of the Northern Caucasus), Moscow, 1972, issue 13, pp. 3–12.

Machabeli, G.A., Silica Accumulation and Benthonites, *Proiskhozhdenie i prakticheskoe ispol'zovanie kremnistykh porod* (Origin and Practical Utilization of Siliceous Rocks), Moscow: Nauka, 1987, pp. 176–185.

Milanovskii, E.E. and Khain, V.E., *Geologicheskoe stroenie Kavkaza. Ocherki regional'noi geologii SSSR* (Geological Structure of the Caucasus: Outlines of Regional Geology of the Soviet Union), Moscow: Mosk. Gos. Univ., 1963, issue 8.

Romanov, N.T., Tectonics: The Eastern Caucasus, *Geologiya SSSR 1* (Geology of the Soviet Union), vol. 9: Northern Caucasus, Moscow: Nedra, 1968, part 1, pp. 634–643.

Sedletskii, V.I., Agarkov, Yu.V., Boiko, N.I., and Talpa, B.V., Silicites of the Northern Caucasus and Their Practical Utilization, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 10, pp. 92–101.

Tokmakova, P.I., Benthonites, *Mineral'nye resursy* (Minerlal Resources) part 1: Metal and Nonmetal Minerals, Rostov-on-Don: Rostov. Gos. Univ., 1978, pp. 179–182.

Yasamanov, N.A., Paleothermometry of Paleogene Seas in the Southern Soviet Union, *Izv. Akad. Nauk. SSSR, Ser. Geol.*, 1977, no. 4, pp. 134–141.

Yasamanov, N.A., *Landshaftno-klimaticheskie usloviya yury, mela i paleogena yuga SSSR* (Lanscape and Climatic Conditions of the Jurassic, Cretaceous, and Paleogene in the Southern Soviet Union), Moscow: Nedra, 1978.

Yasamanov, N.A., Paleothermometry of Jurassic Cretaceous, and Paleogene Periods in Some Regions of the Soviet Unions, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1980, vol. 55, no. 3, pp. 117–125.