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ПРОБЛЕМЫ ПАЛЕОПОЧВОВЕДЕНИЯ И ГЕОАРХЕОЛОГИИ

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ВЛИЯНИЕ СОСТАВА И СВОЙСТВ ХВАЛЫНСКИХ ОТЛОЖЕНИЙ НА ЭВОЛЮЦИЮ ПОЧВ ВОЛГО-УРАЛЬСКОГО МЕЖДУРЕЧЬЯ (ПО РЕЗУЛЬТАТАМ МИНЕРАЛОГИЧЕСКИХ И МИКРОМОРФОЛОГИЧЕСКИХ ИССЛЕДОВАНИЙ)

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В северо-западной части Прикаспийской равнины для двух разных типов почв, подстилаемых слоистыми отложениями, проведено сравнение макро-, микроморфологических, гранулометрических, физико-химических показателей и минералогического кварц-полевошпатового коэффициента криогенной контрастности (ККК). Значения ККК для подстилающих почвы отложений ≥1 свидетельствуют о криогенных преобразованиях осадка. Скачкообразное распределение коэффициента ККК в зависимости от текстурного класса слоев (ККК <1 для суглинистых, ККК ≥1 для глинистых) слоистых шоколадных глин у оз. Эльтон в обнажении Лисья балка (+12 м над у. м.) указывает на сезонный привнос и отложение материала верхней части нижнехвалынских морских отложений в водоемы со слабой проточностью на границе голоцен-плейстоцена. Для территории с высотой +26 м над у. м. (Джаныбекский стационар) тоже выявлены лессовидные слои с ККК ≥1, в которых отмечены включения фрагментов шоколадных глин, похожих на глины у озера Эльтон. Это свидетельство того, что отложения слоистых шоколадных глин близ оз. Эльтон являются одним из источников нижних лессовидных слоев отложений на территории Джаныбекского стационара. В сравниваемых почвах на одной и той же глубине (около 100 см) отмечены признаки синлитогенного криоаридного педогенеза: гранулярная структура и гипсовые аккумуляции с признаками растворения и перекристаллизации. В поверхностных "теплых" слоях отложений сформированы разные типы почв, что связано с разными факторами почвообразования в современных и палеоклиматических условиях голоцена. Предполагаем, что после этапа повышенного атмосферного увлажнения в хроноинтервале 3500–3000 л. н. развитие поверхностных почв происходило по-разному. На недренированной территории стационара при неглубоком залегании грунтовых соленых вод сформировался характерный трехчленный солонцовый комплекс с микрорельефом, включающий изученный разрез солонца на микроповышении. На дренированной плоской поверхности у оз. Эльтон промытость почвы от легкорастворимых солей до глубины 70 см маркирует этап повышенного атмосферного увлажнения. Карбонатность лессовидных "теплых" отложений, низкий уровень грунтовых вод и современный аридный педогенез не позволили на этой территории проявиться солонцовому процессу. В результате на этой поверхности сформирована бурая аридная гипсоносная почва. С 2000-х гг. на Джаныбекской равнине происходит увеличение аридности климата, сопровождающееся небольшим увеличением количества осадков зимнего периода, что вызывает более глубокое весеннее промачивание почвы. В результате в верхних 50 (70) см изученных почв отмечены повышенная биогенная активность и усиление гумусонакопления, вынос легкорастворимых солей и перераспределение карбоната кальция. Микрорельеф обусловливает относительную выраженность этих процессов.

Ключевые слова: Solonetz, Calcisol, эволюция почв, изменение климата

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1. INTRODUCTION

The Volga-Ural interfluve occupies a major part of the Caspian lowland, which covers the northern coast of the Caspian Sea in a semicircle. The deposits of the Volga-Ural Interfluve are closely related to changes in the boundaries of the Caspian Sea as a result of transgressions and regressions leading to a change in the lithological composition of surface sediments. These processes are reflected in the features of the composition and structure of the soil-forming rocks. The coastal boundary of the maximum transgression of the Caspian Sea in the Khvalynian period was located at an altitude of +48...50 m, reaching in the north to the foot of the Common Syrt and the slopes of the Syrt Zavolzhye. The question of the stages of the Khvalynian regression of the Caspian Sea and the stages of its delay at different hypsometric levels remains debatable. Retreating at the end of the Upper Quaternary, the Caspian Sea exposed a flat, south-sloping seabed, which already had irregularities due to the activity of sea waters and salt tectonics. As the sea receded, the formation of peculiar landscapes characteristic of the modern semi-desert zone of the south-east of the Russian Plain gradually began on the drained surface.

The entire surface of the Caspian lowland is covered with marine sediments of different ages, which are mainly represented in the north by yellow-brown heavy and medium loams, in the south they are replaced by light and desalinated loams and sands. The most specific for the soil formation of the Lower Volga region are Lower Khvalynian Chocolate clays. They are confined to the second terraces of the Volga and Ural rivers and are not characteristic of the Volga-Ural interfluve (Svitoch et al., 2017). The age of Lower Khvalynian Chocolate sediments according to the latest available dates lies in the range of 25–12.6 thousand years ago (Yanina et al., 2017; Kurbanov et al., 2021). Chocolate clays have a complex polyfacial layering and characteristic crystallooptical properties (Lebedeva et al., 2018). The most frequent occurrence of Chocolate clays in the Volga-Ural Interfluve was noted in a series of depressions located parallel to the Volga valley. This was described earlier by M.P. Britsyna (1954) and confirmed by our field studies and analysis of soil literature (fig. 1). For many Holocene soils, it was noted that the Khvalynian layered (or covertly layered) sediments with the inclusion of seashells are covered by a layer of younger terrestrial formations, which is loess.

Since the late 1970s, an increase in climate humidity has been observed in the Northern Caspian region. At first glance, the changes are insignificant: total annual temperature increased by 1.3°C, precipitation increased by 50 mm, evaporation during the warm period decreased by 70 mm. However, it is known that arid and semiarid landscapes are very sensitive to such changes. Since the territory is drainless, the change in climate humidity leads to a synchronous increase in the groundwater level. These changes have already been reflected in the vegetation of the north of the Caspian lowland. Thus, an increase in the participation of mesophytic vegetation species and an increase in the projective coverage on all elements of the microrelief were registered (Novikova et al., 2004; Sizemskaya, Sapanov, 2010).

The aim of study is to identify the features of microstructure, mineralogical and physico-chemical properties of soils associated with the composition and structure of soil-forming rocks, with modern and relict processes of soil formation in a changing climate.

2. MATERIALS AND METHODS

The first study site is located on micro-elevation between 3d and 4th State Forest Belts of the Janybek Experimental Station (Institute of Forestry, RAS) (+26 m altitude, 49°23′54.2″ N 46°47′46.6″ E). Living soil cover consists of *Bassia prostrata* (L.) A.J. Scott, *Salsola laricifolia, Lepidium perfoliatum* L., *Agropyron desertorum* (Fisch. ex Link) Schult., *Festuca valesiaca* Schleich. ex Gaudin, *Tortula desertorum* Broth. The soil (pit 2–15, 49°23′14.0″ N 46°47′25.0″ E) on this site is attributed to Gypsic Solonetz (Albic Clayic Cutanic Differentic Magnesic Hypernatric Raptic). This soil section belongs to one of the chronographs of the combined study of changes in soil properties and climatic conditions on the subject of the Russian Science Foundation project No. 21-74-20121. Water table is 5.35 m. The second study site is located on the 8 m high exposure at the Fox Dry Valley near Elton Lake (+12 m altitude), so the groundwater has not been opened. The soil (pit 6–19, 49°16′39.5″ N 46°40′32.0″ E) on this site is attributed to Haplic Calcisol (Loamic, Raptic) with close bedding by Lower Khvalynian Chocolate clays. The age of the deposits was determined from the shells of a marine mollusk (*Didacna ebersini*) in the lower layers of Chocolate clays on the depth of 4 m. Living soil cover is represented by *Artemísia vulgáris* (L.).

Field description was performed according to FAO Guidelines for Soil Description (2006). Soil types were determined using the World Reference Base for Soil Resources (2015). Micromorphological analysis was conducted using international terminology (Stoops, 2021) with equipment of the Center for Collective Use “Functions and properties of soils and soil cover” of the FRC V.V. Dokuchaev Soil Science Institute. The grain size analyses for fine earth material (<1 mm) was performed by the conventional pipette method (Kachinskiy, 1965). Textural classes were scaled to international standards (Guidelines for Soil Description, 2006) using the construction of cumulative curves (Shein, 2005). Soil salinization was assessed according to the criteria given in the monograph “Salt-affected soils of Russia” (Pankova et al., 2006). The organic carbon was determined by the modified Tyurin method (GOST 26213-91, 1992). Clay fraction (<0.001 mm) was extracted according to Gorbunov (1963). To characterize the degree of participation of the cryogenic weathering process in the formation of deposits and soils the coefficient of cryogenic contrast was used:

$$CCC = Q1/F1 : Q2/F2,$$

(a)

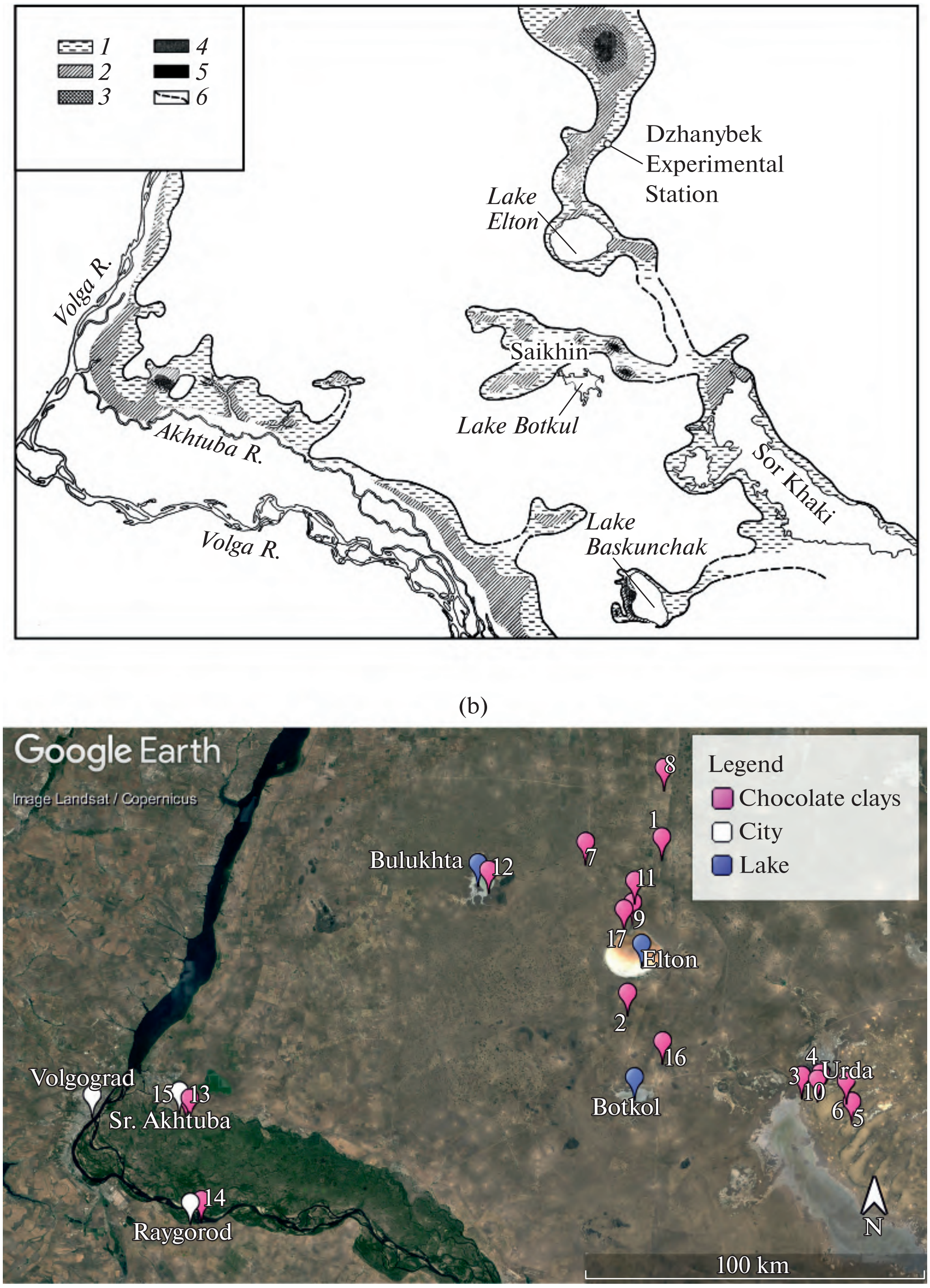

Fig. 1. (a) – spatial distribution of Chocolate clays in the Northern Caspian and Volga regions (Britsyna, 1954): 1–5 – horizons of Chocolate clays with a thickness of 0–2, 2–5, 5–8, 8–13 and over 13 m, respectively; 6 – the assumed boundary of the distribution of Chocolate clays before their destruction by denudation processes. (b) – distribution of Chocolate clays according to literature data and personal findings: 1 – Rode and Polsky (1961); 2–4 – Kovda (1950); 5–6 – Yakubov (1938); 7 – Plotnikova et al. (2019); 8 – Demkin and Ivanov (1978); 9–12, 17 – personal finds of M.P. Lebedeva; 13 – Lebedeva et al. (2018); 14–15 – Makshaev and Svitoch (2016); 16 – Britsyna (1954).

Рис. 1. (а) – схема распространения шоколадных глин в Северном Прикаспии и Поволжье (Britsyna, 1954): 1–5 – горизонты шоколадных глин толщиной 0–2, 2–5, 5–8, 8–13 и более 13 м соответственно; 6 – предполагаемая граница распространения шоколадных глин до начала их разрушения и денудации. (b) – распространение шоколадных глин согласно литературным данным и личным находкам ученых: 1 – Роде, Польский (Rode, Polsky, 1961); 2–4 – Ковда (Kovda, 1950); 5–6 – Якубов (Yakubov, 1938); 7 – Плотникова и соавт. (Plotnikova et al., 2019); 8 – Демкин, Иванов (Demkin, Ivanov, 1978); 9–12, 17 – личные находки М.П. Лебедевой; 13 – Лебедева и соавт. (Lebedeva et al., 2018); 14–15 – Макшаев, Свиточ (Makshaev, Svitoch, 2016); 16 – Брицына (Britsyna, 1954).

where Q1 and F1 are the content of quartz and feldspar, respectively, in the fraction 0.05–0.01 mm; Q2 and F2 are the content of quartz and feldspar, respectively, in the fraction 0.1–0.05 mm (Rogov, 2009).

Fractions 0.05–0.01 and 0.1–0.05 mm for the calculation of CCC were obtained by sieving from the total residue of particles ≥0.01 mm after clay extraction. The quartz and feldspar content were determined using a SEM microanalyzer JEOL JSM-6610LV (Center for Collective Use "Laboratory of Radiocarbon Dating and Electron Microscopy", Institute of Geography RAS).

3. RESULTS AND DISCUSSION

3.1. Field morphology. According to the obtained data, the smoothing of the hummock-hollow microrelief described for the Janybek station caused by the lowering of the surface of micro-elevations has now been noted (Konyushkova, Abaturov, 2016). This is most clearly appeared near the depression or near the burrows of soil animals. Moistening of salic lower horizons as a result of rise in groundwater levels (from 7 to 4–5 m over the last 30–40 years) and the transition of sodium sulfate (thenardite) into solution, causing repacking and compaction of subsolonetzic pseudo-sandy material, is considered as a mechanism leading to lowering of modern microrelief (Lebedeva, Konyushkova, 2016). Suffusion subsidence is characteristic of loess and is described as one of the mechanisms of formation of microhollows for territories with meadow-steppe solonetzic complexes. With close bedding of soils with Chocolate clays, the subsidence of the surface is not characteristic (Britsyna, 1954).

Gypsic Solonetz (soil pit 2.15). The main type of structure in the E horizon is tiled, but in some zones there is clearly visible differentiation by type of porosity. The upper part of the horizon is dense, below there is a microhorizon (0.5 cm thick) with well-developed vesicular pores, which is gradually turning into a microhorizon with a platy structure (0.5–2 cm) below. The coffee-brown solonetzic horizon with characteristic prismatic (columnar) structure lies under E horizon. Salt pedofeatures of various forms (fading, streaks) appear from 20 cm. Soil effervescence from 10% HCl is recorded from the same depth. Small gypsum veins and yellowish saline mineral concentrations are marked from a depth of 30 cm, large gypsum intergrowths are confined to clay layers from a depth of 70 cm. There are many small roots in the upper horizons, there are few roots in the lower horizons, but they are larger.

On the depth of 70–100 cm litogenic layered structure was described, in the lower horizon (100–120) signs of layered structure are presented. An oval mole passage with chocolate-colored clay material is marked in this layer (fig. 2, (a)).

Haplic Calcisol (soil pit 6.19). There are a lot of burrowing animal emissions on the surface. The soil material is silty loam and silty clay. The soil profile has a well-defined reddish-fawn color with a large number of ochre spots (presumably with an increased iron content). Soil effervescence from 10% HCl is recorded from the surface.

From a depth of 50 cm, small fragments of Chocolate clay appear (fig. 2, (b)). From a depth of 70 cm, thin layers of Chocolate clay and loess deposits alternate. In the 70–102 cm layer, Chocolate clay layers lie horizontally parallel to each other, ochre spots and soft ochre layers are confined to the contacts of Chocolate clays and loess. Chocolate clays with a gray hue lie in a layer of 102–138 cm. From a depth of 120 cm, the color of the profile changes – there are brown interlayers on the pale yellow silty material. In a layer of 138–160 cm, there is a layer of loose gray clays with ochre spots and gypsum veins and large crystals. In a layer of 160–200 cm thick units of gray-dove-coloured clays alternate with layers of loess. A *Monodacna caspia* shell was found at a depth of 130 cm. Small fragments of unidentifiable shells were found at a depth of 160–170 cm. From a depth of 200 cm there are vitreous gypsum intergrowths.

Therefore, at the macro level, the morphological properties of the compared soils are different, which determined their different classification position.

3.2. Soil micromorphology. In the upper horizons of both soils, low humus content and zoogenic aggregation of silt material was noted. In Calcisol, fragments of Chocolate clays are often found already at a depth of 0–7 cm (fig. 3, (b)), in contrast to the similar horizon of the Solonetz, which is characterized by a thin lenticular structure (fig. 3, (a)).

Below is solonetzic horizon (6–20 cm), which has a characteristic angular-blocky microstructure and striated b-fabric. The features are a relatively small number of thin clay coatings, the presence of humus-clay and clay-ferruginous coatings, including around the microbiota passages. Excrements of soil microfauna, strongly decomposed plant residues and Fe-Mn nodules were also noted. The pedofeatures noted in the solonetzic horizon indicate the current stage of an increase in average annual temperatures with an increase in precipitation and the development of mesophytic vegetation (Novikova et al., 2004). This led to a decrease in the mobility of fine matter, the appearance of ferruginous-manganese nodules in the solonetzic horizon of the Solonetz. Also this led to an increase in the amount of plant residues and an increase in the degree of their humification both in the Solonetz and Calcisol (fig. 4, (a)).

In Calcisol, at a depth of 20–35 cm, various transformations of Chocolate clays fragments were noted with their inclusion in the intrapedal material with micrite impregnation. Micrite nodules with diffuse boundaries are noted in the groundmass near large

(a) (b)

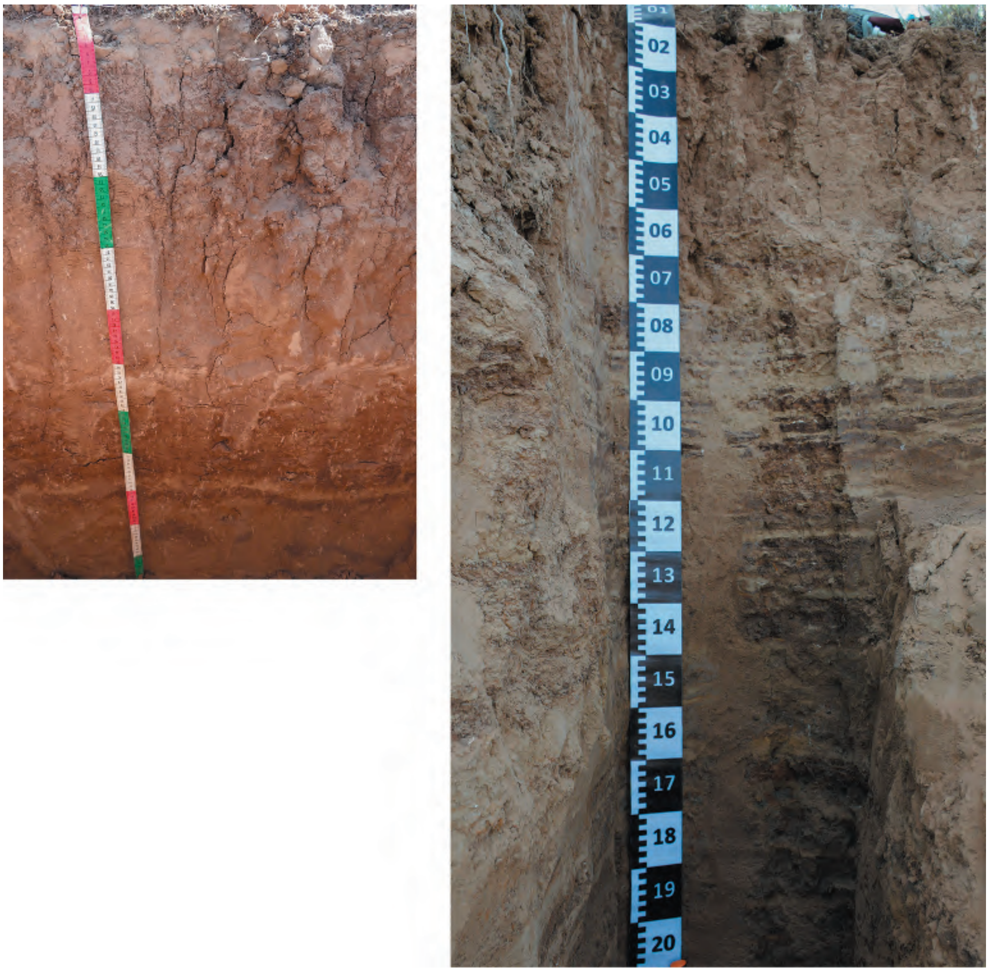

Fig. 2. Study sites: (a) Gypsic Solonetz; (b) Haplic Calcisol.
Рис. 2. Изученные почвенные профили: (a) Gypsic Solonetz; (b) Haplic Calcisol.

voids. Clay fragments have angular and rounded shapes, small fragments predominate (140–300 μm), there are larger ones (800 μm, occasionally 1250 μm), which consist of a fine silt clay material (fig. 3, (d)). There were no pedofeatures of mobility of clay micromass.

In Solonetz at a depth of 30–50 cm, clays fragments are so strongly assimilated that they greatly increase the content of fine micromass among the silt particles, creating a compacted silty-clay groundmass (fig. 3, (c)). Below (50–100 cm), a loose packing of semi-rounded clay fragments of silt and fine sand dimensions among silicate grains is noted, forming a pseudo-sandy horizon, which is characteristic for the Solonetzes of the Janybek station (Rode, Polsky, 1961). Below 100 cm, the horizon ABkzb was diagnosed with micro features of relict soil formation (fig. 4, (b)): high aggregation of clay-humus-carbonate material (biogenic, cryogenic ooid), a small number of gypsum infillings. This makes it possible to consider this horizon as a buried slightly humic horizon formed in cold arid conditions. We assume that the Fe-Mn dendritic nodules noted here are the result of the current high groundwater level.

In Calcisol in mono-clay layers at a depth of 55–63 cm, fracturing and fragmentation Chocolate clays into platy units were noted (fig. 3, (f)), and at a depth of 70–77 cm there were also micro features of different generations of gypsum infillings (fig. 5, (d)). In Solonetz at a depth of 50–70 cm, the material of Chocolate clays with the same composition does not have a platy structure. It is aggregated (fig. 3, (e)) and forms hypocoatings. Gypsum infillings in Solonetz (fig. 5, (c)) are most likely formed as a result of the capillary ascension of saline groundwater and crystallization in the pores in the capillary-moisture zone. We assume that in Calcisol, smaller gypsum crystals were formed as a result of the dissolution of larger old gypsum crystals and redeposition from solution, since we see crystals of different shape, size and fracturing next to each other

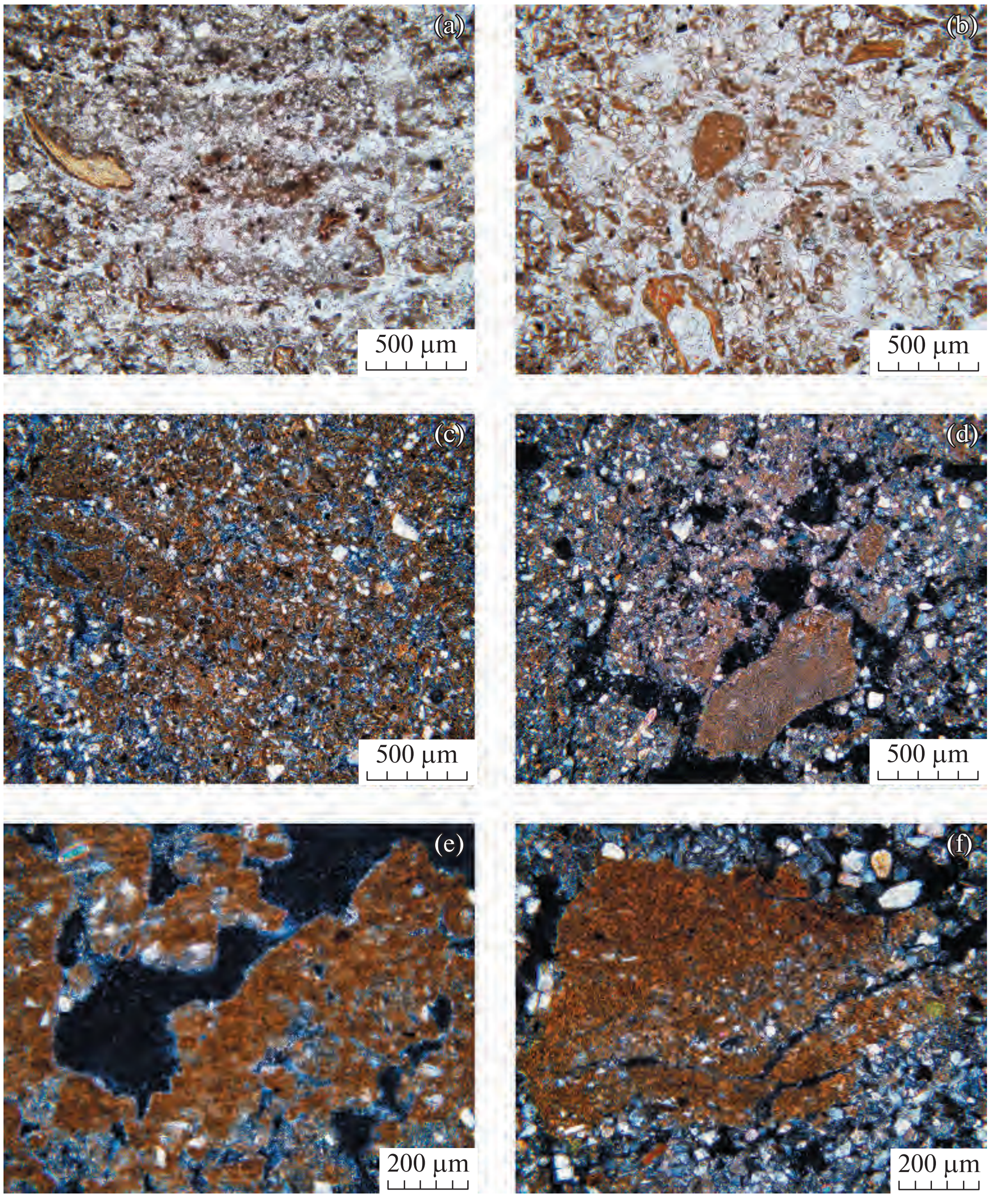

Fig. 3. The microstructure of Solonetz (a, c, e) and Calcisol (b, d, f) with close bedding by Lower Khvalynian Chocolate clays: (a) – lenticular microstructure (0–6 cm, PPL); (b) – fragments of Chocolate clays in Ek horizon (0–7 cm, PPL); (c) – assimilated fragments of Chocolate-like clay material (30–50 cm, XPL); (d) – fragments of Chocolate-like material assimilated to varying degrees (20–35 cm, XPL); (e) – fragments of Chocolate clays transformed by pedogenesis (50–70 cm, XPL); (f) – having a larger size than in Solonetz, disintegrating fragment of Chocolate clay (55–63 cm, XPL).

Рис. 3. Микроструктура солонца (a, c, e) и бурой аридной почвы (b, d, f) с близким подстиланием Нижнехвалынскими шоколадными глинами: (a) – линзовидная микроструктура (0–6 см, PPL); (b) – фрагменты шоколадных глин в горизонте Ek (0–7 см, PPL); (c) – ассимилированные фрагменты материала, по составу сходного с шоколадными глинами (30–50 см, XPL); (d) – в разной степени ассимилированные фрагменты материала, по составу сходного с шоколадными глинами (20–35 см, XPL); (e) – трансформированные почвообразованием фрагменты материала, по составу сходного с шоколадными глинами (50–70 см, XPL); (f) – крупный разрушающийся фрагмент шоколадной глины (55–63 см, XPL).

(fig. 5, (d)). In Solonetz at a depth of 80–90 cm, clay is microaggregated and included in the silty material (fig. 5, (a)). In Calcisol at a depth of 70–77 cm, Chocolate clay aggregates have the same composition and shape in separate microlayers (fig. 5, (b)), which are combined with layers of silty material. This allows us to assume the same genesis of these layers in the studied soils that are distant from each other.

The modern Calcisol in the Fox Dry Valley is formed on a polyfacial layered thickness of Chocolate clays (fig. 5, (e, f)). The similarity of the composition and structure of Chocolate clays in the profiles of So-

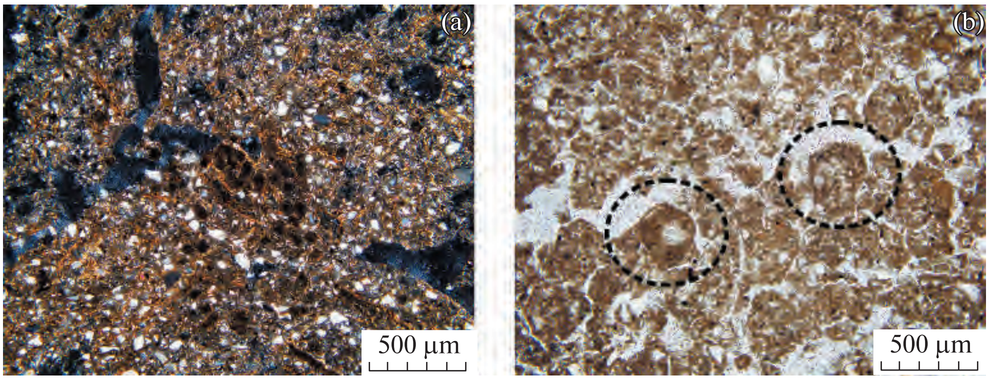

Fig. 4. Microstructure of Solonetz, Caspian Lowland: (a) subangular blocky microstructure, striated b-fabric, organic residues and excrements in Btnz horizon (6–20 cm, XPL); (b) rounded biogenic aggregates (black outline) with fine organic material in the groundmass in BCkzb horizon (100–120 cm, PPL).

Рис. 4. Микроструктура солонца, Каспийская низменность: (a) округло-блоковая микроструктура, струйчатая ориентация тонкодисперсного глинистого вещества, органические остатки и экскременты в горизонте Btnz (6–20 см, XPL); (b) округлые биогенные агрегаты (черный контур) с органическим веществом в составе тонкодисперсной массы в горизонте BCkzb (100–120 см, PPL).

lonetz and Calcisol shows that the source of clay fragments in the Solonetz of the Janybek station are deposits of the Lower Khvalynian Chocolate clays from dry valleys near the lake Elton, including from the Fox Dry Valley located 20 km from the station.

3.3. Analytical features. The studied soils differ from each other in the degree of biogenic processing of the upper thickness (0–50 cm) – Calcisol contains more organic carbon than Solonetz. The compared soils differ greatly in the thickness of the upper horizons washed from salts. The upper 50 cm of Calcisol are not saline, and below the salinity appears, but remains weak to a depth of 120 cm. Solonetz is a highly salinized soil over the entire thickness of the profile, except for the unsaline horizon E. In Solonetz, Cl-SO_4 with gypsum and Na type of salinization prevails. In Calcisol, SO_4 with Na type of salinization prevails. Toxic salts predominate in the composition of the salts of all saline horizons (tabl. 1).

The profile distribution of calcium carbonate of the studied soils is very notably different. The upper 20 cm of Solonetz is washed from calcium carbonate, while Calcisol effervesce from 10% HCl from the surface. In Solonetz the calcium carbonate content increases with depth and reaches a maximum at a depth of 100–120 cm, and then decreases again. In Calcisol the calcium carbonate content also increases with depth, but reaches a maximum at a depth of 50–70 cm. The maximum content of calcium carbonate in Calcisol is only 1% lower than in Solonetz, but the values of calcium carbonate content in the lower layers of both soils (170–200 cm) are very close (tabl. 1).

The clay content in the upper horizon (0–6 cm) of the Solonetz is 2 times less than in the underlying one. This is an attribute of the eluvio-illuvial differentiation of the clay content in the soil profile, which is characteristic of the Solonetz. In the other horizons of the Solonetz the clay content varies slightly with depth. However, it should be noted that the upper 50 cm are characterized by an increased content of the fraction with a size of 0.002–0.063 mm. Deeper than 50 cm its content decrease (tabl. 2).

On the contrary, in Calcisol, the clay content varies significantly from horizon to horizon, which is related to the number of assimilated Chocolate clays fragments and reflecting lithological heterogeneity. The granulometric composition of Solonetz change little with depth (silty clay, silty clay loam), only horizon E (0–6 cm) has a silt loam texture class. At the same time, the granulometric composition of Calcisol is heterogeneous, silt loam, silty clay loam и silty clay layers alternate (tabl. 2). The heterogeneity of the granulometric composition of the Calcisole profile reflects the lithogenetic heterogeneity of this soil.

The CCC value close to 1 in the E horizon of the Solonetz is a sign of seasonal freezing, which is additionally diagnosed by the separation of fine-silty material in lenticular aggregates (fig. 3, (a)). The value of CCC ≥1 in the Solonetz was noted from a depth of 50 cm and below (tabl. 2), which indicates that the material of these horizons has experienced a period of permafrost (Rogov, 2009). We assume that the presence of rounded Chocolate clay aggregates in the silty material is due to these harsh conditions (fig. 3, (c, e), fig. 5, (a)).

In Calcisol, similar microstructure features and the highest CCC values (≥1.2) were noted for layers of Chocolate clays with a higher content of clay fraction (70–77 and 87–120 cm), which indicates their identical genesis and comparable freezing conditions with

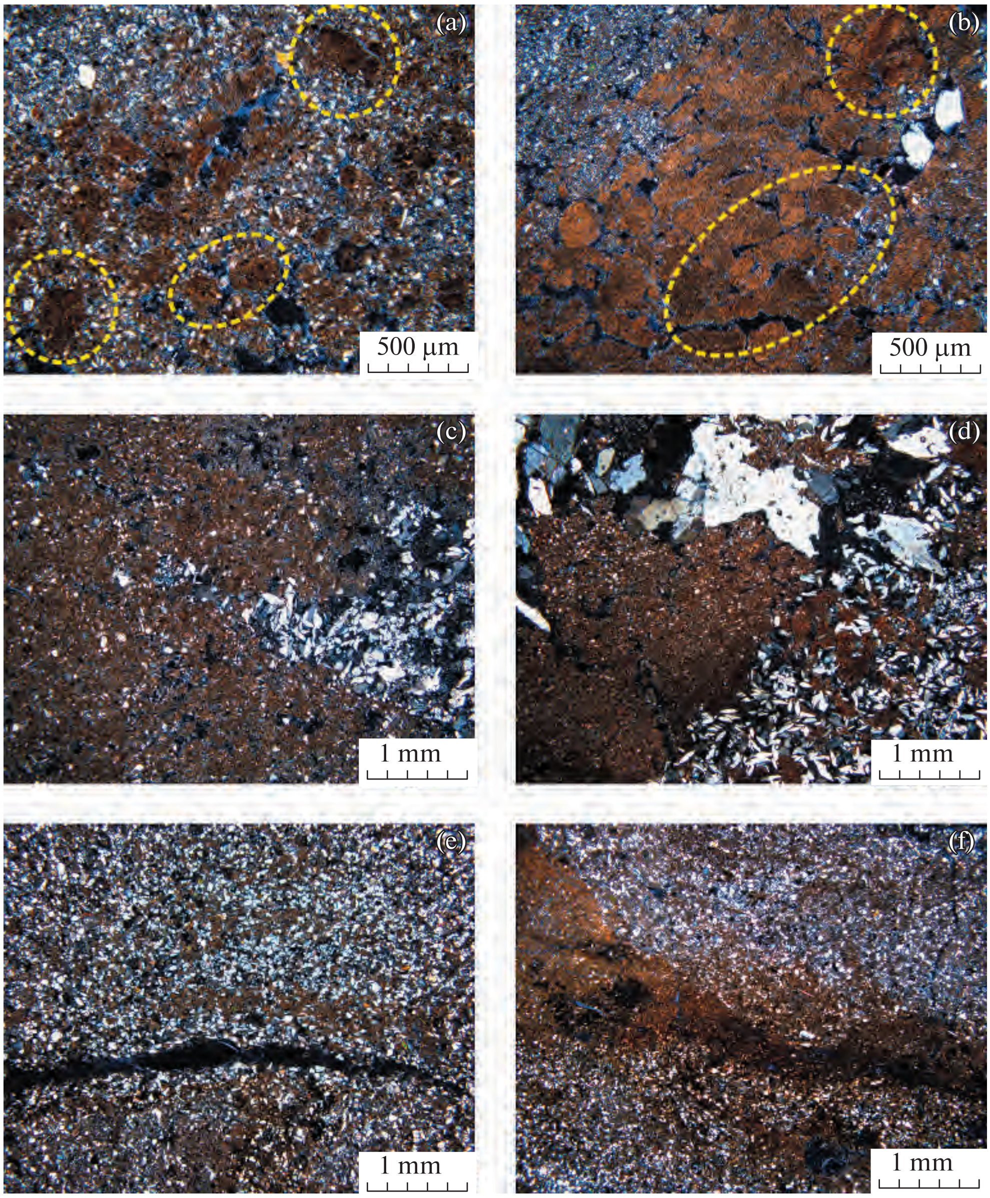

Fig. 5. The microstructure of Solonetz (a, c,) and Calcisol (b, d–f) with close bedding by Lower Khvalynian Chocolate clays (XPL): (a, b) – aggregated silty clay material showed by yellow outline (82–86 and 70–77 cm respectively); (c, d) – gypsiym cristals of different age and origin (100–120 and 70–77 cm respectively); (e, f) – intermittent layers of clay and fine sand materials (146-160 and 160–200 cm respectively).

Рис. 5. Микроструктура солонца (a, c,) и бурой аридной почвы (b, d–f) с близким подстиланием Нижнехвалынскими шоколадными глинами (XPL): (a, b) – агрегированный пылевато-глинистый материал, показанный желтым контуром (82–86 и 70–77 см соответственно); (c, d) – гипсовые кристаллы разного возраста и происхождения (100–120 и 70–77 см соответственно); (e, f) – перемежающиеся слои глины и тонкого песка (146–160 и 160–200 см соответственно).

clay layers in the studied Solonetz (tabl. 2). For most of the silty layers in Calcisol, CCC< 1, which suggests that they formed under warmer conditions. Such a distribution of CCC in layers with different granulometric composition allows us to assume the seasonality of their deposition dynamics. The possibility of such a genesis of layered Chocolate clays was described earlier (Arkhipov, 1958; Moskvitin, 1962), but this requires further research.

4. CONCLUSION

The comparison of microfeatures, grain size distribution and coefficient of the cryogenic contrast

Table 1. Selected chemical features of the soils of Caspian Lowland
Таблица 1. Некоторые химические показатели почв Каспийской низменности

Horizon	Lower boundary, cm	Corg, %	$CaCO_3$, %	Total sum of dissolved ions (%)	Sum of toxic salts, %	Degree and type of soil salinization
Soil pit 2.15						
E	6	0.74	NA	0.1	0.1	non existent
Btnz1	20	0.47	non existent	0.1	0.1	slight, SO_4-Cl with participation of soda and Na
Btnz2	30	0.29	1.85	1.1	1.0	strong, SO_4 Na
Bknyz	50	0.14	4.58	2.4	1.9	very strong, Cl-SO_4 with gypsum and Mg-Na
Bkyz1	70	NA	6.95	2.3	2.1	very strong, Cl-SO_4 and Mg-Na
Bkyz2	100	NA	6.07	2.6	2.3	very strong, Cl-SO_4-Na
ABkzb	120	NA	8.18	2.2	2.0	very strong, Cl-SO_4-Na
Ckyz1	150	NA	6.34	2.3	1.9	very strong, Cl-SO_4 with gypsum and Na
Ckyz2	170	NA	5.54	2.4	2.0	very strong, Cl-SO_4 with gypsum and Na
Ckyz3	200	NA	4.75	2.0	1.7	very strong, Cl-SO_4 with gypsum and Na
Soil pit 6.19						
Ek	7	1.08	2.80	0.2	0.1	non existent
Bk1	20	0.46	4.41	0.1	0.1	non existent
Bk2	35	0.44	6.21	0.1	0.1	non existent
Bk3	50	0.50	7.21	0.1	0.1	non existent
Bkyz	70	NA	4.21	0.7	0.2	slight, SO_4 with gypsum and Na
2Cdky	77	NA	4.41	0.6	0.3	slight, SO_4-Mg
3Cdky	87	NA	4.80	0.4	0.3	slight, SO_4-Mg-Na
4Cdky	120	NA	4.59	0.4	0.3	slight, SO_4-Mg-Na
5Cdz	150	NA		1.1	1.0	strong, SO_4 Na
6Cdz	170	NA		0.6	0.6	medium, SO_4 Na
6Cdz	200	NA		0.9	0.8	strong, SO_4 Na

(CCC) of two soils was carried out: Calcisol on an outcrop in the Fox Dry Valley near Lake Elton (+13 m altitude) and Solonetz on micro-elevation on the territory of the Janybek station (+26 m altitude). General and specific features due to paleoclimatic and lithogenic factors of soil formation have been identified. In different soils at a distance of approximately 15 km from each other, the same pattern was noted: the change of CCC at a depth of 50 (70) cm from "warm" to "cold" deposits. The upper loess-like material with CCC <1 can be called "warm", and the lower material because of CCC ≥1 is "cold". The apparent morphological and granulometric layering of the Lower Khvalynian chocolate clays in the Fox Dry Valley outcrop, underlying the Calcisol, is accompanied by a discontinuous distribution of CCC, which suggests their deposition in conditions of seasonal freezing. There was no discontinuous distribution in the values of CCC for the Solonetz, possibly due to the fact that samples were not taken from very thin dusty lenses and interlayers noted in the description in the field. We assume that the layers in the compared soils with the same cryogenic contrast coefficient were formed under the same paleoecological conditions – strongly freezing. The presence of sharp-angled small fragments of chocolate clays mainly in the "cold" lower loess layer and destroyed fragments of clays in the "warm" upper layer of Solonetz, located at a greater

Table 2. Grain size distribution, textural classes and the coefficient of cryogenic contrast in the selected horizons of the studied soils, Caspian Lowland

Таблица 2. Гранулометрический состав, текстурные классы и коэффициент криогенной контрастности изученных почв Каспийской низменности

Horizon	Lower boundary, cm	Grain size distribution			Textural classes	CCC
		Clay (<0.002 mm), %	Silt (0.002–0.063 mm), %	Sand (0.063–2 mm), %		
Soil pit 2.15						
E	6	17.8	66.5	15.7	silt loam	0.92
Btnz1	20	37.5	52.4	10.1	silty clay loam	0.64
Btnz2	30	41.1	50.2	8.7	silty clay	0.87
Bknyz	50	36.9	52	11.1	silty clay loam	0.49
Bkyz1	70	45.2	44.1	10.7	silty clay	1.13
Bkyz2	100	43.3	47.3	9.4	silty clay	1.00
ABkzb	120	41.3	47.4	11.3	silty clay	1.00
Ckyz1	150	37.7	46.3	16	silty clay loam	0.92
Ckyz2	170	37.6	48.4	14	silty clay loam	NA
Ckyz3	200	37.9	50.7	11.4	silty clay loam	NA
Soil pit 6.19						
Ek	7	12.6	58.3	29.1	silt loam	0.85
Bk1	20	21.1	56	22.9	silt loam	0.72
Bk2	35	30.2	55.9	13.9	silty clay loam	0.65
Bk3	50	34.3	52.9	12.8	silty clay loam	0.4
Bkyz	70	22.5	55	22.5	silt loam	0.56
2Cdky	77	48.5	44.6	6.9	silty clay	1.27
3Cdky	87	18.2	70.2	11.6	silt loam	0.64
4Cdky	120	49.7	44.5	5.8	silty clay	1.22
5Cdz	150	31.9	53.2	14.9	silty clay loam	0.99
6Cdz	170	17.8	59.3	22.9	silt loam	0.85
6Cdz	200	22.5	56.4	21.1	silt loam	1.43

altitude than the Calcisol, allows us to consider it as a product of aeolian denudation of the dusty-clay layers of the Lower Khvalynian marine sediments near Lake Elton.

In layered sediments with the same value of the cryogenic contrast coefficient for both pits, signs of paleopedogenesis were noted. In Calcisol, granular aggregation of clay material in plane voids between chocolate clay tiles was noted, in Solonetz, characteristic cryoarid aggregation was noted in loess material at a depth of more than 1 m. Large irregular-shaped gypsum accretions marking layers near the saline water level during the retreat of the Khvalynian Sea (Rode, Polsky, 1961) are relict for both soil pits, since their genesis is associated with zones of complete saturation with sulfate waters (Lebedeva, Konyushkova, 2016). The modern recrystallization of gypsum with the formation of small rhomboidal crystals indicating a weak modern washing regime of soils in modern arid conditions is noted. The washing of the upper part of the Calcisol from soluble salts indicates the presence of a stage of increased atmospheric moisture in its evolutionary development. On the one hand, the suffosion microrelief characteristic of loess has not been formed here due to the layering of sediments and the high drainage of the territory. On the other hand, due to the rapid discharge of water down a gentle slope into the lake, a Solonetz profile has not formed here either. For the undrained Janybek plain, soil salinization due to periodic capillary ascension of saline groundwater from a depth of 4–8 m is occurred. The period of increased atmospheric humidification was noted for the chronointerval 3500–3000 years ago (Borisov et al., 2006). Exactly at this time the three-component solonetz complexes characteristic of the modern soil cover of the Janybek plain were formed. The degree of chocolate clay fragments integrity in the upper "warm" loess layer depends on the intensity of modern soil formation processes: biogenic activity, humus accumulation, eluvial-illuvial migration of the humus and clay components, surface hydromorphism. Currently, these processes are conducting with increased intensity due to climate change (Romanis et al., 2022).

INFLUENCE OF THE COMPOSITION AND PROPERTIES OF KHVALYNIAN DEPOSITS ON THE EVOLUTION OF SOILS OF THE VOLGA-URAL INTERFLUVE (BASED ON THE RESULTS OF MINERALOGICAL AND MICROMORPHOLOGICAL STUDIES)

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In the northwestern part of the Caspian Plain, a comparison of macro-, micromorphological, granulometric, physico-chemical parameters and mineralogical quartz-feldspar cryogenic contrast coefficient (CCC) was carried out for two different types of soils underlain by layered sediments. The values of the CCC for the underlying sediments are ≥1, which indicates cryogenic transformations of the sediment. The abrupt distribution of the CCC depending on the texture class of layers (CCC <1 for loamy material, CCC≥1 for clay) of layered chocolate clays near Lake Elton in the Fox Dry Valley outcrop (+12 m altitude) indicates the seasonal introduction and deposition of material from the upper part of the Lower Khvalynian marine sediments into reservoirs with weak flow at the boundary of the Holocene-Pleistocene. For the territory with of +26 m altitude (Janybek station), loess-like layers with CCC≥1 were also identified, in which inclusions of fragments of chocolate clays are similar to clays near Lake Elton. This is evidence that the deposits of layered chocolate clays from Fox Dry Valley are one of the sources of the lower loess-like layers of sediments on the territory of Janybek station. In the compared soils at the same depth (about 100 cm), signs of synlithogenic cryoarid pedogenesis were noted: granular structure and gypsum accumulations with signs of dissolution and recrystallization. Different types of soils were formed in the surface "warm" layers of sediments (CCC<1), which is associated with different factors of soil formation in modern and paleoclimatic conditions of the Holocene. We assume that after the stage of increased atmospheric humidification in the chronointerval 3500–3000 years ago, the development of surface soils occurred in different ways. On the undrained territory of the station, with a shallow occurrence of saline water-table, a characteristic three-component solonetz complex with a microrelief was formed, including the studied soil pit of the Gypsic Solonetz on a micro-elevation. On a drained flat surface near Lake Elton, the washing of the soil from easily soluble salts to a depth of 70 cm marks the stage of increased atmospheric moisture. The carbonate content of loess-like "warm" sediments, deep water-table and modern arid pedogenesis did not allow the solonetzic pedogenesis to manifest in this area. As a result, Haplic Calcisol was formed on this surface.

Since the 2000s, there has been an increase in climate aridity on the Janybek plain, accompanied by a slight increase in winter precipitation, which causes deeper spring soil wetting. As a result, in the upper 50(70) cm of the studied soils, increased biogenic activity and increased humus accumulation, removal of soluble salts and redistribution of calcium carbonate were noted. The microrelief determines the relative severity of these processes.

Keywords: solonetz, brown arid soil, soil evolution, climate change

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