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Diagenetic Mineral Formation in Biogenic Structures (Paleogene, Northeastern Caucasus)

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Abstract—Rare biogenic structures, after which diagenetic minerals are developed, are described from Paleogene rocks of southern Dagestan. It is shown that these minerals form tabular mica-like and colloform aggregates confined to fucoids. In terms of composition, they represent the glauconite group minerals. Tabular and colloform minerals are compared with globular glauconite occurring in host sandy rocks. It is demonstrated that the globular variety is characterized by higher K and Fe contents, whereas the tabular variety has a higher SiO_2 content. The probable mechanism of the formation of tabular and colloform minerals in biogenic structures is discussed.

INTRODUCTION

The study of authigenic mineral formation in coeval rocks developed over a large territory makes it possible to assess diagenetic transformations depending on changing facies environments. In this respect, Paleocene–Eocene rocks of the Caucasian region, which are mainly composed of mixed biogenic–terrigenous sediments, represent a favorable study object. At the sedimentation and diagenesis stages, they contained a noticeable amount of primarily basinal organic matter (OM), which promoted active diagenetic processes. Paleocene–Eocene rocks developed in different areas enclose various (authigenic diagenetic) formations, such as abundant sulfide nodules, common phosphate, carbonate, siliceous, and barite concretions, as well as small authigenic aggregates (phosphate grains and zeolite crystals).

The study of rocks in the South Dagestan Facies Zone revealed that they are characterized by an elevated intensity of silicate diagenetic mineralization owing to a high bioproductivity of siliceous organisms in this part of the paleobasin. In carbonate-dominated sediments (the Rubas-chai River section), the diagenetic redistribution of biogenic silica resulted in the formation of numerous nodules and lenticular interbeds mainly composed of SiO_2, whereas terrigenous sequences are characterized by a wide development of the glauconite-group minerals up to the point of the formation of glauconite interbeds associated with hardgrounds at some levels.

In the lower Eocene sequence, we discovered biogenic structures, which enclose authigenic phyllosilicate minerals with some slightly unusual parameters. These biogenic structures, which resulted from the life activity of some organisms, are sufficiently rare and confined to sediments of certain facies environments. The aim of this work is a comprehensive study of these biogenic structures, including their description, establishment of their origin, elucidation of the composition of authigenic minerals confined to these biogenic structures, and their comparison with similar minerals occurring in host sediments.

CHARACTERISTICS OF BIOGENIC STRUCTURES AND HOST SEDIMENTS

The section of mainly carbonate and clayey–carbonate Paleocene–Eocene sediments of southern Dagestan (the Rubas-chai River) includes a sequence of fine-grained, light-colored and compact carbonate sandstones, about 40 m thick. At some levels, the sandstones are silicified. According to (Shutskaya, 1970; Muzylev, pers. communication), the sandy sequence is referred to the lower Eocene (Ipresian).

The sandstones are characterized by subhorizontal and gently wavy bedding formed by alternating thin (several millimeters), gray and white laminae mainly composed of clastic silicate material and biogenic calcareous mud, respectively. The bedding is locally disturbed by bioturbation.

The clastic silicate material is represented by angular quartz grains (30–50 vol %) with an admixture of feldspars (up to 10 vol %). Biogenic components make up about 50 vol % of the rock with sharply dominant and variably recrystallized carbonate foraminiferal tests. Both silicate and biogenic components of the rock are well sorted and dominated by grains 0.1–0.2 mm in size.

The sandstones contain dispersed glauconite globules (not more than 10 vol %). Most globules are localized within laminae of a clastic silicate material. Dimensions of glauconite grains (0.1–0.2 mm) are close to those of the major clastic components.

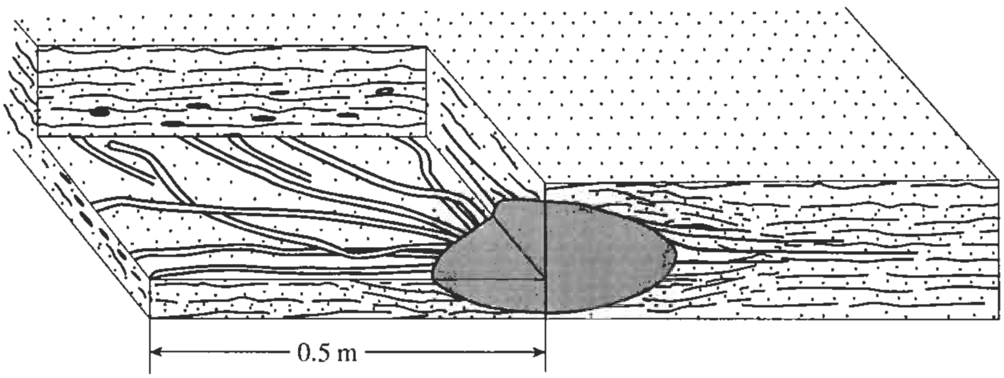

Fig. 1. A sketch image of the biogenic structure from lower Eocene sandstones of southern Dagestan (Rubas-chai River area).

The sandstone cement is mostly composed of a basal, crystalline carbonate material (calcite with an insignificant admixture of ankerite). Biogenic laminae sometimes enclose sufficiently large areas cemented by a micritic carbonate substance. The sandstones contain thin cracks filled by fibrous chalcedony and microporous opal.

At several levels, the sandstones enclose very unusual siliceous lenses with radial, slightly curved, and diverging dark green bands (Fig. 1). The lenses represent flattened compact nodules with an uneven surface dissected by cracks with chalcedony sinters. The nodules, up to 20–25 cm across and 4–5 cm thick, are characterized by an irregular, ocherous yellow to black color. The divergent, narrow (1–2 cm), slightly wavy, radial bands, 30–40 cm long, locally intersect and gradually wedge out. The band-shaped channels approach siliceous lenses at different levels and sometimes envelope the lenses (Fig. 1). On the plane, which is perpendicular to the axis of bands, the channels resemble strongly flattened (1–2 mm thick) and short (a few centimeters) lenses located at different levels and filled by a green or dark green mineral substance. In some cases, the small lenses have the form of flattened ellipses, up to 5–6 mm thick. If the channels are oblique to the bedding surface, they acquire an almost rounded shape.

The microscopic study of the internal structure of nodules reveals that they represent accumulations of microcoprolites (Fig. 2) locally enriched in small foraminiferal tests. All components are completely replaced and compactly cemented by a homogeneous, microspherulitic silica aggregate with an irregular impregnation of fine-dispersed iron sulfides, which emphasize primary forms of biogenic components. Every separate nodule together with the system of diverging narrow bands represent a genetically single biogenic structure. Bromley (1996) reported a series of similar radiating burrow systems registered both in recent and ancient sediments. Most of them, however, are characterized by smaller dimensions. For instance, the considered formations show some morphological and dimensional similarity with biogenic structures reported by Bromley and Asgaard (1972) from Jurassic fine- and medium-grained sandstones of eastern Greenland. They interpreted the structures as living chambers of crustaceans, which could freely move within sediments, and diverging channels as tunnels, through which organisms could penetrate into sediments and back. Main differences between southern Dagestan and eastern Greenland biogenic structures are related to their fossilization patterns. In the eastern Greenland burrow systems, channels diverging from the central

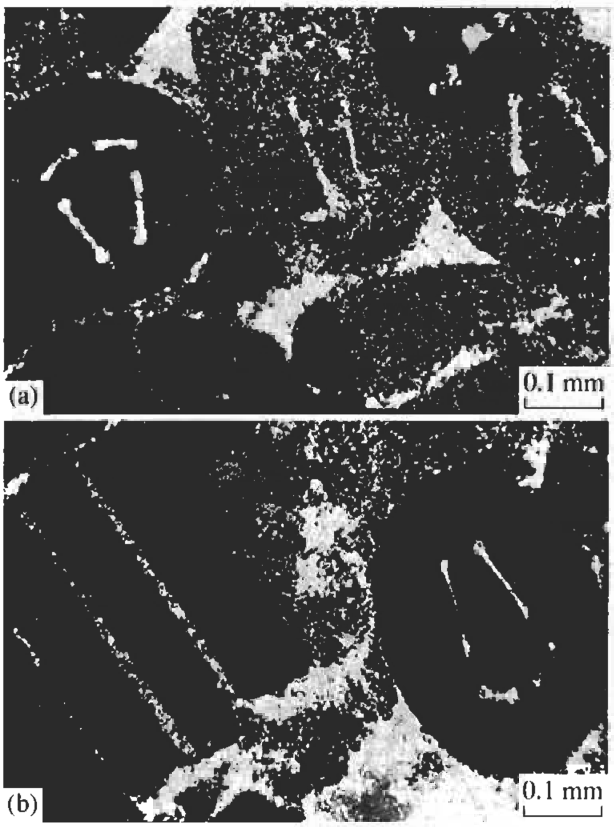

Fig. 2. Microphotographs of coprolites from the siliceous lens and their internal structure.

chamber are filled with a material of host sediments and the initial appearance is significantly preserved (the authigenic mineralization was not registered). In our case, the channels did not practically preserve their primary form, since they were significantly flattened and filled by newly formed green-colored authigenic minerals.

Coprolites are often abundant in the studied rocks (Khvorova, 1953; Maslov, 1960; and others). One should know their morphology and internal structure to understand their origin. Coprolites discovered in the Ipresian rocks represent small (less than 1 mm) cylindrical bodies randomly distributed throughout the rock mass (Fig. 2). They are crosscut by four drainage (according to the terminology of O.S. Vyalov) channels located symmetrically to the main axis. In modern coprolites of such type, channels are formed by finger-like protrusions from the rear end of an animal stomach (Vyalov, 1978).

The study of the internal structure of coprolites, which are localized in the siliceous lens representing the central part of the biogenic structure, allows organisms responsible for their formation to be established with a sufficient confidence. Coprolites with an identical or similar internal structure were recorded in Jurassic rocks of England (Kennedy *et al.*, 1969), Lower Cretaceous sections of Hungary (Palik, 1965), and Triassic, Jurassic, and Cretaceous rocks of North Africa and Europe (Brönnimann, 1972; Brönnimann and Zaninetti, 1972; Brönnimann *et al.*, 1972). Similar microfossils were also reported by Maslov (1960) from Tertiary rocks of the Tadjik Depression. All data on coprolites available at that time are given in the Atlas of rock-forming organisms (Maslov, 1973). Vyalov (1978 and others) found similar coprolites in Turonian rocks in the Amudar'ya River area. In the Caucasian region, similar but not identical microfossils were registered in phosphate concretions within clays of the Goryachii Klyuch Formation (upper Paleocene) of the central Caucasus (Senowbari-Daryan and Silantiev, 1991). In all cases, researchers considered coprolites of this type as a product of the life activity of Decapoda (Crustacea) representatives. Therefore, the formation of biogenic structures and associated coprolite accumulations in the study region should also be considered as a result of the life activity of these organisms.

Sometimes, researchers note the presence of green minerals in crustacean (Decapoda) burrows, which were referred to glauconite, although their composition was not studied (Bromley and Asgaard, 1972; and others). With respect to some characteristics, the green minerals, which we observed in burrows, are somewhat unusual. That is why we performed special studies of their composition and compared them with glauconite in host rocks.

CHARACTERISTICS OF AUTHIGENIC MINERALS

Minerals filling burrows are mainly represented by relatively soft, dark green aggregates, which usually cover their inner surface over the entire length in the form of film or thin crust and are distinct against the background of the light-colored enclosing sediments. Under the optical microscope, the thin (millimeter-scale) lenses are observed as tabular mica-like structures (Figs. 3a, 3b) usually enveloping grains of the enclosing rock. Sometimes, they include small calcite crystals, quarts grains, and globular glauconite (the glauconite grain is indicated by an arrow in Fig. 3a). In thicker burrows, the filling mineral material shows a zonality. The peripheral part of the channel is mostly composed of a dark green mica-like mineral, which acquires blue color toward the central part. Tabular patterns are gradually replaced by less regular, macroscopic colloform mineral mass.

Plates usually reveal strong pleochroism varying from the yellowish white to intense dark green color with a domination of the mica-type interference colors. Less common are aggregates with poor pleochroism, less bright interference colors, and undulatory extinction.

Globular glauconite from enclosing sandstones is mainly represented by isometric (or elongated and rounded) dark green grains with a smooth or slightly uneven surface. Some globules have an irregular form with highly smoothed edges. In thin sections, they are characterized by a uniform and intense green color, which does not practically change under crossed nicols, and a chaotic internal structure of microaggregates.

Authigenic minerals were studied with the application of the high-resolution scanning electron microscopy, X-ray and electron-diffraction methods, along with quantitative microprobe and chemical analyses. We studied the dark green tabular (Sample 3011/3t) and light bluish green colloform (Sample 3011/3c) aggregates from biogenic structures, as well globular glauconites from enclosing sandstones (Sample 3011/3g). To obtain monomineral preparations for the SEM study of the nanotexture, tabular aggregates were picked by hand. The same samples were also used for microprobe investigation.

Inasmuch as the admixture of globular glauconite in sandstones does not exceed 10%, their 0.1–0.2-mm fraction was concentrated approximately to 75–90% using electromagnetic separators. The nanotexture was studied in most characteristic globules. Using the X-ray diffraction method, minerals were analyzed in oriented preparations from the <0.001-mm fraction obtained by elutriation of the material enriched in glauconite globules. The microprobe analysis of statistically random globules was performed in the polished section of sandstones.

Nanotextural Features. Under the scanning electron microscope, transverse slices of *tabular mineral* reveal

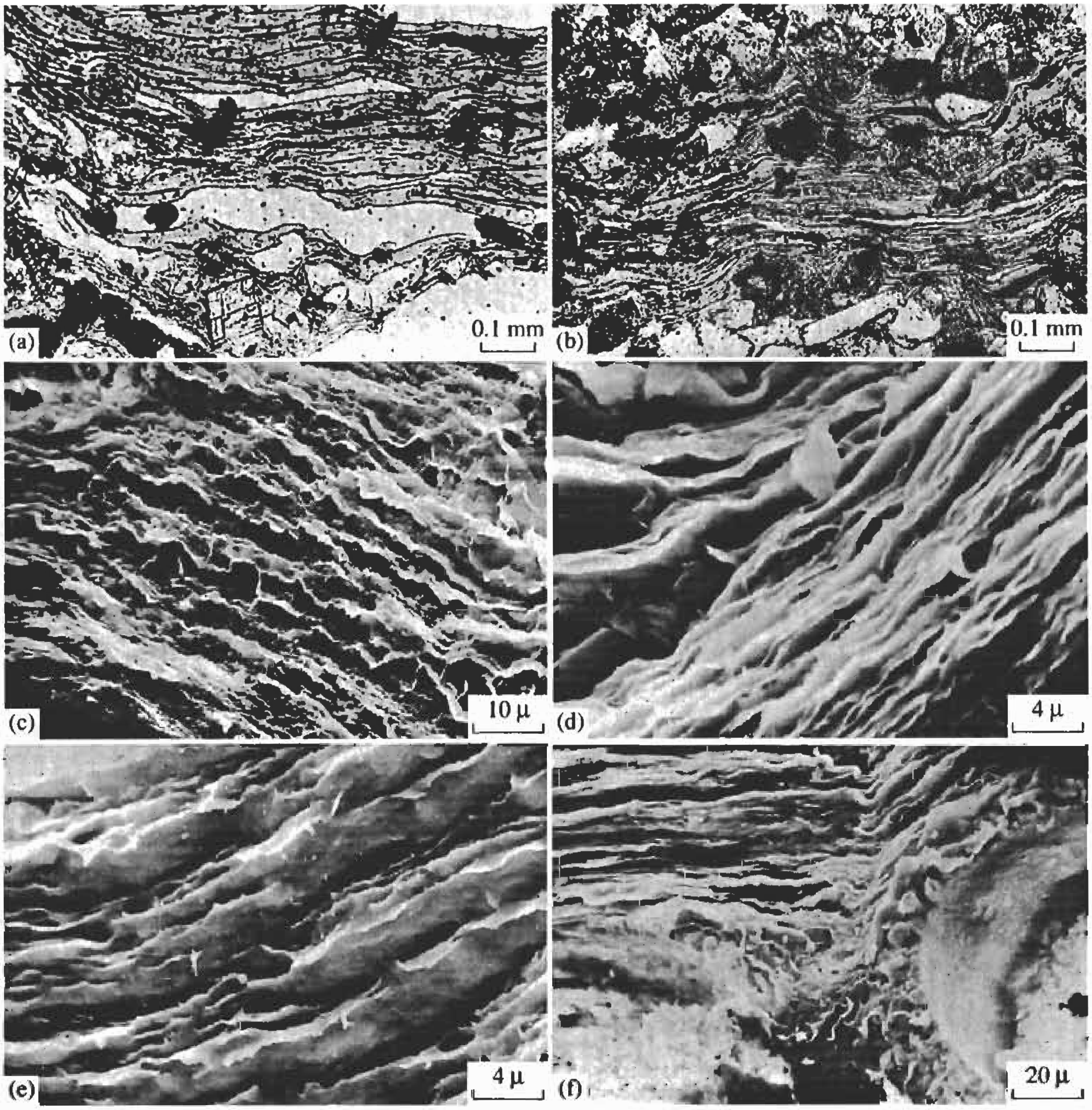

Fig. 3. (a, b) Microtexture and (c–f) nanotexture of a tabular mineral of the glauconite group. (a, b) Photomicrographs of the tabular mineral in thin section; the arrow in Fig 3a indicates a globular glauconite grain sealed within the tabular mineral; (c–f) photomicrographs of the tabular mineral under the scanning electron microscope; 3f shows foraminiferal tests enveloped by glauconite scales.

a lamellar- and lepidoblastic-parallel texture (Figs. 3c–3f). The thickness of flakes and scales is 0.*n* μm. The lepidoblastic-parallel texture is formed by relatively short (2–5 μm) and slightly curved scales overlapping each other, thus imparting an imbricate pattern to the texture (Fig. 3c). The lamellar-parallel texture is built by larger (10*n* μm) plates that are tightly, almost continuously arranged in the sample within the observation zone. Their edges are usually subparallel and relatively straight (Figs. 3d, 3e).

Under the scanning electron microscope, *colloform mineral aggregates* associated in fucoids with tabular ones are characterized by a greater diversity of the nanotexture: both subparallel and chaotic varieties are present. The subparallel texture is formed by thickened restiform aggregates (Figs. 4a, 4b). Nonoriented textures (cellular- or honeycomb-type) are formed by a chaotic intergrowth of very small (less than 1 μm) isometric curved scales (Figs. 4c, 4d).

Under the scanning electron microscope, *globular glauconite* is mostly characterized by a microrelief- and fissures-free smooth surface. The splinting surface reveals a chaotic intergrowth of rosette-, cluster-, and fan-shaped aggregates (Figs. 4e, 4f). Scales composing

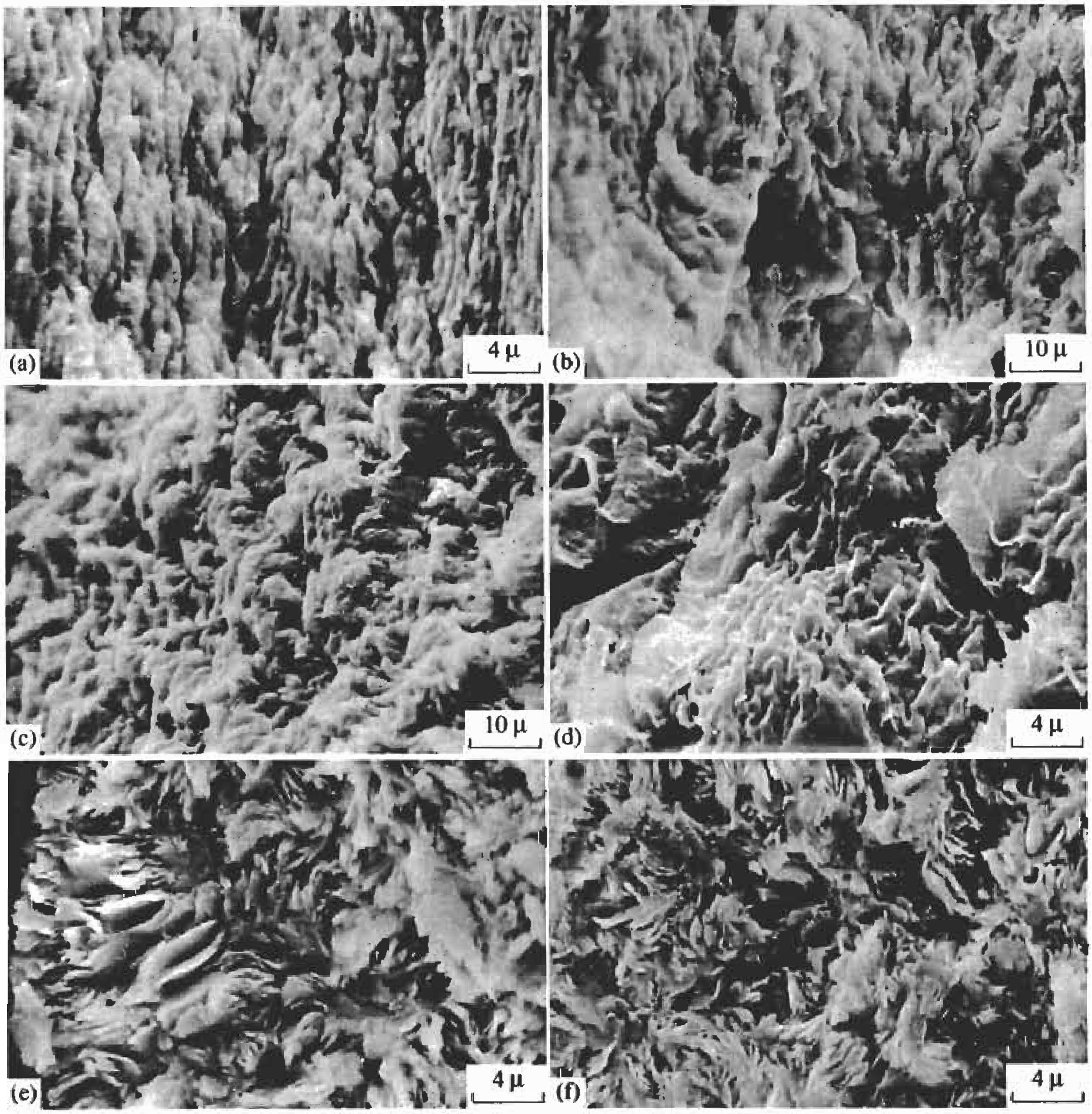

Fig. 4. Nanotexture of the (a–d) colloform mineral of the glauconite group and (e, f) globular glauconite from enclosing sandstones.

these aggregates are usually 1–2 μm in size. The similar texture is typical of globular glauconites and was described in many publications (Nikolaeva, 1977; Nikolaeva *et al.*, 1981; Lisitsyna and Butuzova, 1981; Odin *et al.*, 1988; Geptner and Ivanovskaya, 1998; and others).

The above-mentioned nanotextures of the tabular mineral were practically never described for authigenic, dioctahedral, Fe-rich micaceous minerals. In the opinion of Odin and Fullagar (1988), the elongated-tabular appearance of microcrystallites (up to 20 μm long and 0.2–0.3 μm thick) is typical of celadonite. However, SEM images of celadonite demonstrated in the above work are devoid of nanotextures with a parallel arrangement of microcrystallites.

The internal texture of colloform segregations is probably transitional from lamellar- and lepidoblastic-parallel varieties with a distinct crystalline appearance to the less ordered and sometimes close to glauconite-type textures of globular structures.

Results of X-ray Diffraction Studies. In diffraction patterns, the natural tabular mineral is close to micas with an elevated Fe content (Fig. 5, Sample 3011/3t, a). The observed insignificant shift of the first basal reflection to the low angle region (d_{001} = 10.50–10.70 Å) and related slight distortion of the regularity of basal reflections imply the presence of swelling interlayers. It is noteworthy that the sample saturation with ethylene glycol results in the separation of the first basal reflection into two contiguous peaks: more intense peak with d_{001} = 9.80–9.93 Å and less intense one with d_{001} = 10.80–11.00 Å (Fig. 5, Sample 3011/3t, *b*), suggesting the alternation of mica and smectite layers with the short-range order factor $S \gg 1$ (Drits *et al.*, 1993). The comparison with theoretical diffraction patterns calculated for mixed-layer mica–smectite formations (Drits and Sakharov, 1976) showed that the studied mineral is closest to the mixed-layer phase of dioctahedral mica–smectite with the content of swelling layers not more than 10–15% and the short-range order factor $S = 3$, indicating the trend toward a relatively high ordering of the alternation of mica and smectite layers at the studied level of their proportions.

The elementary cell parameters of tabular mineral determined by the electron-diffraction method are as follows: $a = 5.24$ Å, $b = 9.072$ Å, and $c = 10.11$ Å at β = 101.2 Å. These values correspond to the dioctahedral Fe-rich mica.

Diffraction patterns obtained for the colloform mineral reveal a phase heterogeneity (Fig. 5, Sample 3011/3c, *a*, *b*). Two mixed-layer Fe-rich mica–smectite phases with d_{001} = 11.20 Å are present as main components. This is inferred from the separation of the first basal diffraction into three contiguous peaks (more intense peak with d_{001} = 9.8 Å and two less intense ones with d_{001} = 11.5 Å and d_{001} = 12.6 Å) owing to the presence of two mixed-layer mineral phases. They differ in the content of swelling layers and structural ordering degree. For instance, the first phase contains as much as 10–15% swelling interlayers with the short-range order factor $S = 3$ and is identical to the above-described phase of the tabular mineral, whereas the second phase contains up to 25% swelling interlayers with $S = 2$ (Drits and Sakharov, 1976). The sample also contains an admixture of organic-rich smectites, which are revealed by several weak reflections in the low angle region: d_{001} = 14.70–18.00 Å in the initial preparation and d_{001} = 18.60 Å in the preparation saturated with ethylene glycol.

Diffraction patterns obtained for the oriented preparation of sandstone fraction enriched in dark green globules correspond to those of quartz and Fe-rich mica with d_{001} = 10.00 Å (Fig. 5, Sample 3011/3g, *a*, *b*). When the preparation is saturated with ethylene glycol, the first basal reflection is only insignificantly shifted (up to d_{001} = 9.98 Å), indicating the absence of swelling layers in the mineral structure and allows it to be interpreted as mica.

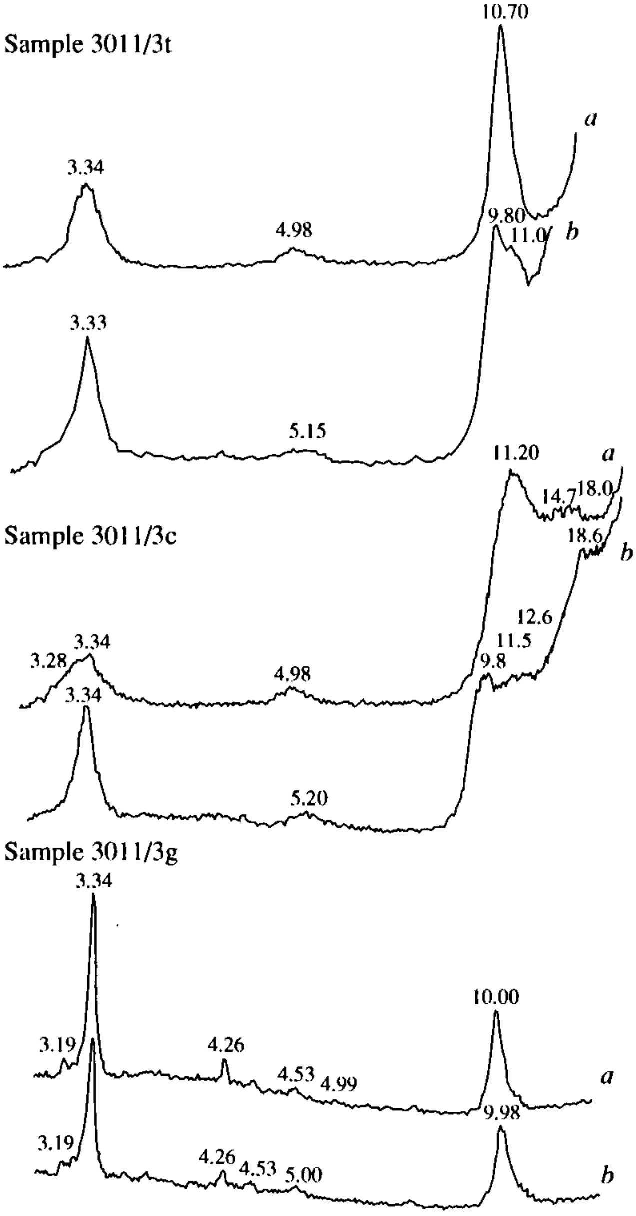

Fig. 5. Diffractograms of oriented preparations. (*a*) Natural state; (*b*) saturated with ethylene glycol.

Chemical Composition of Minerals. The chemical characteristics of three morphological varieties of green phyllosilicates are presented in the table. The results are mainly based on the microprobe (Camebax) data. The tabular mineral was also subjected to silicate analysis. As is seen from the table, the Fe_{tot} i.e., (Fe_2O_3 + FeO) content prevails over that of Al_2O_3 in all varieties (11.78–20.68 and 5.43–10.18%, respectively) and the K_2O content ranges from 5.17 to 8.99%.

Colloform mineral aggregates (Sample 3011/3c) are characterized by a lower content of main components and lower values of their sum (probably owing to elevated contents of volatile components), relative to the tabular mineral. Besides, they reveal a phase heterogeneity in X-ray image. Therefore, the reliable interpretation of data obtained for the colloform aggregates is hampered.

Chemical characteristics obtained for tabular and globular minerals support the diffraction data suggest-

Chemical composition of authigenic minerals from lower Eocene sandstones of southern Dagestan, %

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	TiO_2	H_2O^+	H_2O^-	Total
Tabular variety (Sample 3011/3t)												
1*	53.32	8.13	13.98	1.55	4.65	1.56	5.41	0.24	0.08	6.60	3.96	99.29
2	54.35	8.20	14.66		5.15	0.92	6.05	0.13	0.09	n. a.	n. a.	89.20
3	54.55	7.98	15.08		5.13	0.57	6.15	0.05	0.13	"	"	89.62
4	53.97	7.37	15.27		5.16	0.51	6.25	0.11	0.07	"	"	88.71
Colloform variety (Sample 3011/3c)												
5	51.41	9.30	11.78		4.91	0.58	5.17	0.09	0.08	"	"	83.37
6	49.66	8.91	12.67		4.70	0.71	5.29	0.21	0.06	"	"	82.22
Globular variety (Sample 3011/3g)												
7	51.23	10.18	16.72		4.03	0.36	7.31	0.09	0.11	"	"	90.03
8	51.56	9.50	17.76		4.30	0.65	7.59	n. d.	0.15	"	"	91.51
9	52.13	8.16	19.07		4.75	0.64	7.89	0.09	0.08	"	"	92.81
10	51.53	8.43	18.45		4.40	0.51	8.05	0.12	0.12	"	"	91.61
11	51.74	8.18	18.37		4.21	0.44	8.18	n. d.	0.14	"	"	91.26
12	51.25	7.12	20.68		4.26	0.53	8.53	0.04	0.08	"	"	92.49
13	51.63	7.22	20.55		4.52	0.44	8.54	n. d.	0.06	"	"	92.96
14	52.18	5.43	20.00		5.30	0.67	8.99	n. d.	0.09	"	"	92.66

* The silicate analysis of the sample was performed using the wet method; the sample also contains MnO (0.02%) and P_2O_5 (0.16%); CO_2 was not detected C_{org} = 0.25% (K.A. Stepanova, analyst). Other analyses were performed using the microprobe (Camebax) method (G.V. Karpova, analyst). (n. a.) Not analyzed, (n. d.) not detected.

ing that the Fe-rich dioctahedral 2:1 phyllosilicates represent the glauconite group minerals. However, the tabular glauconite bears some specific features.

In the tabular mineral (Sample 3011/3t), the SiO_2 content determined by both the silicate analysis (53.32%) and microprobe analysis (53.36–54.55%) methods is rather high (table). Using the silicate analysis data, as well as assuming that the whole SiO_2 is included in the mineral structure and the anion framework $[O_{10}(OH)_2)^{-22}]$ is constant, we obtained the following average crystallochemical formula:

$$K_{0.50}Na_{0.03}Ca_{0.11}\,(Al_{0.6}Fe^{+3}_{0.77}Fe^{+2}_{0.09}\,Mg_{0.51})_{1.97}$$

$$\times\,(Si_{3.90}Al^{+4}_{0.1})_4.$$

It shows that the Si cation content is 3.90 f.u., which significantly exceeds the admissible limit for a typical glauconite. Therefore, the affiliation of the studied mineral to celadonite, which is characterized by a high degree of tetrahedral position occupation by Si (Si cation content is as much as 3.8–4.0 f.u., according to Drits and Kossovskaya, 1991), is necessary to discuss. Additionally, morphological and structural features of the mineral are most typical of celadonite rather than glauconite (Odin and Fullagar, 1988). Noteworthy is also a sufficiently high MgO content in the considered mineral (table).

Although quartz and mineral phases of amorphous silica were not revealed by the X-ray or electron microscopy methods, the absence of quantitative chemical data on the free silica content hampers a reliable identification of the mineral composition based on the calculated crystallochemical formula. Therefore, percentages of mineral-forming oxides are used in further discussion.

The Fe/Al ratio in the studied mineral is more typical of glauconite rather than celadonite, because, according to (Buckley *et al.*, 1978; Odin *et al.*, 1988), the latter is usually characterized by higher Fe contents and lower Al contents (Fe_2O_3 + FeO and Al_2O_3 contents are 16–28 and 0.5–6.0%, respectively).

The noticeable K deficit (K_2O 5.41–6.25%) in the tabular mineral is probably related to the presence of swelling interlayers in its structure. This conclusion is consistent with diffraction patterns of the glauconite group minerals. In contrast, celadonites are usually characterized by higher K contents, e.g., the K_2O content is 7.69–9.89% (Buckley *et al.*, 1978) or 7.0–9.5% (Odin *et al.*, 1988). The formation of mixed-layer phases is also less typical of them, relative to glauconites.

In the opinion of Drits and Kossovskaya (1986, 1991), the *b* parameter of the elementary cell is not an unambiguous criterion for discrimination between glauconite and celadonite. Nonetheless, many researchers use this criterion accepting the value of $b \leq$ 9.06 Å for typical celadonites and $b >$ 9.06 Å for typical glauconites (Kameneva *et al.*, 1981; Drits *et al.*, 1993).

As was noted, the *b* parameter of the tabular mineral is equal to 9.072 Å and more typical of glauconite, although this slightly elevated value is not prohibited for celadonite (Lipkina *et al.*, 1987; Drits *et al.*, 1993).

Taking into consideration the aforesaid, the studied dark green tabular mineral can probably be classed with glauconite, although elevated SiO_2 and MgO contents make it somewhat similar to celadonite as well.

Data on the chemical composition of globular glauconite (table, Sample 3011/3g) were obtained using the microprobe method. Therefore, we can compare the contents of main components in globular and tabular glauconites. Despite some heterogeneity of the chemical composition of globules with respect to the distribution of mainly Fe and Al contents and subordinate K, Si, and Mg contents (table), one can detect several substantial differences in the chemical composition of tabular and globular glauconites. For instance, as compared with the tabular variety, globules are characterized by higher K_2O and Fe_{tot} contents but lower SiO_2 and MgO contents, while the Al_2O_3 content is almost similar in both varieties (table).

On the whole, the chemical composition of dark green globular minerals in sandstones is rather typical of glauconites. This conclusion is also consistent with the data of Bunin (1968a, 1968b) on globular glauconites from lower Eocene rocks in southern Dagestan.

As compared with the globular variety, the tabular glauconite from fucoids is depleted in Fe but enriched in K and Mg. It shows a mixed-layer pattern (10–15% of swelling layers), which is probably responsible for lower K contents in the tabular mineral.

DISCUSSION

Paleocene–Eocene rocks of southern Dagestan are characterized by active processes of diagenetic mineral formation. At present, they are almost barren of organic matter, which was sufficiently abundant in fresh sediments and was buried along with numerous remains of calcareous and siliceous organisms. However, sedimentation environments in the region, e.g., relatively shallow-water settings, sediment reworking owing to unstable hydrodynamics suggested by the ubiquitous cross bedding, and bioturbation, promoted rapid decomposition of organic matter and the formation of slightly reductive conditions in sediments. Diagenetic processes and dissolution of foraminiferal tests produced a basal calcite cement in sandstones. Simultaneously, rare sulfide (pyrite) micronodules and globular glauconite grains (similar in size with the terrigenous material of host sediments) were formed. Inasmuch as oxidized varieties are absent amid glauconite globules, the glauconite reworking, which is suggested by its confinement to laminae of terrigenous material rather than biogenic mud, was probably subordinate and accompanied by an insignificant displacement of sediments.

Locally, for instance within the discussed biogenic structures, diagenetic processes were more intense than the background activity. Products of biological activity contained an elevated amount of organic matter. The central part of biogenic structures accumulated abundant excrements of Decapoda crustaceans enriched in C_{org} and P compounds. As a result of diagenetic processes, all these products were metasomatically replaced by silica to form a silicified lens with abundant sulfide mineralization, suggesting active sulfate-reducing processes in the area. Curved patterns of sandstone laminae, which envelop the silicified lens, suggest the lens formation during the early stage of diagenesis before the diagenetic consolidation of sediments and accumulation of basal calcite cement.

Burrows of Decapoda crustaceans in sandstones were not infilled with the host sediment. Their walls were covered by an organic substance produced by organisms during the movement in sediments (burrows are barren of coprolites). Pore waters of sandstones were enriched in many chemical components, particularly biogenic SiO_2, which was produced as a result of the dissolution of diatoms and radiolaria, cations released during the metasomatic replacement of terrigenous feldspars with carbonates, and others. Organic matter in burrows favored the formation of specific diagenetic conditions, which were more reductive than the environment in enclosing sediments. The diffusion influx of substance from pore waters and local specific conditions promoted the formation of tabular and colloform Fe-phyllosilicates with a fine-dispersed pyrite admixture. During the diagenetic consolidation, burrows were crumpled and transformed into flattened bands. The diffusion influx of substances from enclosing sediments through burrow walls supplied a construction material for the newly forming minerals, first of all, into the contact zone of diagenetic silicates where the content of K and other cations is higher, relative to the mineral in central (axial) zones of burrows. Consequently, micaceous varieties were formed in the periphery of burrows, whereas the mineral with a noticeable share of mixed-layer phases was formed in the central zone with the lesser cation supply.

In sectors where relationships of globular and tabular minerals can be observed, it is seen that globular glauconite is enveloped by scales of the tabular variety (Fig. 3a); i.e., at first glance, it can be assumed that there is a significant difference in their formation time. Nonetheless, both of them represent products of diagenetic processes. The difference between them lies in the fact that the globular glauconite could be formed in several stages. After the formation in the upper sediment layer during the early diagenesis, the glauconite could be involved in reworking and, in this case, represent an allothigenic mineral. However, the reworking was insignificant and reworked sediments were practically deposited at the same site or only slightly displaced. As a result, sediments were differentiated into thin laminae mainly composed of terrigenous material with globular glauconite and laminae with prevalent biogenic mud. The tabular glauconite, which was also formed during diagenesis in biogenic structures enclosed within sediments after the formation of globular glauconite, did not suffer subsequent reworking.

Shutov (1984) reported a joint occurrence of two generations of glauconite group minerals in the siliceous sandstone horizon of the Paleocene Yamnen Formation near Skole (eastern Carpathians). The minerals differ in geological position in the section and chemical composition. They are represented by the globular glauconite dispersed in sandstones and the skolite developed on walls of fucoids in the same sandstones. Unfortunately, this author provided no description and did not indicate morphological features of skolite aggregates. To explain formation conditions of these minerals, he proposed a model assuming the existence of a hydrothermal substance source common for both globular glauconite and skolite.

In our opinion, there is no need to look for sources of mineral-forming components other than bottom waters or diagenetic processes in accumulated sediments to explain the origin of authigenic phyllosilicates in sedimentary rocks of southern Dagestan.

CONCLUSION

(1) Biogenic structures are found in lower Eocene (Ipresian) rocks of southern Dagestan. Based on the unusual internal structure of coprolites confined to these burrows, it is assumed that the latter represent traces of Decapoda crustaceans.

(2) Burrows bear abundant authigenic mineralization. Coprolite accumulations in the central part of these structures are completely replaced by silica with abundant pyrite microinclusions. Burrows are filled with the newly formed, glauconite group minerals of two morphological varieties: tabular (mica-like) and colloform. They also differ in textural and chemical parameters: the tabular variety is enriched in silica, K, Mg, and Fe, relative to the colloform one, which is characterized by a larger share of mixed-layer phases. The globular glauconite from enclosing sediments contain more Fe and K but less SiO_2, as compared with the varieties from burrows. Tabular, colloform, and globular glauconite varieties formed at early diagenetic stages. Differences between them are induced by specific features of geochemical conditions within sediments and biogenic structures.

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