Bentonite clays of the Central Kyzylkum and their material composition and engineering and geological properties, Uzbekistan

M Zakirov[1*], *I* Agzamova[1], *N* Normatova[1], *D* Begimkulov[1], *G* Ochilov[1] and *M* Juliev[2,3,]

[1]Tashkent State Technical University, University street 2, 100095 Tashkent, Uzbekistan
[2] "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Kori Niyoziy street, 39, 100000, Tashkent, Uzbekistan
[3]Turin Polytechnic University in Tashkent, Little Ring Road street 17, 100095 Tashkent, Uzbekistan

Abstract. The authors consider the conditions of occurrence, composition, and properties of the Eocene clays of the Paleogene, common in the northern part of Tamdytau, which were the foundation of the structures. The present study of the authors is aimed at studying the problem of the long-term interaction of Eocene clays with water and identifying the features of changes in their material composition and properties; the variability of the composition, properties of clays, and the reasons for these changes are analyzed. The main factors determining the differences in the composition and properties of Paleogene clays are: genetic - different salinity of the sea basin or less saline at which the reservoirs were connected with the open sea; zonal-climatic - different humidity and other physical properties. So far, no unified methodology has been developed for predicting the composition and properties of clays at the base of structures when interacting with water. The results of granulometric analysis established that Paleogene clays are classified as highly dispersed soils containing more than 55% of clay particles. Analysis of the diffraction pattern showed that the clay fraction of the studied samples contain montmorillonite (M), hydromica (H), kaolinite (K), mixed-layer formations of the montmorillonite-hydromica series.

1 Introduction

It is known that clays and clayey soils have a specific feature to change their properties when interacting with water, i.e., exhibit structural instability. In many cities and towns, these soils create serious problems leading to accidents and catastrophes of structures interacting with these soils, subject to urbanization and technogenic development [1–4].

Eocene clays of the Paleogene are widespread in the Central Kyzylkum and are located within the depths of the active zone of the foundations of structures in the territories of cities and towns such as Zarafshan, Muruntau, Uchkuduk, Tamdybulak, Mingbulak, etc [2,5,6]. A significant problem for construction is swelling clays, structurally unsTable soils, which change their building properties when the humidity changes. With the water

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[*] Corresponding author: mukhiddinjuliev@gmail.com

saturation of clays and their long-term interaction with water, compressibility increases and strength decreases, and almost all other properties change. So far, no unified methodology has been developed for predicting the composition and properties of clays at the base of structures when interacting with water [3,5,7]. Methods for predicting the strength of clays based on their short-term or long-term soaking, used in design and survey organizations, cannot provide reliable values of strength indicators, because do not take into account changes in the composition and properties of clays that occur over a long time of interaction with water. The present study aims to study the problem of the long-term interaction of Eocene clays with water and to reveal the features of changes in their composition and properties [5,7].

2 Materials and methods

2.1 Study area

In general, Paleogene clays are distributed throughout the territory of the Central Kyzylkum. The Early Eocene is characterized by a slight increase in the open shallow sea basin, in which clays and marls were formed [5,7]. The land was preserved only in the region of the Tamdytau mountains and northern Nuratau (Figure 1). Iron sulfide crystals (pyrite, marcasite) found in the Lower Eocene rocks indicate some contamination of the basin with hydrogen sulfide. A complex of organic remains indicates its connection with the Fergana and North Caucasian basins. In the late Eocene time, the transgression reached its maximum, small islands remained only in the eastern part of Tamdytau and northern Nuratau [4,8,9]. And the basin remained open and shallow with a depth of no more than 200 m. When analysing and changing the outlines of demolition areas and the general nature of sedimentation during the Cretaceous and Paleogene, it was revealed that the most significant transgressions in the Kyzylkums immediately follow the manifestation of folding phases and are probably due to them. Engineering-geological characteristics of Paleogene clays. Geological characteristics of the territory. We have analyzed the composition and properties of Paleogene clays during studies of seismic microzoning of cities and towns in Central Kyzylkum [5,7,10].

The swelling ability of clays is directly dependent on their fineness. Therefore, all monoliths and samples were subjected to granulometric analysis to determine the content of particles of different sizes as a percentage of the mass of the rock.

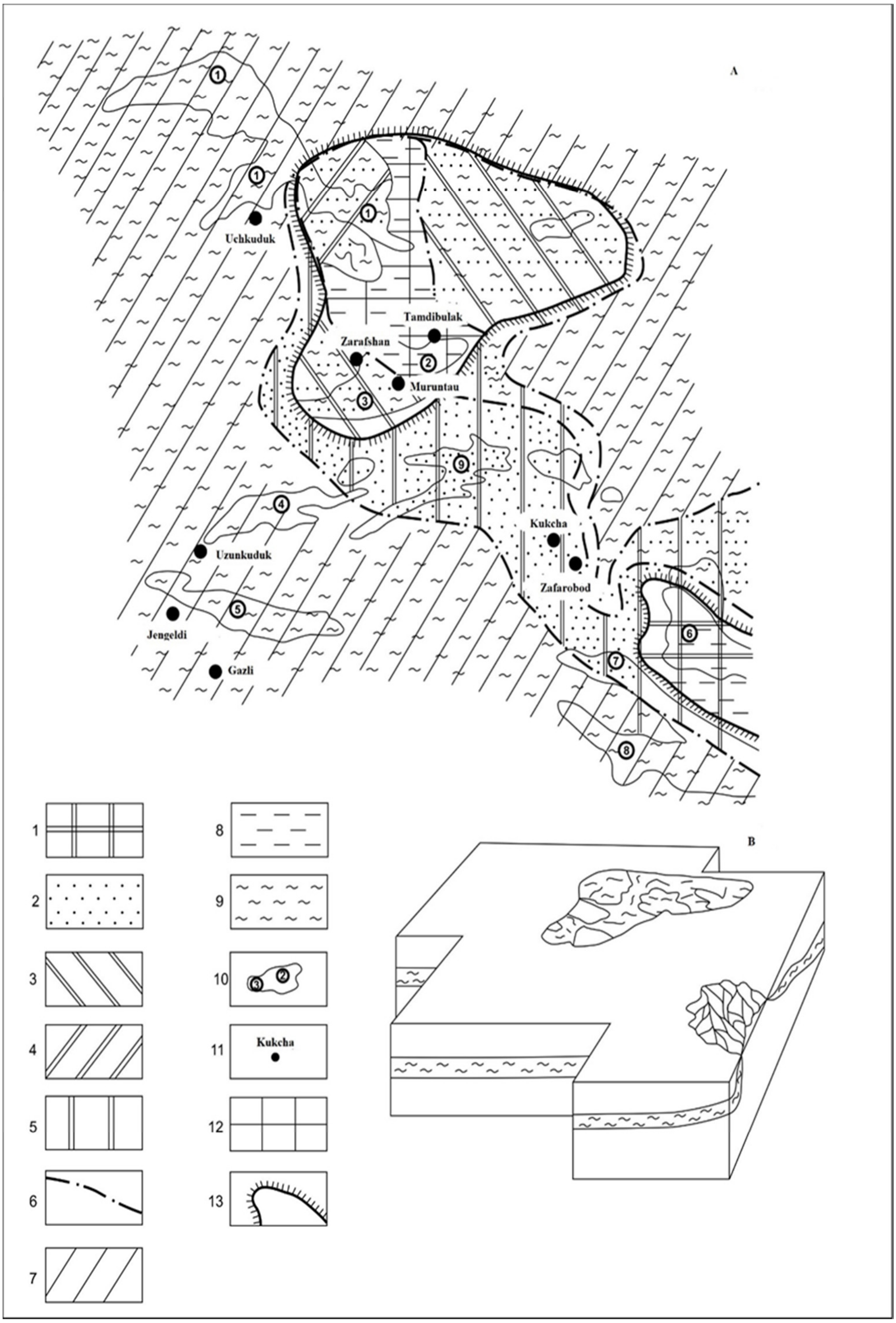

Fig. 1. Scheme of the lithological-paleogeographic setting of the Central Kyzylkum for the Early Eocene time.

A - scheme; B - sectional diagram. 1- low mountains; 2-siliceous rocks; 3-low plains; 4-hilly plains; 5-coastal-marine zone; 6-border of facies zones; 7-deep part of the shelf; 8 complex complex of sedimentary, metamorphic and igneous rocks; 9-siltstones, mudstones, clays, various shales; 10-Modern mountain structures; 11-settlements; 12-elevated plains; 13-borders of land and sea.

2.2 Methods

To establish the influence of hypergene processes on the quantitative content of individual fractions - from the modified part to the unchanged part, a combined method was used with the addition of pyrophosphate, proposed by M.F. Vikulova. As a result of the analysis, fractions larger than 1.0 mm were isolated; 1.0-0.5mm; 0.5-0.25mm; 0.25-0.1 mm (sieve method); 0.1-0.05mm; 0.005-0.001 mm or less (by pipetting method). Swelling Eocene clays of the study area are mainly divided into 2 varieties according to their granulometric composition: Fine clays - the content of the clay fraction is more than 50%; Coarse clays - the content of the clay fraction is from 25 to 50% (Figure 2).

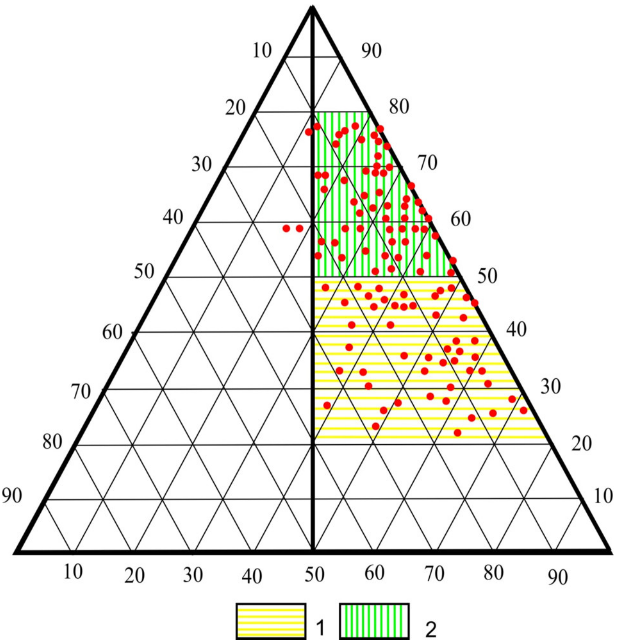

Fig. 2. Results of granulometric analysis of Paleogene clays of northern Tamdytau. 1 - clays of the lower horizons - dispersed; 2 - clays of the upper horizons – coarse.

3 Results and discussion

In most cases, coarsely dispersed clays are presented in the upper part of the section, where they are enriched in carbonate, sulfate, and water-soluble salts under the action of secondary (superimposed) processes, which significantly change the fractional composition of clays. This occurs through the aggregation of primary, smaller particles, which was repeatedly confirmed after the removal of aggregating agents by chemical action (treatment of clays with acetic or weak 3.0-5.0% hydrochloric acid), due to which the dispersion of clays increased, and they passed into the category of finely dispersed. Finely dispersed clays form part of the section (at a depth of more than 3.0 m), where their original appearance has been preserved.

Thus, a change in the clay fraction (in the direction of increase) is observed up to a depth of 2.5-3.0 m. Below, the clay retains its original fine dispersion (Figure 3). The aforesaid is confirmed by compiling histograms of the granulometric composition of Eocene clays of Northern Tamdytau, which facilitates the readability of digital data and their genetic explanation. They are of no small importance in studying the formation of water-physical properties.

According to the analysis of histograms, less sorted clays with a two- and sometimes three-vertex graph, characteristic of surface horizons (up to 3.0 m), and well-sorted clays with a single-vertex graph, with a maximum clay fraction, characteristic of the lower layers, were established.

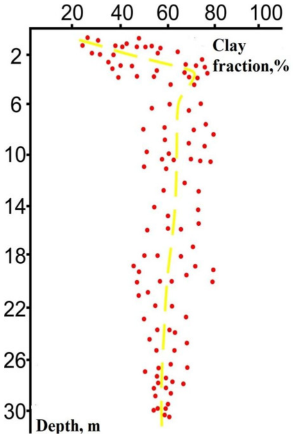

Fig. 3. Changes in the clay fraction of Paleogene clays in depth.

Thus, the Eocene clays of northern Tamdytau belong to the category of both finely dispersed and coarsely dispersed, which is confirmed by histograms. The predominance of unimodal graphs indicates the formation of clays in calm sedimentation conditions.

Semi-minerality and finely dispersed clays require a special approach to their study. This feature poses complex questions for researchers, which can only be solved with the help of thermal, X-ray, electron microscopy, and other modern methods.

At this stage of the study of clay minerals, one of the main methods for accurate diagnosis of the complex composition of clays is X-ray analysis. Analysis of the diffraction pattern showed that the clay fraction of the studied samples contain montmorillonite (M), hydromica (H), kaolinite (K), mixed-layer formations of the montmorillonite-hydromica series. Of the non-clay minerals, gypsum, quartz, feldspars, and calcite were identified (Table 1).

Montmorillonite, the main rock-forming clay mineral in the study area, is widespread. Refinement of the complex morphological features of montmorillonite makes it possible to determine their physicochemical and other properties. This explains the great interest in the exact diagnosis of the structure and varieties of this mineral by X-ray diffraction. The difficulty of a complete study of montmorillonite is due to its fine dispersion, and sometimes poor crystallization, which gives a rather poor diffraction pattern, consisting mainly of a series of basal reflections (001) and two-dimensional diffraction bands (h, k). The second, no less important circumstance that complicates the study of montmorillonites is that they have an exceptionally large range of variations in crystal chemical and structural characteristics, often combined in crystals of one mineral.

Table 1. The quantitative content of minerals in clays according to X-ray analysis.

№ of samples	Depth of sampling, m	Mineral content, %							
		H	**M**	**K**	**H/M**	**Quartz**	**Feldspar**	**Ca, CO_3**	**Gypsum**
Upper horizon									
1	1.0	10	45-50	5	-	5	Mica	20-25	10
4	2.5	10	30	5	-	5	Mica	Mica	50
6	2.5	5	35-40	5	-	5	-	Mica	50-55
8	2.0	5-10	50-55	5	-	5	-	Mica	30-35
9	2.5	5-10	30-35	-	5	Mica	Mica	Mica	55-60
28	2,0	15	40-45	15	-	10-15	Mica	10-15	Mica
	30	15	65	15	-	5	Mica	Mica	-
	1.5	10	55-60	5	-	5-10	Mica	Mica	5-10
Lower horizon									
15	3.5	15	60	15	-	5	Mica	Mica.	-
	3.5	15	60-65	10	-	5-10	Mica	-	-
	4.0	5-10	55-65	Mica	5-10	15	5	5	-
66	6.0	5	90	15	-	-	-	-	-
64	7.0	5	90	5	-	-	-	-	-
62	10.0	5-10	70	Mica	-	-	-	-	-
	12.0	10	70	10	-	-	Mica	-	-
35	19.0	10	70-75	10	Mica	Mica	Mica	-	-
	20.0	15	60	15	-	5	-	-	-

Chemical analysis is the most accurate method for determining the composition of Eocene clays. In addition, the determination of the composition of exchangeable cations in saline rocks is associated with methodological difficulties, since the interaction of Eocene clays with salt solutions-reagents results in partial dissolution of CaCO3, MgCO3, and CaSO42H2O salts contained in the rock. And it is not always possible to distinguish calcium carbonate or sulfate from exchangeable calcium.

The clays studied by us are complex compounds of various clay and non-clay minerals, the ratio of which varies from 2.5-3.0 m and increases from 25.5 to 50.5%. With increasing depth, its content stabilizes within 50-60% (Table 2, Figure 4).

Al2O3 content reaches 15.6%. It should be noted that the increased content of F2O3 (up to 8%), with the allowable limit according to A.G. Betekhtin, not more than 5% for clays from clay minerals of the montmorillonite group, associated with the presence of free iron minerals (jarosite, limonite, magnetite and etc.). CaO (in some samples) contains up to 22.4%. On the whole, its content fluctuates over a wide range, from 0.5 to 16%; CO2 - from 0.10 to 9.48, rarely 11.44 - 12.32; SO3 - from 0.26 to 12.82, rarely 14.35-22.03%. The content of CaO, CO2, and SO3 in clays indicates the presence of carbonates (calcium, dolomite, fragments of fauna) and gypsum crystals and placers. The formation of carbonate content and gypsum content is a consequence of physical and chemical processes in arid climatic conditions. Their influence can be determined by the decrease in content with depth.

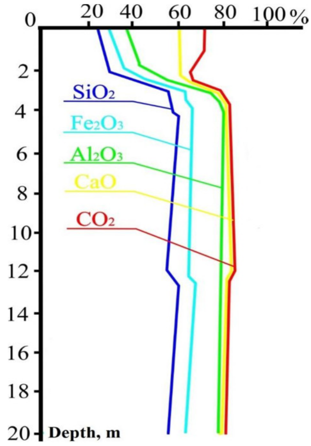

Fig. 4. Changes in the chemical components of Paleogene clays of Northern Tamdytau.

Table 2. The average content of components characteristic of the Eocene clays of Northern Tamdytau, in%.

Number of definitions	**Depth of sampling**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**$-CO_2$**	**$^-SO_3$**
84	1.0	25.5	7.15	4.16	0.16	21.3	1.05	1.44	1.0	11.4	11.3
90	1.5	28.1	7.15	3.64	0.29	22.4	1.51	1.4	1.23	8.4	9.1
70	2.0	31.0	7.8	6.15	0.39	15.4	1.51	1.6	1.4	4.4	4.8
76	2.5	40.0	9.7	5.2	0.39	9.8	1.52	2.16	1.3	2.5	2.1
81	3.0	55.6	12.0	7.3	0.58	1.4	1.51	2.6	1.4	2.16	2.5
85	3.5	56.8	13.6	7.8	0.68	1.4	1.5	2.2	1.6	1.6	4.3
70	4.0	60.59	14.9	8.1	0.39	2.3	1.4	2.2	1.59	1.3	2.1
57	5.0	59.8	15.1	6.8	0.98	2.3	2.15	2.16	1.6	1.0	1.44
57	10.0	57.8	15.6	7.9	0.78	2.8	2.02	2.4	1.7	0.8	1.4
57	15.0	58.6	14.3	7.3	0.58	1.4	1.8	2.41	2.02	0.55	0.9
57	20.0	57.1	15.9	7.8	0.39	2.3	2.28	2.41	2.25	0.8	1.1

The clays of the Central Kyzylkum are distinguished by a significant content of MgO (0.5-3.5%), TiO2 (0.19-0.98%) and Na2O (1.05-2.15%). This is due to the content of exchangeable cations in clays, as well as the presence of magnesian silicates, palygorskite, in the form of impurities, which is due to arid lithogenesis.

To study the content of salts in Eocene clays and their changes with depth, an analysis of the water extract was carried out. Based on its results, the probable composition of salts and their content were calculated (Table 3). CaSO4 salts (from 0.3 to 9.1%) NaSO4 (from 0.2 to 3.8%), and MgSO4 (from 0.64 to 2.27%) prevail over calcium bicarbonate Ca (HCO3)2 (from 0.13 to 0.36%) and sodium chloride NaCl (from 0.1 up to 1.03%).

Thus, according to the result of chemical analysis, a decrease in the content of water-soluble salts of calcium sulfate, sodium, sodium chloride, and calcium, as well as bicarbonates with depth was established (Figure 5). This confirms the results of granulometric, X-ray, and other analyzes, according to which the surface clays are coarsely dispersed, and the lower ones are finely dispersed. We used this method mainly to establish the mineral composition of clays, and confirm the result of X-ray, thermal and other analyzes (Table 3).

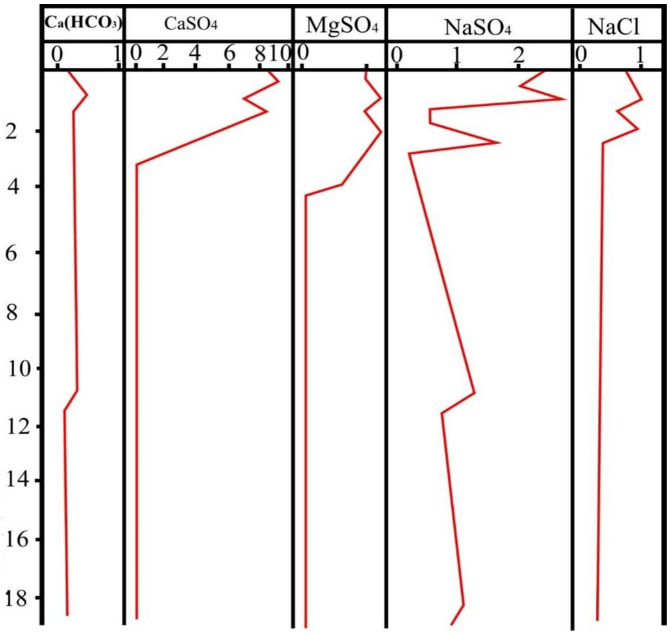

Fig. 5. The quantitative content of salts in the clays of Northern Tamdytau and their change in depth.

The studies of bedrock and weathered varieties of Eocene clays fully confirm the experimentally obtained deep geochemical transformations in the process of weathering, concerning both the liquid and solid phases. So, in the weathered varieties of Eocene clays, the $^{-2}$SO4 ion accumulates, and in the solid phase, pyrite disappears completely, oxide iron, gypsum, and jarosite appear, the content of amorphous silica increases, and the content of carbonates decreases. Gypsum and jarosite in the form of crystals and powder fill weathering cracks, and weathered clays acquire an ocher-brown color due to iron oxides. Their formation occurs due to the secondary salinization of Eocene clays in the condition of a weak water exchange capacity - various types of water entering the clays due to human activities and atmospheric precipitation. This leads to the accumulation of sulfate ions, and exchange reactions contribute to the accumulation of magnesium ions in pore waters.

Table 3. The average salt content of the water extract of Eocene clays of northern Tamdytau.

Number of definitions	**Depth. m**	**Ca $(HCO_3)_2$**	**$CaSO_4$**	**$MgSO_4$**	**Na_2SO_4**	**NaCl**
80	1.0	0.13	8.20	1.08	2.64	1.03
86	1.5	0.28	9.48	1.18	1.96	1.58
70	2.0	0.37	6.75	1.33	2.86	0.87
76	2.5	0.25	9.13	1.01	0.76	0.76
81	3.0	0.24	5.87	1.48	0.67	0.59
85	3.5	0.23	3.46	1.33	1.64	0.62
70	4.0	0.21	0.59	0.64	0.26	0.38
57	5.0	0.2	-	-	0.52	0.43
57	10.0	0.2	-	-	1.01	0.36
57	15.0	-	-	-	0.94	0.15
57	20.0	-	-	-	1.20	0.17

The content of exchangeable potassium is lower by 2.0–2.5 times in the strongly weathered parts of the Eocene clay section compared to the lower horizons, which is associated with its mobilization in the authigenic jarosite mineral. A comprehensive study of the material and disperse composition of the studied Eocene clays, from primary to their weathered varieties of the upper part of the section, indicate a close genetic relationship between them, in particular, the inherited high dispersion of Eocene clays. However, according to the degree and nature of structural bonds, clays differ sharply from each other. So, from bottom to top along the section of the studied Eocene clays, the nature of structural bonds changes from stabilization in the lower horizons. Where organic substances serve as a reliable stabilizer, coagulation-cementation bonds in the weathered varieties of the upper clay horizons. They are enriched with secondary salts, amorphous silica, iron oxides, and gypsum in the form of crystals and powders filled with weathering cracks. An analysis of sources and the results of our research indicates that the upper horizons are subject to physicochemical weathering due to the aridity of the climate than the lower horizons of Eocene clays.

4 Conclusions

1. Paleogene clays in the studied areas of cities and towns serve as the basis for engineering structures over a large area and often cause cracking, both on the surface and on buildings and structures.
2. The conducted studies of bedrock and weathered varieties of Eocene clays fully confirm the experimentally obtained deep geochemical transformations in the process of weathering, concerning both the liquid and solid phases. So, in the weathered varieties of Eocene clays, the $^{-2}$SO4 ion accumulates, and in the solid phase, pyrite disappears completely, oxide iron, gypsum, and jarosite appear, the content of amorphous silica increases, and the content of carbonates decreases. Gypsum and jarosite in the form of crystals and powder fill weathering cracks, and weathered clays acquire an ocher-brown color due to iron oxides.
3. Gypsum in Paleogene clays is characterized by reflections with an interplanar spacing of 7.57; 4.27; 3.78; 3.5; 3.04 Å, etc. When it is heated, anhydrite is formed with its characteristic diffraction reflections at 3.87; 3.5 Å, etc. As the depth increases, the gypsum content decreases from 60% to traces. At a depth of more than 3.0 m, it is absent.
4. Post-genetic transformations of Paleogene clays, a consequence of their occurrence in a special climatic zone with different degrees of moisture, together with different sedimentation conditions, led to differences in physical and mechanical properties with depth.

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