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GLAUCONITE CONTENT IN THE PALEOGENE DEPOSITS OF SOUTHERN KAZAKHSTAN

Annotation. The article considers the glauconite-bearing nature of the Paleogene deposits in the Syr Darya Depression. It summarizes the results of a comprehensive study of the material composition and formation conditions of glauconitic sandstones associated with the Paleogene strata of the depression. The patterns of spatial and stratigraphic distribution of productive glauconite horizons are described. Consequently, a sedimentation cycle of the Paleocene and Eocene periods is identified, reflecting the evolutionary trends of the Paleogene sedimentary basin in the study area. These findings provide a foundation for a new predictive strategy in the exploration of promising glauconite occurrences and deposits.

Keywords: glauconite; Kainarbulak Formation; stratigraphy; grain morphology; Paleocene; shelf facies; South Kazakhstan.

Introduction

Glauconitic sands are widespread within the southeastern part of the Greater Karatau Mountains and the territory of the Syr Darya sedimentary basin. They are confined to the lower part of the Kainarbulak Formation, which is dated to the Late Paleocene – Early Eocene. Glauconitic sand layers have been identified in the Burgem, Balaburgem, Ukasha-Ata, Atabai and Urangai areas in the Turkestan District of the South Kazakhstan Region. Occurrences are also known in the Zhanakorgan District of the Kyzylorda Region, including Kainarbulak, Kainar, Kyrash-Tobe, Kos-Uyenki, Zhanaaul and others.

The Paleogene deposits of the region have been studied in sufficient detail. Over the years, this subject have been explored by T.A. Mordvilko [11], V.N. Razumova and A.G. Chernyakhovsky [12], V.A. Zagoruiko, V.A. Bykadorov [3], A.V. Loseva, B.S. Tsirelson [13], S.M. Blyakhova [2] and others.

Within the central part of the Karatau Range, the deposits of the Kainarbulak Formation have been destroyed by erosion. However, on both of its slopes, as well as within the Syr Darya and Shu-Sarysu sedimentary basins, they are widely developed. On the southwestern slope of the Karatau, the rocks of the formation are exposed in significant areas, while on the northeastern slope they have been penetrated by numerous boreholes. The most complete and representative section of the formation is observed in the northwestern part of the range, on both the southwestern and northeastern slopes.

The Kainarbulak Formation is divided into three distinct units, each with a different lithological composition (Figures 1, 2) [4, 8]. The lower unit is distinguished by variability of its lithological composition along its strike. Its structure is dominated by gray and dark gray silty clays with a small amount of organic (sapropelic) matter and pyrite, interbedded of quartz-glauconite sandstones and sands. In some areas, on the contrary, it is dominated by clayey quartz-glauconite sandstones, and occasionally by gravelites with phosphorite nodules. The glauconitic sands and sandstones form tabular and lenticular horizons up to 3 meters thick, characterized by wide lateral development. The thickness of the unit varies from several meters to 25 meters. The middle unit is represented by chocolate-colored silty clays with subordinate intereds (0.1-0.5 m) of gray calcareous siltstones with fine cross-lamination. Its thickness is usually less than 20 meters. The upper unit is composed of gray and dark gray silty, non-carbonate clays with a thickness of 10 to 25 meters.

Thus, the section of the Kainarbulak Formation has a number of specific features that allow it to be confidently identified in sections, both in outcrops and in boreholes. These features include its predominantly clayey composition, lack of carbonates, enrichment in organic matter and pyrite, as well as gray and dark gray color of rocks, the presence of a horizon of "chocolate-colored" clays in the middle part, interlayers and lenses of quartz-glauconitic sand at the base.

In most of the studied area, the Kainarbulak Formation lies with an erosional unconfority on the underlying Paleocene deposits. However, in areas where these deposits are absent, it unconformably overlaps various older strata, including Cretaceous or pre-Mesozoic formations.

The age of the Kainarbulak Formation is determined by the remains of mollusk, foraminifera and palynological assemblages. In the lower part of the formation, A.V. Loseva and K.A. Lyadzhina collected and identified the following species: *Barbatia* sp., *Ostrea* cf. *bellovacina* Lam., *Cyprina morrisi* Sow., *Trapezium* sp., *Nemocardium edwardsi* Desh., *Pitar tranquillia* (Desh). P. *laevigata* (Lam.), P. *deplanatus* Los., P. *monteneis* Cossm., P. *ovalina* Desh., *Dosiniopsis fallax* Desh.,

D. *bellovacensis* Desh., *Tellina hybrida* Desh., *Gari edwardsi* Morris, *Solecurtus subcompressus* Netsch., S. *subsolenoides* War., S. *vialovi* Los., *Pholadomya koninchi* Nyst, *Calyptraea suessoniensis* Orb., *Cylichna* cf. *volgensis* Netsch. These findings suggest that the host deposits can be assigned to the Late Paleocene (Kachin Horizon) [8].

The identified foraminiferal assemblage is analogous to those of the Suzak Beds of Central Asia and indicates a Late Paleocene – Early Eocene age of the host deposits.

Thus, based on the contained fossil remains and the stratigraphic position, the age of the Kainarbulak Formation is determined to be Late Paleocene to Early Eocene.

As previously noted, glauconitic sands and sandstones form layer- and lens-shaped bodies up to 5 meters thick and extend over significant areas. Typically, glauconite occurs in small amounts in the rocks from trace quantities up to 8-10%, and higher concentrations are recorded much less frequently.

The composition of the clastic material of the glauconitic sands of the Kainarbulak Formation includes 27 different minerals. Psammitic clasts are usually irregular in shape and poorly or partially rounded. The surface of some grains is covered with a film consisting of iron hydroxides.

The primary rock-forming minerals are quartz (ranging from 26.49 to 44.36%), glauconite (from trace amounts up to 27%), and feldspars (from 4.38 to 17.37%). Most samples contain a significant content of siliceous rock fragments – from 3.82 to 12.43%.

Fragments of other rocks, such as argillites, quartz-mica schists, are in much less abundant – from fractions of a percent to 1.63%. Only two samples contain higher amounts (6.09 and 11.52%, respectively). Fragments of rocks are typically found in coarse- and medium-grained fractions.

In addition to mineral components, there are phosphatized fragments of marine vertebrate bones, shark teeth, and coprolites. The size of the phosphate components varies within 0.2-0.5 mm, with some specimens reaching 0.7-1.0 mm. Their color is typically brown to dark brown, although gray, dark gray, and whitish varieties occur less frequently. The dominant morphologies of coprolite grains are rod-shaped and rounded-oval to egg-shaped.

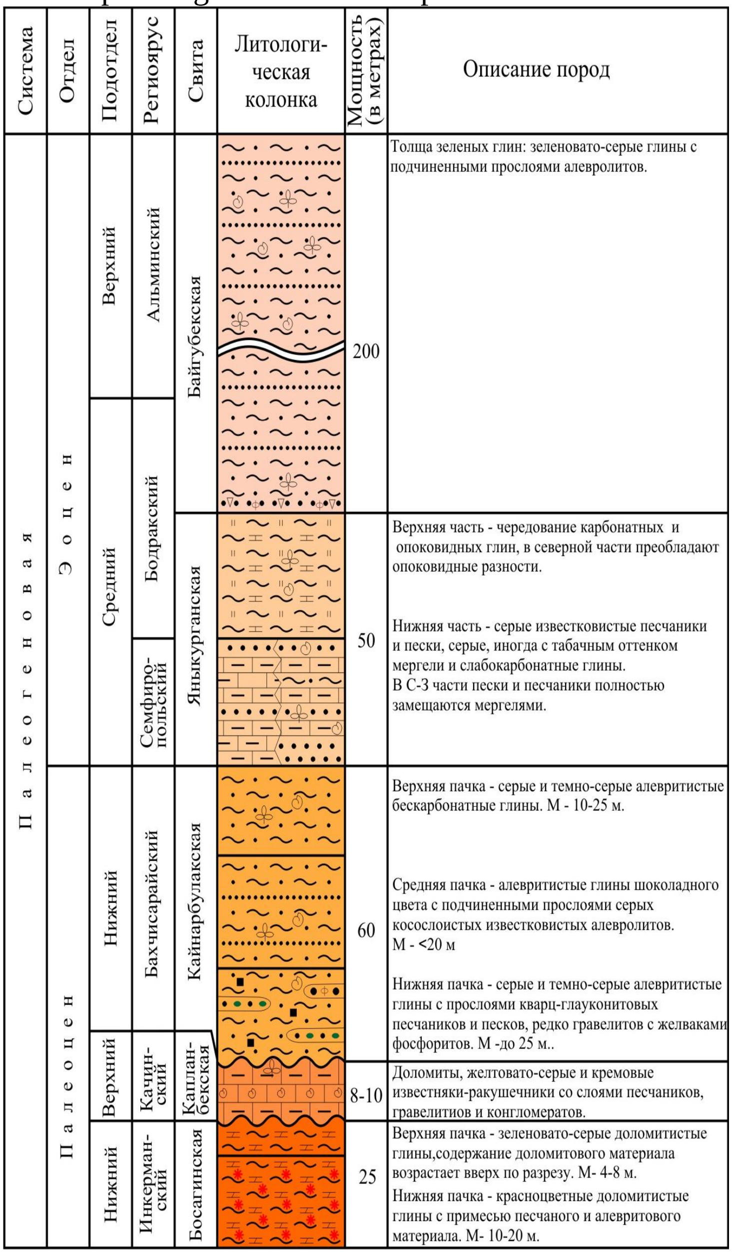

Fig. 1 - Generalized lithological-stratigraphic column of the Kainarbulak Formation deposits in the Karatau Range and Syr Darya Depression

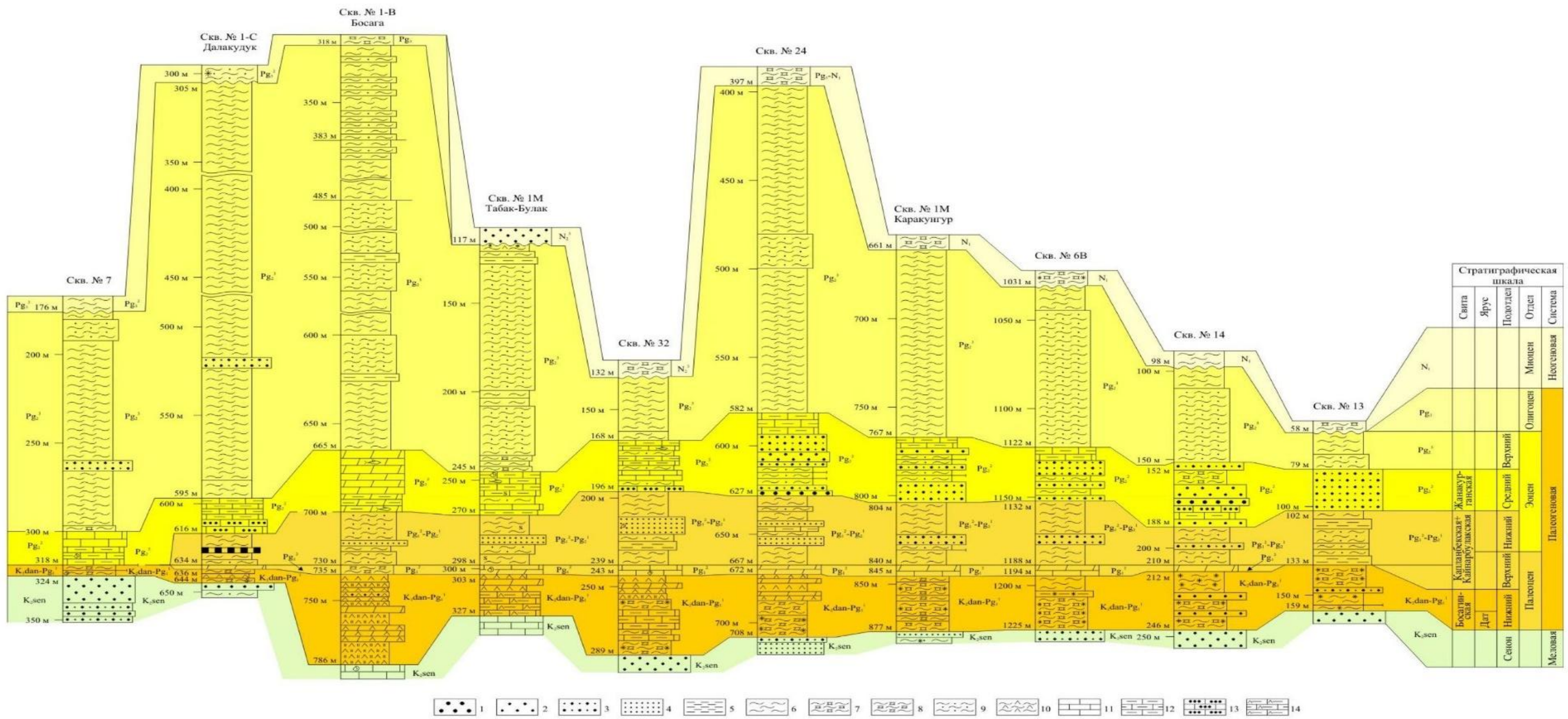

Fig. 2. Geological cross-section of the Kainarbulak Formation along the profile from Borehole No. 7 to Borehole No. 13

Legend: Lithological rock types: 1 – gravelites, 2 – sandstones, 3 – sands, 4 – siltstones, 5 – argillites, 6 – clays, 7 – calcareous clays, 8 – dolomitic clays, 9 – sandy clays, 10 – clays with anhydrite interbeds, 11 – limestones, 12 – clayey limestones and marls, 13 – sandy limestones, 14 – clayey limestones with anhydrite interbeds, 15 – dolomites, 16 – clayey dolomites, 17 – dolomites with anhydrite interbeds, 18 – anhydrites, gypsums, 19 – anhydrites with dolomite interbeds, 20 – oil shales. Diagenetic formations: 21 – silicification, 22 – iron oxides and hydroxides, 23 – glauconite. Organic remains: 24 – fauna, 25 – fish imprints. 26 – rock layers that do not fit into the column scale. Layer boundaries: 27 – conformable boundaries, 28 – erosional boundaries.

The cement is predominantly clayey and clay-carbonate, and much less often siliceous.

Glauconitic sands and sandstones containing variable amounts of volcanogenic ash material are quite common. For example, in the Burgem area, dense, evenly grained tuffaceous sandstones of a greenish-gray color with a rough fracture are developed. The rocks are strongly weathered and fractured, with cracks filled with calcite. The most widespread are medium-grained varieties of these rocks. The structure is psammitic in combination with vitriclastic. Lamination is faint, represented by thin, horizontal layers. The terrigenous material is well sorted, sub-rounded to well-rounded. The grain size of the psammitic material ranges from 0.2 to 0.5 mm.

Origin of glauconite. It has been established that elevated concentrations of glauconite are confined primarily to facies of relatively coarse sediments of the outer shelf and upper part of the continental slope, particularly in regions with high biological productivity of waters and intensive accumulation of organic matter. Glauconite is formed in areas with significantly reduced sedimentation rates, at the sediment-water interface, where it is commonly associated with organic matter [5, 9].

In terms of iron content, glauconite-bearing layers are classified as economic-grade ironstones, although they are rarely exploited for metal extraction. A generalized diagram of the distribution of diagenetic iron minerals in shelf sediments, including glauconite, is shown in Figure 3 [5].

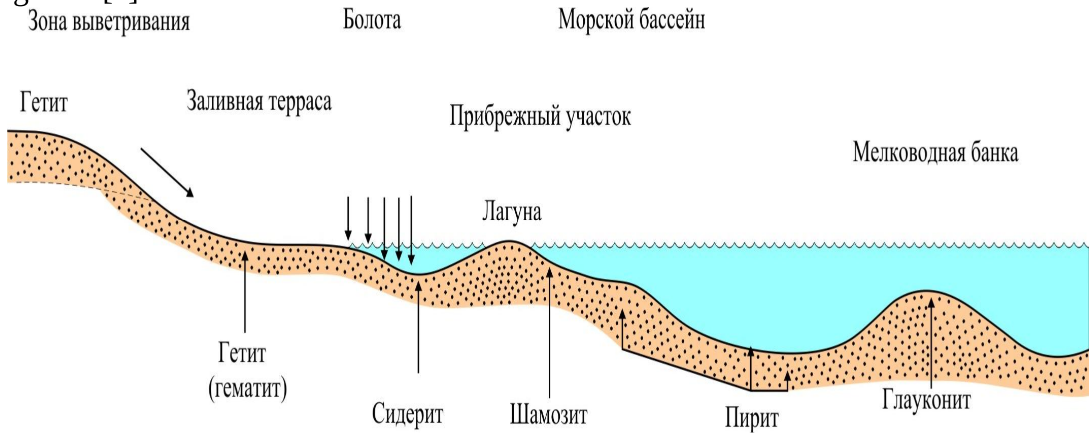

Fig. 3 - Schematic cross-section illustrating various environments where diagenetic iron minerals may form

Geochemical and chemical composition data suggest that glauconite forms at low temperatures in an environment that is neither strongly oxidizing nor reducing. The optimal depths for glauconite formation are belived to range between approximately 50 and 1000 meters. Other conditions favorable to glauconite formation include high mobility of bottom waters and relatively low temperatures.

However, these parameters are difficult to determine precisely, as glauconite is stable in seawater and can be transported within the marine environment. As a result, it can occur in a dispersed form in marine mudstones, in clean, well-sorted cross-bedded shallow-water sands, or as a minor component in turbiditic deposits in basins.

There is considerable disagreement about the nature of the chemical reactions leading to the formation of glauconite and the parameters controlling this process. It is generally accepted that glauconite is formed by the transformation of degraded smectite or illite layers into more ordered mixed-layer structures. However, recent observations suggest that glauconite neoformations may originate within pore spaces [6, 7]. Most likely, glauconite has of a polygenetic nature.

Morphology of glauconite grains. Glauconite occurs as soft grains (hardness 2-3) with bright grass-green, yellowish-green and greenish-blue coloration. It is found in sandstones and sandy-clayey rocks, typically ranging from 0.1 to 0.5 mm in size (Fig. 4). Their shape is mostly irregular, angular, due to fracturing of primary grains and their subsequent disintegration into smaller fragments. Only a few grains display ideal rounded or oval morphologies.

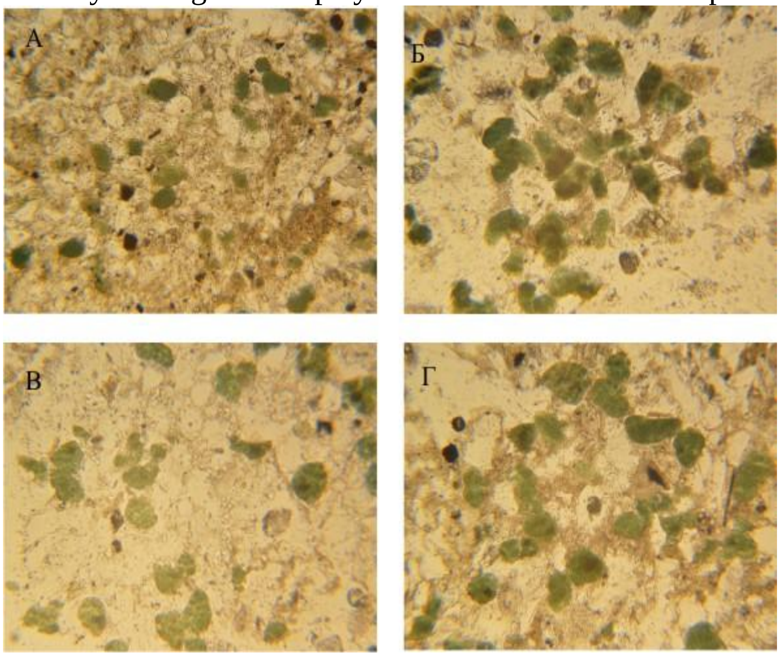

Fig. 4. Glauconite grains in fine-grained sandstones of the Kainarbulak Formation
A – Sample No. 175, Borehole No. 32, depth interval 235 m; B – Sample No. 579, Borehole No. 24, depth interval 653 m;
C – Sample No. 454, Borehole No. 6v, depth interval 1165 m; D – Sample No.387, Borehole No. 14, depth interval 200 m;
Magnification 40^X, nicols are parallel.

Quartz-glauconite aggregates cemented by iron hydroxides are frequently observed. Occasionally, glauconite forms intergrowths on the surface of quartz fragments, forming "hedgehog-like" structures. In some clasts, voids are present, with walls commonly covered with limonite. The grains are relatively clean, with rare and thin inclusions. Some individual grains contain a dense black speckling along their edges or dispersed throughout the grain. Conformable and incorporation structures associated with the intrusion of quartz or feldspar fragments into glauconite grains are occasionally present. The structure of glauconite is colloform. Under crossed nicols, it appears as a fine-aggregate or scaly-aggregate texture, while the characteristic green coloration remains visible. Some grains display high interference color, which is associated with epigenetic processes. Among the secondary minerals, gypsum is rarely observed (in isolated samples) in the form of grains of prismatic habit. The results of X-ray diffraction (XRD) structural analysis of glauconite grains and associated minerals are presented in Table 1.

Table 1 - Main X-ray diffraction lines of glauconite and associated minerals

No.No. p/p	Mineral	Jrel	dhkl, A	Jrel	dhkl, A	Jrel	dhkl, A
1	Glauconite	100	10,1	100	3,59	30	4,53
2	Montmorillonite	100	12-15	60	5,01	80	4,50
3	Kaolinite	100	7,18	100	3,58	100	1,488

4	Goethite	100	4,18	30	2,69	25	2,45
5	Quartz	100	3,34	35	4,25	17	1,817
6	Calcite	100	3,03	34	1,872	29	3,85
7	Gypsum	100	7,56	57	3,06	51	4,27

In clarifying the question of the formation of glauconite grains, their morphology plays a significant role. It is determined, on the one hand, by the shape of the particles, and on the other, by the external features of their surface. Undoubtedly, in morphological studies it is also necessary to take into account the color, the presence of cracks and the material filling them, transparency and other typomorphic features determined during the mineralogical analysis. It was the morphology of the grains that played a notable role in the emergence of numerous hypotheses regarding the origin of the material. The wide variety of glauconite morphotypes can generally be divided into the following categories: a) spheroidal grains or microconcretions, sometimes with inclusions of another mineral; b) veinlets, coatings, spots, cement, etc., filling and cementing cracks, pores, cavities within grains of other minerals or fossil skeletons [8]. The primary and the most thoroughly studied form is undoubtedly the first type, whereas the second type is established only in the presence of granular glauconite (see Fig. 5.6).

Opinions on the origin of fine-grained glauconite-bearing material vary. Some researchers consider it to be authigenic, while others believe that fine-grained glauconite is formed as a result of destruction, reworking and peptization of granular sediments. The latter can be proven by experimental studies conducted by Vermund [7, 8], which demonstrated that glauconite, which has a low hardness of 2, is easily abraded and broken down to the size of pelitic particles during the reworking process. Apparently, this is how glauconitic clays are formed. According to I.V.Nikolaeva [9], the study of fine-grained glauconite is of great importance for clarifying the genetic characteristics of its formation. Morphometric analysis of glauconite grains can significantly contribute to the understanding of facies conditions of minenal formation. The variety of glauconite grain morphologies collected from different localities testifies to the conditions of its formation in the uppermost layers of marine sediments. Being a soft and plastic mineral, glauconite under increasing overburden pressure, gradually taking on a wide range of forms as sediments accumulation , is easily deformed.

The morphology of glauconite grains is also affected by sediment reworking and chemical processes. Reworking results in destruction of primary grains and rounding of the formed fragments. In contrast, chemical processes lead to the formation of new minerals due to the transformation of glauconite. Evidence of these processes can be numerous indentations, a large number of flattened and angular fragments, as well as a relatively small number of well-rounded grains. However, it has been proven (I.V. Nikolaeva, [9]; M.Yu. Kameneva [8]) that glauconite forms through layer-by-layer crystal growth mechanism. Therefore, the dominant crystal form of glauconite would be expected to be spheroidal.

Two main crystal morphologies of glauconite can be distinguished (Fig. 5 C, D):

1. Plates or flakes, thin, flat, mostly isometric and elongated. Their edges are usually irregular and highly undulating, while straight, linear ones are much less common. This form of crystals is typical of group I glauconite grains, i.e. those with a fewer expandable interlayers and a more ordered crystal structure.

2. Small isometric and elongated scales and their aggregates, with an average size of about 0.1 µm, and the largest ones reaching up to 0.5 µm. This form of mineral crystals is characteristic of the II and III groups of glauconite grains, i.e. more altered, montmorillonized varieties.

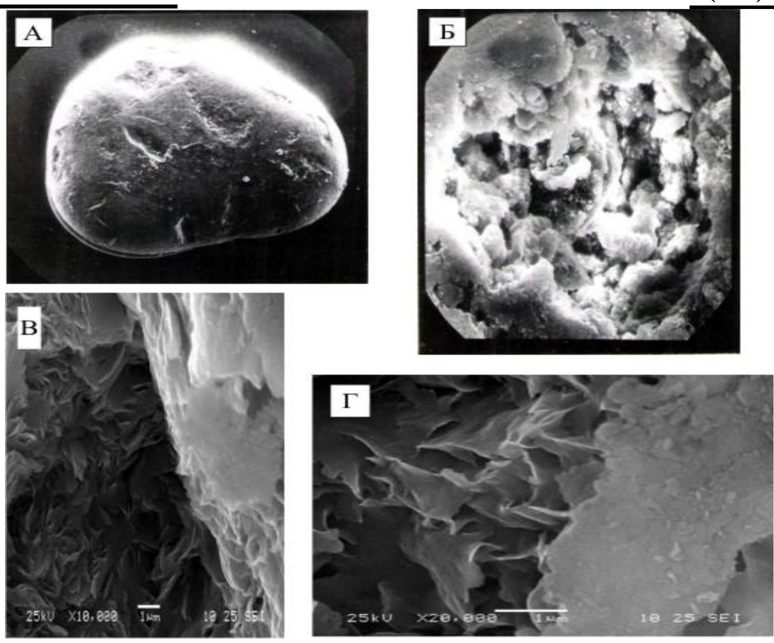

Fig. 5 - Electron microscopic images of the surface of glauconite grains of the Kainarbulak suite

A - a grain of dark green glauconite with a glossy surface with traces of dents, group I, magnification 180^x; B - a grain of glauconite with a rough matte surface, group II, magnification 1000^x; C, D - tablets and petals of the smallest glauconite crystals, respectively, at magnifications of 2000^x and 4000^x.

Based on the above, it follows that the glauconites of the Kainarbulak Formation have a heterogeneous and disordered structure, determined by the presence of swelling interlayer spaces.

It should be noted that the paleogeographic conditions of accumulation of glauconite sands of the Kainarbulak Formation (Pgl-2kn) are characterized by a new stage of sedimentation caused by a new transgression of the Neotethys Ocean from the southwest at the end of the Paleocene. The transgression occurred rather rapidly, and by the middle Eocene, the marine basins had reached the same extent as those during the Maastrichtian. The Neotethys had a limited connection to the global ocean, therefore the main factors controlling sedimentation were wave-related processes. According to classification, the sedimentary basin refers to "shallow marine environment dominated by wave and storm regime". The most intensive transport and deposition of sediments in such settings occurs during storm seasons. In modern analogues of such seas, moderate storms affect sediments down to depths of 100 meters, while strong "winter" storms influence depths up to 200 meters. Moreover, large waves cause the process of downwelling – the downward movement of surface water to deeper layers. The resulting unidirectional bottom currents flow slightly obliquely offshore or parallel to the shoreline.

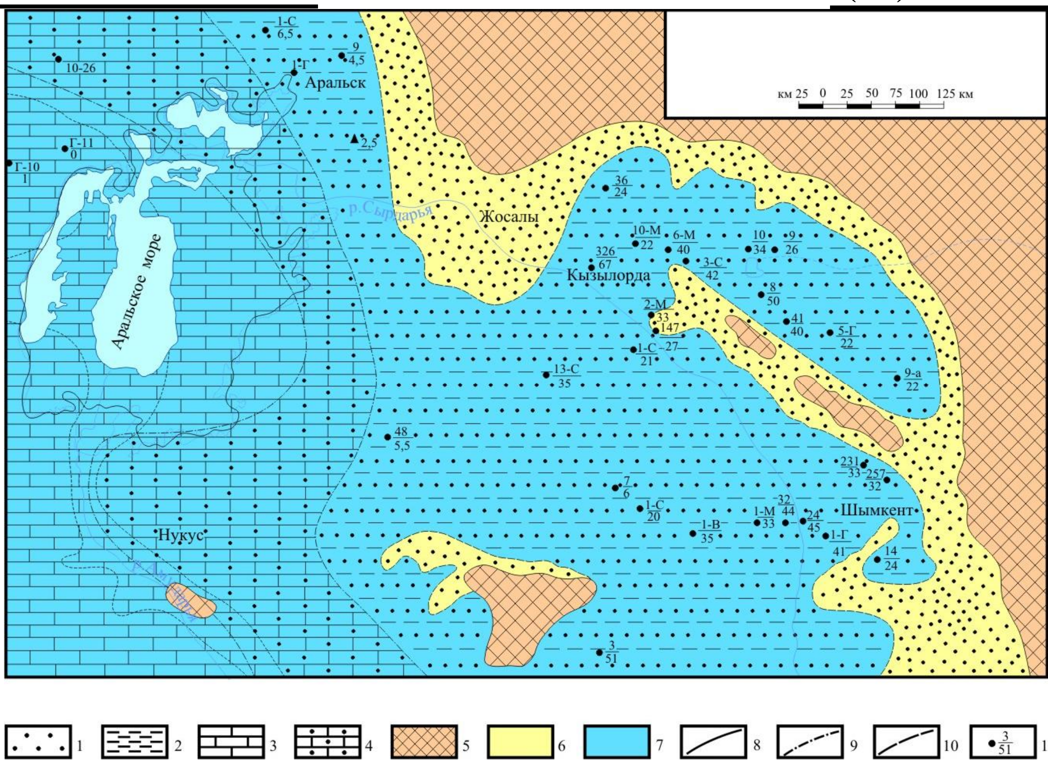

Fig. 6 - Paleogeographic map for the end of the Paleocene – beginning of the Eocene of the Karatau Range, the Syr Darya Depression and the East Aral Basin

Legend: Lithological rock types: 1 - sandstones, gravelites, conglomerates, 2 - siltstones, argillites, clays with subordinate sandstone interlayers, 3 - limestones, 4 - sandy and argillaceous limestones. Paleogeographic settings: 5 - areas of provenance (land), 6 - coastal-marine plains, 7 - shallow sea (shelf zone). Boundaries: 8 - paleogeographic settings, 9 - facies complexes, 10 - subsequent erosions. 11 - wells (numerator - well number, denominator - thickness of deposits).

During the late Paleocene and early Eocene, most of the adjacent land represented peneplained, slightly elevated plains with intensive weathering processes, with isolated lacustrine-alluvial freshwater or slightly saline basins. Therefore, the input of clastic material was relatively low. In the section of the Kainarbulak Formation, clays and siltstones dominate with a subordinate amount of sands and sandstones. Near river mouths, on the contrary, sandy material was predominantly deposited. The sediments of the Kainarbulak Formation accumulated within a fairly shallow shelf zone. Moreover, clay-carbonate deposits with interbedded sands were formed on the outer shelf, whereas the inner shelf was characterized by quartz and quartz-glauconitic sands, siltstones and clays (see Fig. 6). At a considerable distance from the shoreline, the proportion of terrigenous facies gradually transitioned into terrigenous-carbonate facies, with a progressive decrease and eventual disappearance of terrigenous material in the sediments. Further offshore, sediments became increasingly calcareous, transitioning into calcareous sandstones, sandy limestones, clayey limestones, marls). The climate during this time was relatively warm.

In facies terms, the Kainarbulak Formation is divided into sandy, mixed sandy-muddy, and muddy shelf facies.

A block diagram showing the facies conditions of the shelf with a predominantly stormy regime is shown in Figure 7.

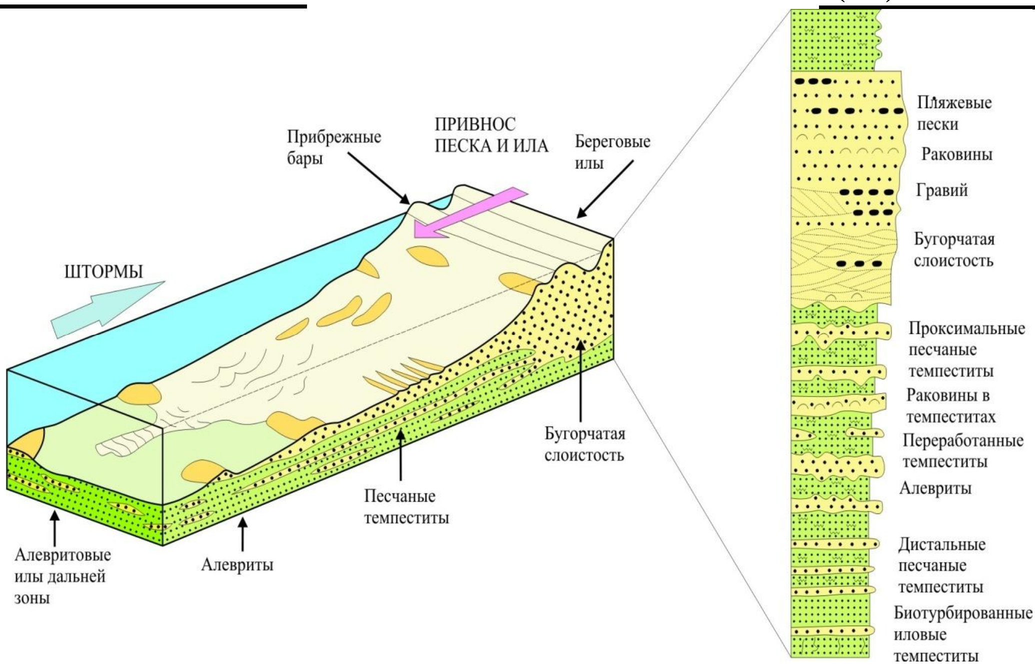

Fig. 7 - Sedimentation model and typical section of a shelf with a predominant storm regime

The sediments of the sandy facies in the outer zone are represented by quartz and quartz-glauconite sandstones and, much less frequently, gravelites. The most widespread textures in these deposits are symmetrical and asymmetrical ripple marks, as well as hummocky cross-stratification. The morphology of accumulative sandy bodies is the most diverse; however, longitudinal ridges and various bars predominate. Their size also varies widely from a few meters to several tens of kilometers in length, with thicknesses ranging from 1 to 15-20 meters.

Analysis of changes in the content of the major minerals and grain-size distribution indicates that during the formation process the glauconite-bearing beds experienced two reworking events. Moreover, the first was less intense than the subsequent one. During reworking, there was an increase in the coarse- and medium-grained sand fractions with a decrease in the fine sand, silt and clay fractions. At the same time, fragmentation and mechanical sorting of grains occurred. The result was a decrease in the glauconite content in the 0.5-0.1 mm fraction, and a sharp increase in the 0.05-0.01 mm fraction. These processes occurred most intensively during the second, stronger and more prolonged reworking event.

Apparently, glauconite-bearing beds occasionally emerged above the water surface during reworking, as in some samples there are no heavy mineral fractions except for the limonite-hematite group. This is accompanied by an increase in the glauconite content. As is well known, limonite is formed in the oxidation zone under surface or near-surface conditions.

In conclusion, it should be noted that the prospects of the area are by no means limited to the identified glauconite deposits. Further exploration is likely to reveal new, larger, and richer accumulations of this mineral resource.

Summarizing the data on the stratigraphic and tectonic settings of glauconite-bearing horizons, it is necessary to emphasize a key regularity of their spatial and stratigraphic distribution – namely, confinement to the transgressive basal layers of the marine Paleogene sequence, which in some cases is represented by the Paleocene-Lower Eocene Kainarbulak Formation, and in others – the Upper Paleocene Akzhar Formation. The thickness of the glauconite horizon, represented by sands and sandstones and containing a certain amount of nodular phosphorites, ranges from a few meters to 10-12 meters in different sections. In addition, the thickness increases from the southern areas of glauconite distribution (the Turkestan-Kentau region) in the northern direction, toward the flanks of the Lower Syr Darya Uplift. The capacity of the horizons also changes in local areas depending on the complex relief of the pre-Paleogene erosional surface. Consequently, to select sites most favorable for exploration and further development of glauconite deposits, sufficiently detailed geological investigations within the zone of its distribution are necessary.

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ГЛАУКОНИТОНОСНОСТЬ ПАЛЕОГЕНОВЫХ ОТЛОЖЕНИЙ ЮЖНОГО КАЗАХСТАНА

Аннотация. В статье рассматривается глауконитоносность палеогеновых отложений Сырдарьинской впадины. Обобщены материалы комплексного изучения вещественного состава, условий формирования глауконитовых песчаников приуроченных к палеогеновым отложениям впадины. Описаны закономерности распределения в разрезе и пространстве продуктивных горизонтов глауконита. Следовательно, определен цикл этапов осадкообразования палеоценового и эоценового времени, отражающий направленность эволюции палеогенового осадочного бассейна исследуемого района, в дальнейшем способствующий возможности для разработки территории в новой стратегии прогнозирования поиска перспективных залежей, проявлений и месторождений глауконита.

Ключевые слова: глауконит; Кайнарбулакская свита; стратиграфия; морфология зерен; палеоцен; шельфовые фации; Южный Казахстан.

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ОҢТҮСТІК ҚАЗАҚСТАННЫҢ ПАЛЕОГЕН ШӨГІНДІЛЕРІНДЕГІ ГЛАУКОНИТТІҢ ТАРАЛУЫ

Аңдатпа. Мақалада Сырдария ойпатының палеогендік шөгінділерінің глауконитоздылығы қарастырылады. Палеогендік шөгінділермен шектесетін глауконитті құмтастардың түзілу жағдайларын, заттық құрамын кешенді зерттеу материалдары жинақталды. Глауконнттің өнімді горизонттарының бөлімі мен кеңістігінде таралу заңдылықтары сипатталған. Демек, зерттелетін аймақтың палеогендік шөгінді бассейні эволюциясының бағытын көрсететін палеоцендік және эоцендік уақыттың жауын-шашын кезеңдерінің циклі анықталды, әрі қарай перспективалы глауконит кен орындарын, көріністері мен кен орындарын іздеуді болжаудың жаңа стратегиясында аумақты игеру мүмкіндігіне ықпал етеді.

Кілт сөздер: глауконит; Қайнарбулак свитасы; стратиграфия; дән морфологиясы; палеоцен; шельфтік фациялар; Оңтүстік Қазақстан.