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ПРОБЛЕМЫ ПАЛЕОПОЧВОВЕДЕНИЯ И ГЕОАРХЕОЛОГИИ

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СТРОЕНИЕ И УСЛОВИЯ ФОРМИРОВАНИЯ ПАЛЕОПОЧВ РАННЕГО ПЛЕЙСТОЦЕНА В ЛЁССОВО-ПОЧВЕННОЙ СЕРИИ РАЗРЕЗА АЛЧАК-СЕДЛОВИНА (РЕСПУБЛИКА КРЫМ)

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Палеопочвы являются одним из основных палеоэкологических индикаторов, фиксирующих изменения окружающей среды в лёссово-почвенных сериях. Понимание особенностей строения палеопочв и природных процессов, которые их вызвали, позволяет реконструировать ландшафтно-климатические условия на искомых территориях. В статье представлены новые исследования лёссово-почвенной серии разреза Алчак-Седловина, расположенного в горной местности южной части полуострова Крым. В разрезе вскрыты две автоморфные палеопочвы (PS1-AS и PS3-AS) и одна гидроморфная (PS2-AS), которые мы сопоставляем с палеопочвами воронского педокомплекса (МИС 13/15). Это предположение базируется на данных, полученных по результатам комплексного анализа, включающего морфологическое обследование палеопочв и их физико-химические показатели. Установлено, что лёссово-почвенная серия исследуемого разреза Алчак-Седловина формировалась на отложениях V Перчемской террасы, которая соответствует интервалу МИС17. Палеопочвы PS2-AS и PS3-AS развивались по типу Cambisols в условиях теплых степей или лесостепей с периодическим увлажнением и нередко локальным застоем влаги; в холодное время года наблюдалось незначительное промерзание поверхности. Профиль палеопочвы PS1-AS также соответствует типу Cambisols, но он формировался в более сухом климате под степной растительностью, схожей с современной. В районе исследования в периоды аккумуляции лёссового материала и почвообразования сопровождались постоянными эрозионными процессами. В результате чего в лёссово-почвенной серии разреза Алчак-Седловина фиксируются слои крупнообломочного материала, а поверхностные горизонты палеопочв эродированы. Полученный материал позволил по-новому взглянуть на развитие палеопочвенного покрова в горной местности Крымского полуострова. Выявленные характеристики палеопочв разреза Алчак-Седловина, в дальнейшем, можно сопоставить с другими палеопочвами п-ова Крым для интерпретации их возраста и условий формирований.

Ключевые слова: морфология почв, морская терраса, морфоскопия кварцевых зерен, плейстоцен, мучкапское межледниковье

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1. INTRODUCTION

Loess covers about 10% of the Earth's surface (Pye, 1987; Haase et al., 2007; Lu et al., 2020; a.o.). Their deposits preserve ancient soils, representing the climatic conditions in which they were formed (Velichko, Morozova, 2015; Panin et al., 2018; 2019a; a.o.). The sequence of such paleosols in the loess is called the loess-paleosol sequences (LPS), which is used to reconstruct the climatic conditions of past epochs. Thus, the loess cover is one of the main archives reflecting landscape and climatic changes in the Quaternary. This paper proposes a study of the loess-paleosol section Alchak-Sedlovina, located on the Crimean Peninsula. In this area, mainly paleosol studies were carried out only in the western part of the peninsula, where coastal cliffs are composed of thick loess deposits with red-colored paleosols (Veklich, 1968; Veklich, Sirenko, 1976; Pevzner et al., 2004; Panin et al., 2018; a.o.). The uniqueness of the Alchak-Sedlovina section is that it is located in the mountainous part of the Crimea, where detailed studies of paleosols have practically not been carried out.

The LPS of the section is represented by three paleosols, the profiles of which are superimposed on

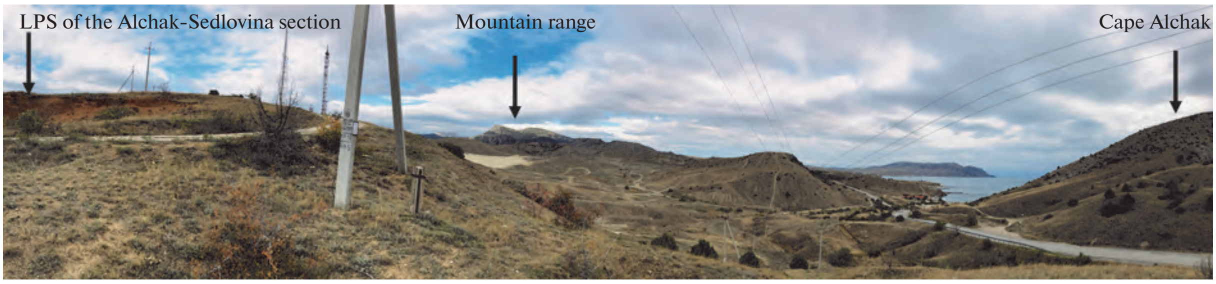

Fig. 1. General view of the Alchak-Sedlovina section and landscape.
Рис. 1. Панорамный вид разреза Алчак-Седловина и ландшафта.

each other, they are crowned by the modern Calcic Cambisol. Their study will expand knowledge about the structure and development of the paleosols of the Crimean Mountains (Veklich, Sirenko, 1976). Multi-proxy analysis with detailed sampling will make it possible to classify the paleosols type and compare them with modern soil analogues. Based on this, we will be able to reconstruct the landscape and climatic conditions that prevailed in this area in the Early Pleistocene.

2. REGIONAL SETTINGS AND METHODS

The study area belongs to the southern coast of the Crimean Peninsula. The landscape is characterized by a hilly-ravine relief; landslide processes and erosional landforms are widely developed here (Muratov, 1960). In the study area, near the town of Sudak, limestone cliffs and mountain ranges (Alchak, Mandjil, Perchem, Sokol, etc.) stand out (Muratov, 1960). The LPS of the Alchak-Sedlovina section (44°50′18″ N; 34°59′44″ E, 54 m asl) (fig. 1, 2) was uncovered on a foothill elevation in a saddle near the northern slope of Mount Alchak, between Mount Alchak and Mount Ay-Georgiy on the paleo-terrace. The loess formation of the studied section based on loams underlain by the V Perchem marine terrace (Chepalyga, 2015; 2017). The study area belongs to the South Coast climatic region, zone IB (Cherenkova, 1959), with a dry subtropical climate of the Mediterranean type (Sudnicin, 2014). According to the climate classification of Köppen-Geiger (Kottek et al., 2006), the territory of the southern coastal zone of Crimea belongs to the Mediterranean type Csa, but the Sudak coast is compared with the more arid zone – Submediterranean subtype. The annual precipitation does not exceed 325 mm (Cherenkova, 1959). The average air temperature in July is 24°C, in January 3...–4°C (Ved', 2000).

2.1. Black sea marine terraces age. To determine the age of the LPS of the Alchak-Sedlovina, section it was necessary the age of the terraces of the town of Sudak and, first of all, the V Perchem Terrace. The first generalization on the terraces of the town of Sudak was carried out by the famous Russian geologist Andrusov (1889), who substantiated up to 4–5 cyclic terraces. At the same time, the author believed that in addition to these terrace levels, there are several more intermediate terraces in the town of Sudak area.

At the beginning of the XXI century, on the basis of detailed interdisciplinary research, it was possible to significantly supplement the Sudak system of terraces in the altitude range of 0–200 m asl up to 12 terrace levels, reveal their structure and age based on paleomagnetic and paleofaunal data (Arkhangelskij, Strakhov, 1938; Arslanov et al., 1983; Chepalyga, 2017). A cyclicity in the structure of the deposits and the height of the surface, as well as in the age of the corresponding terraces, was found to be close to the cyclicity of the Marine Isotope Stage (MIS). As a result, the local system of terraces was based the Sudak Typical Terrace Profile. Based on the height of the top of the marine facies of the terraces, it was possible to establish that the rate of uplift of the southern coast of Crimea in the Sudak region averaged 0.1 mm/year over the past 2 Ma (Chepalyga, 2017).

Eastern vicinities of the town Sudak (from the Eastern Highway to the Frantzuzhenka Cape), terraces are clearly morphologically and geologically expressed from sea level to a height of 75 m asl Some of them are of interest for this work.

II Karangat terrace up to 10–15 m high, in the Sudak terrace system, Cape Frantzuzhenka, Cape Meganom, etc. are exposed in sections and contain the leading species of mollusks *Acanthocardia tuberculata*, *Paphia senescens*, *Mactra corallina*, etc., also characteristic of the Tyrrhenian deposits of the Mediterranean Sea. Therefore, the preliminary name of this terrace according to Andrusov (1889; 1912) is Tyrrhenian. Later, this name was changed to the local Black Sea one along Cape Karangat, where the stratotype of the Karangat deposits was established (Arkhangelskij, Strakhov, 1938). From the deposits of the Karangat stratotype, as well as the parastratotype Eltigen and Tuzla sections, optically stimulated luminescence series of datings were obtained in the interval of 70–140 ka (Kurbanov et al., 2019; 2020). This age of the Karangatian terrace, as well as the parastratotype, was confirmed by the data of paleomagnetic analysis, in connection with the discovery in the lower Karangat

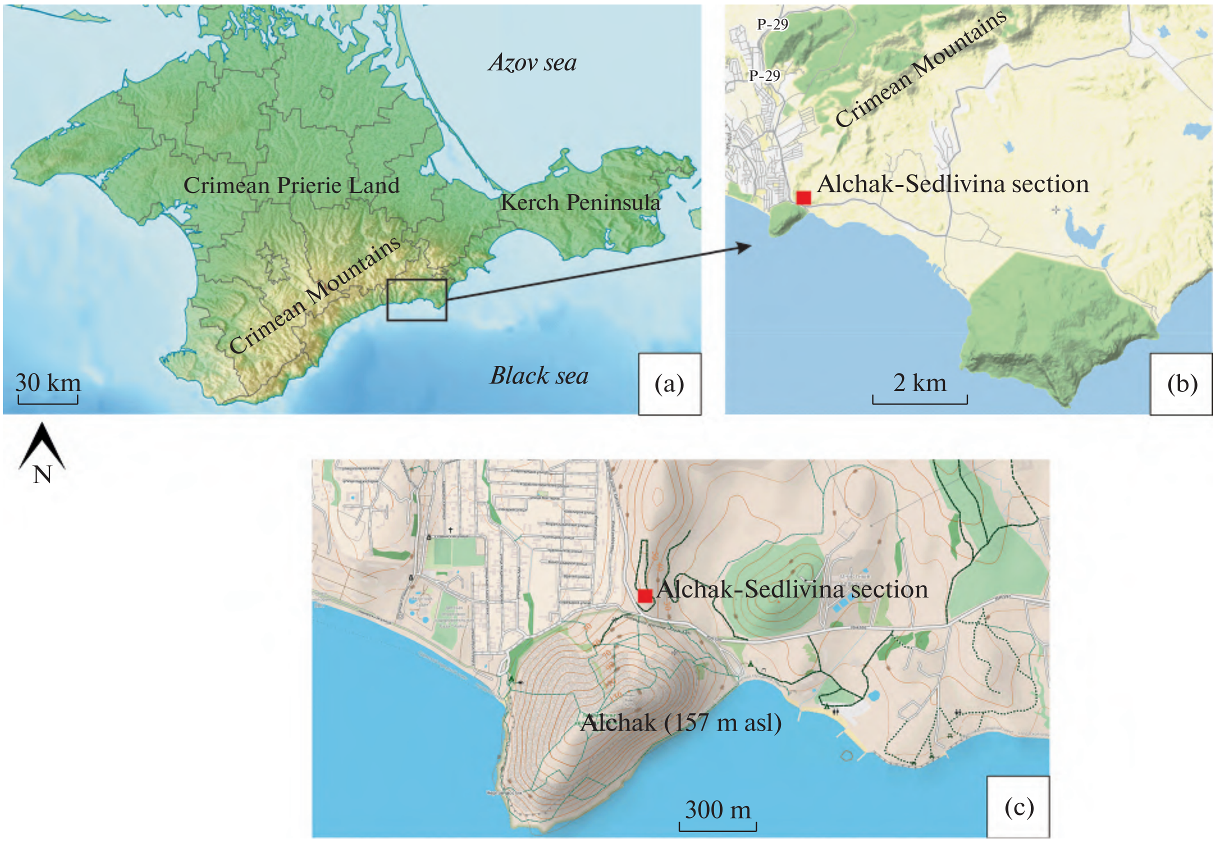

Fig. 2. Geographical position of the Alchak-Sedlovina section (a, b), topography plan (c).
Рис. 2. Географическое положение разреза Алчак-Седловина (a, b), топографический план (c).

of the reverse polarity of the Blake event (~100–121 ka) (Pilipenko, Trubikhin, 2012). All these data indicate the age of the Karangat terrace during the Mikulino interglacial (MIS 5).

The V Perchem terrace has a surface height of about 50 m, a basement of 45 m asl, distinguished by Andrusov (1889) in the town of Sudak. The stratotype of this terrace was established in the Alchak-Sedlovina section, where later a section of subaerial deposits with paleosols was found (Chepalyga, 2015; Chepalyga et al., 2019). The terrace sequence is represented by marine basal pebbles up to 1 m thick and overlain by silts and sands of marine facies 5–6 m thick. The terrace V is analogous to the deposits of the Chauda basin of the Black Sea at Cape Chauda, where the stratotype of the Chauda stage and deposits of the Upper Chauda with rich endemic fauna of the Caspian type are located: *Tschaudia tschaudae*, *Submonodacna pleistopleura*, *Didacna pseudocrassa*, etc. (Andrusov, 1912). In the upper part of these deposits, for the first time in the Black Sea basin, Mediterranean species and planktonic foraminifers appear, which marks the first penetration of sea water into the Black Sea from the Mediterranean at the beginning of the Middle Pleistocene. These sediments with marine species were identified as a new phase of the Chauda basin, called Karadeniz (Chepalyga, 1997) and Epichauda (Fedorov, 1978). The age of the terrace V is determined by MIS 17.

The VI Sugdey terrace 62–64 m high, basement 50–56 m asl is older than the V Perchem terrace. It was identified for the first time and named after the ancient name of the town of Sudak with a stratotype near the Alchak-Sedlovina section (Chepalyga, 2015; Chepalyga et al., 2019). The marine sequence of this terrace corresponds to the deposits of the Lower Chauda at Cape Chauda with the fauna of molluscs of the Caspian type *Didacna baericrassa*, but without representatives of the endemic genus *Tschaudia*. In the stratotype of the Lower Chauda, the normal magnetization of the Brunhes epoch younger than 781 ka was revealed. Age correlates with MIS 19 stage.

2.2. Field survey and samples. The Alchak-Sedlovina section is morphologically described according to the FAO (2006). The color of the deposits was determined using the Munsell color system (2000) on a fresh section wall. Sampling for laboratory analysis was performed continuously with a step of 4 cm. Magnetic susceptibility (MS) in field was measured with a PIMV kappameter with same measuring interval. A total of 51 bulk samples were taken for physical and chemical analyses. Also, 10 bulk samples were taken from each paleosol horizon for morphoscopy of sandy quartz grains. Soils were described according to IUSS Working Group WRB 2014 (2015).

2.3. Laboratory analyses. The particle size distribution of the samples was analyzed using a laser diffractometer Malvern Mastersizer 3000 with liquid sample dispersion unit Hydro EV. The distribution of particles over size fractions was calculated on the basis of the Fraunhofer approximation (Blott, Pye, 2001). Preparation of a bulk sample included the following steps: filling with 10% HCl solution of acid for 24 hours; treatment with 30% hydrogen peroxide solution H_2O_2 until the completed reaction; treatment of the material with a 4% solution of $Na_4P_2O_7$, followed by dispersion of the material using ultrasound. Mastersizer v.3.62 software was used to calculate grain size statistics. When describing soil characteristics, the system 2000–63–2 μm was used (FAO–ISRIC, 1990).

The quartz grain shape and surface were studied following the procedure developed in the Institute of Geography, RAS (Velichko, Timireva, 1995). The modern soil was characterized by 1 sample, followed by 3 samples from each paleosol horizon (fig. 3, 5(a)). Quartz grains with a diameter of 0.5–1 mm were isolated using wet sieving and treated with 10% HCl. The sample of 50 quartz grains from each soil sample were examined under a stereomicroscope at ×40-×50 magnifications. During the analysis, the degree of roundness, relief features, and the type of quartz grain surface was recorded. The roundness class was assessed according to the Khabakov visual scale (Khabakov, 1946) using the Rukhin template (Rukhin, 1969), which includes 5 classes: from 0 to IV, where IV is the perfectly rounded, 0 – angular at all. Next, the roundness coefficient (Q) and the degree of matting (Cm) were calculated (Velichko, Timireva, 1995). For a more detailed characterization of the surface, individual quartz grains were additionally studied using a JEOL JSM-6610LV scanning electron microscope, maximum magnification ×950, all images are made in secondary electrons. The description of surfaces was performed in accordance with Krinsley and Doornkamp (Krinsley, Doornkamp, 1973).

Eight samples taken from paleosol profiles were analyzed for pollen content. Laboratory processing of samples was carried out by the separation method (Grichuk, Zaklinskaya, 1948). To remove carbonates, the samples were heated in a 10% HCl solution, followed by bringing the solution to a neutral pH. Next, the resulting material was treated with 10% $Na_4P_2O_7$ $10H_2O$. The resulting precipitate was separated in a heavy liquid with a density of 2.25 g/cm^3.

3. RESULTS

3.1. Soil morphology. The LPS of the Alchak-Sedlovina section is shown in figs. 4 and 5. Here, the profile of modern soil is represented by two horizons:

ABk (0.4 m) – dark brown (10 YR 5/6) fine-porosity, loam. The structure is granular. Carbonate pseudomycelia stands out along the roots, small carbonate concretions;

BCk (0.9 m) – light brown (10 YR 6/6), loam. The structure is blocky subangular, the horizon is denser. Small carbonate concretions and carbonate pseudomycelia stand out along the surfaces of the aggregates.

Below lies the PS1-AS paleosol, which consists of hor. Bk and BCk. The soil stands out in the LPS with a brownish-pale color, carbonate concretions, and an abundance of clay-humus coatings along the root courses.

Bk (1.88 m) – pale brown (7.5 YR 6/6) lighter in the upper part due to nearby loess, clay loam. Porosity, well structured, granular structure, thin clay coatings along the surfaces of the structure. Carbonate mycelium in pores.

BCk (0.25 m) – brown (7.5 YR 6/6) granular-blocky, clay loam. A molehill was found in the horizon. Carbonate concretions 1 cm in diameter. There are inclusions of unrounded gravel up to 2 cm in diameter.

The PS2-AS paleosol. Its profile is represented by three horizons: Ak, BCk and Ckg.

Ak (0.26 m) – brown (10 YR 6/5), loam. The structure is granular. There are rare inclusions of gravel. A lens 5 cm in diameter was found here, filled with an accumulation of *Helicella Striata* (Z.) snails. There is the crack coming from the layer.

BCk (0.20 m) – brown with a bluish tint (10 YR 6/4) very dense, loam, rarely porous, granular structure. Rare crystals of gypsum have been found. Clay coatings along the surfaces of the structure. Horizon with cracks and layers of fine gravel.

Ckg (0.28 m) – gray with a brown tint (10 YR 6/4), loam, granular structure. The upper part is represented by a layer of gravel, very dense, slightly porous. Carbonate material and formed carbonate concretions up to 2 cm in diameter throughout the layer. Clay coatings and bluish patches gleying along the surfaces of the aggregates.

The profile of the underlying paleosol PS3-AS is as follows: ABk, Bk, BCk.

ABk (0.20 m) – brown (10 YR 5/6) clay loam, lumpy-granular structure, fine-porosity, the layer is permeated with pores up to 0.5 cm in diameter, inclusions of large gravel up to 7 cm in diameter. Clay coatings along the faces of structural units, intense carbonated pseudomycelia and carbonated concretions.

Bk (0.32 m) – pale yellow with a brown tint (10 YR 6/4, 6/6) dry, granular structure, porosity, Fe-Mn coatings on the faces of peds and pores, coprolites, rare inclusions of gravel up to 1 cm in diameter, identical to the overlying layers. Rare concentrations of crystalline gypsum and small carbonated concretions. To the bottom of the horizon, the amount of gravel increases.

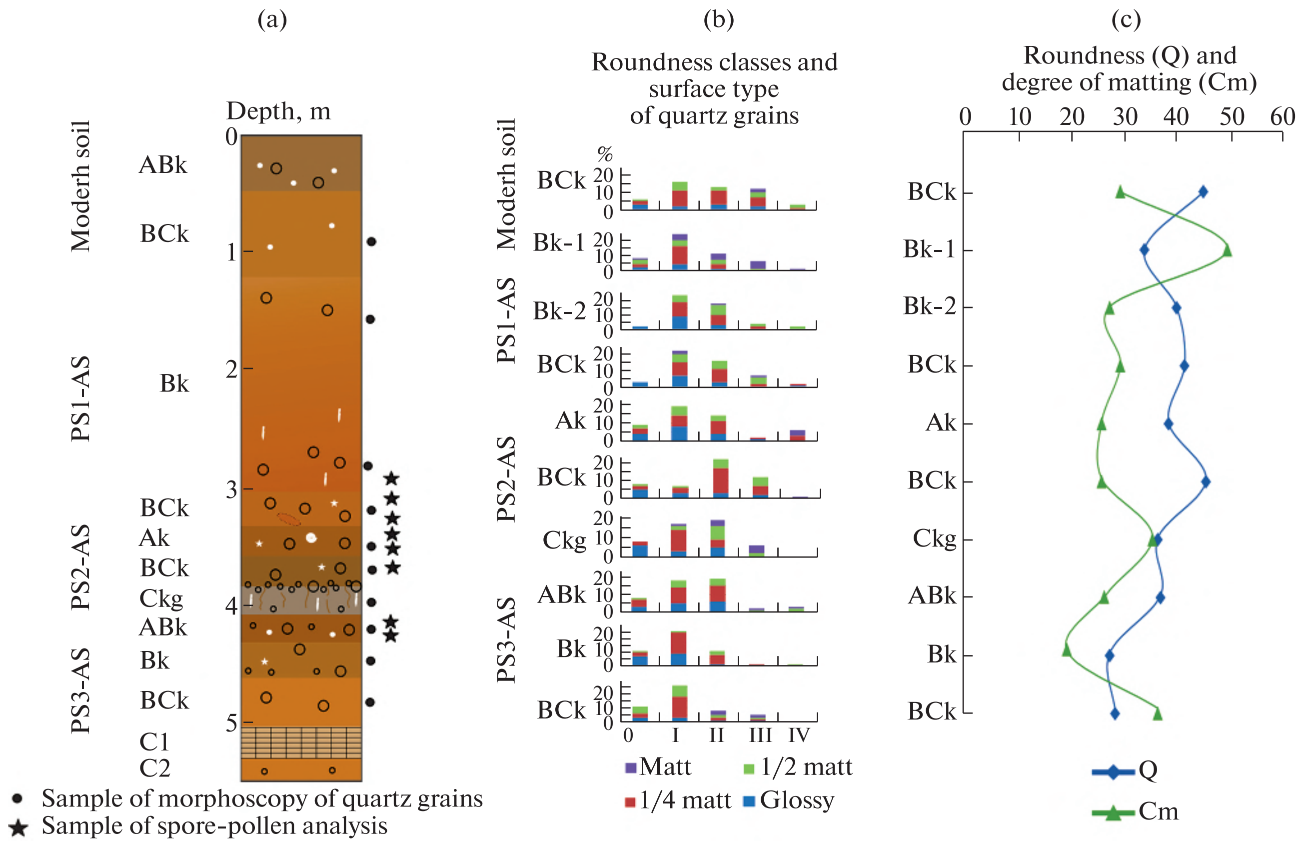

Fig. 3. The LPS of the Alchak-Sedlovina section: (a) – sampling point for spore-pollen analysis and morphoscopy of quartz grains. Morphoscopy of sand quartz grains: (b) – histograms of roundness classes and surface type of quartz grains. *Figure captions*: 0, I, II, III, IV – roundness classes; (c) – distribution charts of Q and Cm coefficient.

Рис. 3. ЛПС разреза Алчак-Седловина: (a) – места отбора проб на спорово-пыльцевой анализ и морфоскопию песчаных кварцевых зерен. Морфоскопия песчаных кварцевых зерен: (b) – гистограммы окатанности и типов поверхности кварцевых зерен. *Условные обозначения:* 0, I, II, III, IV – классы окатанности; (c) – графики распределения значений коэффициентов Q и Cm.

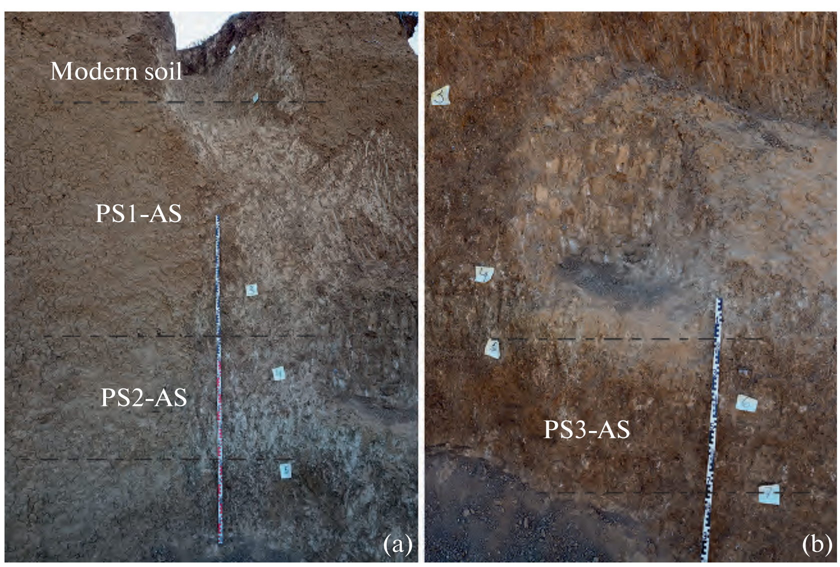

Fig. 4. The Alchak-Sedlovina section with paleosols: (a) – PS1-AS and PS2–AS; (b) – PS3-AS.

Рис. 4. Профили палеопочв в разрезе Алчак-Седловина: (a) – PS1-AS и PS2-AS; (b) – PS3-AS.

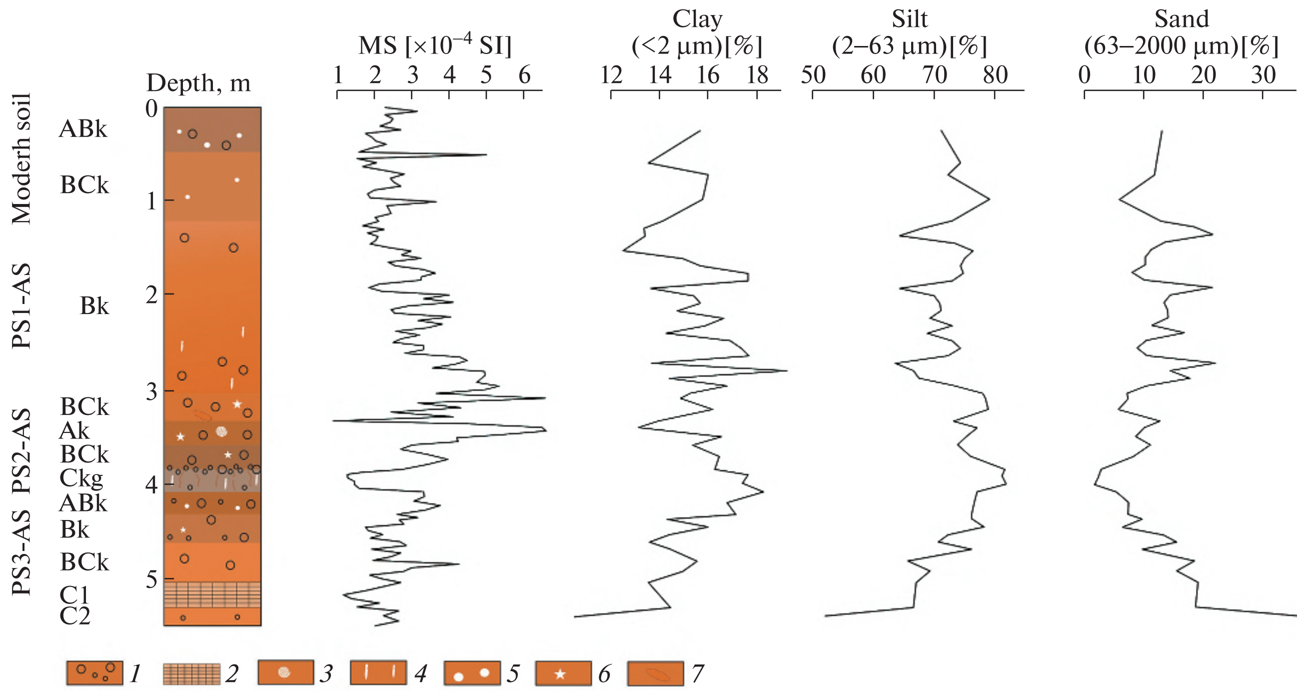

Fig. 5. The LPS of the Alchak-Sedlovina section, values of MS and particle size distribution.

1 – gravel; *2* – gravel layer; *3* – shells of *Helicella Striata* (Z.) snails; *4* – oblong shape carbonate pedofeatures; *5* – carbonate nodules; *6* – crystalline gypsum; *7* – mole burrows.

Рис. 5. ЛПС разреза Алчак-Седловина, значения магнитной восприимчивости и гранулометрического состава.

1 – гравий; *2* – гравелистый слой; *3* – ракушки улиток *Helicella Striata* (Z.); *4* – карбонатные новообразования продолговатой формы; *5* – карбонатные конкреции; *6* – кристаллический гипс; *7* – кротовина.

BCk (0.44 m) – pale yellow (10 YR 6/4, 7/6), dry. Granular structure, non-porous, small gravel inclusions up to 1 cm in diameter. Fe-Mn coatings along the surfaces of the structure and impregnated with carbonates.

The PS3-AS paleosol underlies layer C1, which is a mixture of loam, gravel, and pebbles.

3.2. Particle size and magnetic susceptibility distribution. The LPS of the Alchak-Sedlovina is composed mainly of silt fraction (fig. 5), from 50 to 80% of all fractions. The silt fraction is uniformly distributed over the section; the values decrease towards the bottom of the PS3-AS paleosol. The indicators of the clay fraction are also distributed evenly and do not exceed 20%. There is an insignificant accumulation of the clay fraction towards the bottom of horizons BCk (PS1-AS) and Ckg (PS2-AS). The distribution of clay and silt particles along the profile of the LPS is eluvial-illuvial. The high content of the sandy fraction is confined to the PS1-AS paleosol; individual peaks (up to 20%) are distinguished here. In Ak and BCk horizons of the PS2-AS paleosol, the sand content increases to 15%. Sand mainly accumulates in the lower part of the section, here the values gradually increase from PS3-AS to the C1 horizon.

MS indicates the levels of humus horizons. Low MS values are associated with modern soil (1.7–3.2 $\times 10^{-4}$ SI), individual peaks are visible. In the paleosol PS1-AS MS gradually increases downwards, to a maximum of 6.9 $\times 10^{-4}$ SI at the bottom of the BCk horizon and fall in the transitional part of the BCk horizon to PS2-AS (2.4 $\times 10^{-4}$ SI). The PS2-AS profile shows two MS peaks: in the Ak (6.9 $\times 10^{-4}$ SI) and BCk (4.2 $\times 10^{-4}$ SI) horizons. In the Ckg horizon of this paleosol, the MS values drop sharply. In the PS3-AS paleosol, the average MS values are slightly lower than the overlying paleosols: horizon ABk (3.4 $\times 10^{-4}$ SI), horizon Bk (2.38 $\times 10^{-4}$ SI) and horizon BCk (2.6 $\times 10^{-4}$ SI).

3.3. Morphoscopy of quartz grains. Grains of the I roundness class predominate in the modern soil, as well as in PS1-AS and PS3-AS paleosols, while the I and II roundness classes predominate in PS2-AS (fig. 3, (b)). The coefficient of roundness (Q) across the LPS does not differ in variability and varies from 27.5–45.5% (fig. 3, (c)). The minimum roundness coefficients are found in the lower horizons of the PS3-AS paleosol and take values of 27–28%, the maximum in the BCk horizon of the PS2-AS. In all soils, grains with a quarter-matte and glossy surface predominate, and a small amount of half-matte grains is also present. The coefficient of matting (Cm) ranges from 29 to 45%.

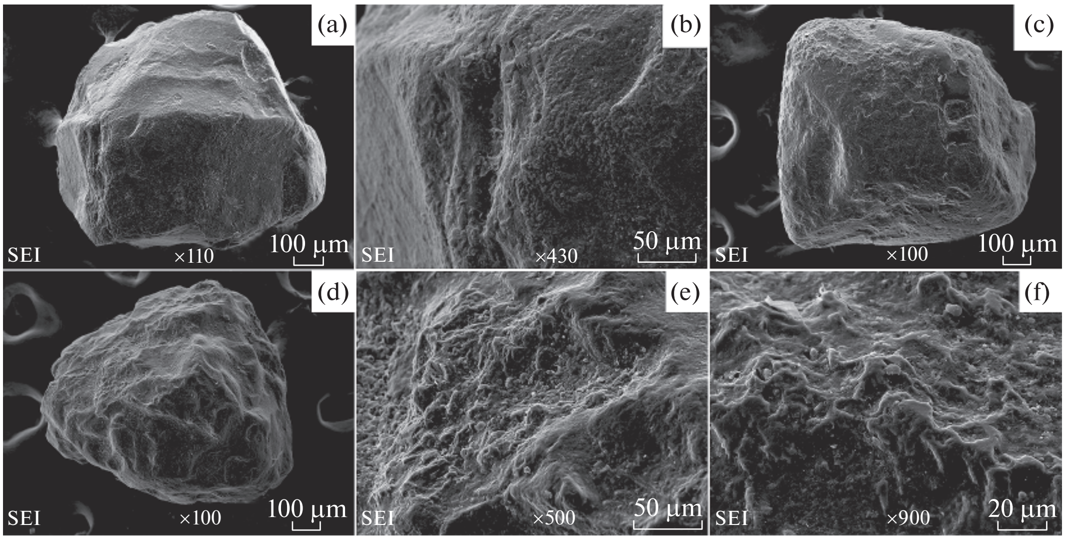

Fig. 6. Quartz grain morphoscopy in the modern soil: (a, b) – parallel grooves; (c, d) – grain with pitted surface; (e, f) – crescent pits.

Рис. 6. Морфоскопия кварцевых зерен из современной почвы: (a, b) – параллельные борозды; (c, d) – зерна с ямчатой поверхностью; (e, f) – серповидные ямки.

Modern soil is characterized by domination of grains I, II and III class of roundness. A large number of grains with a quarter-matt surface. Special interest are particles having two parallel grooves (fig. 6, (a, b)). There are also grains with a pitted surface (fig. 6, (c, d)) and grains with conchoidal fractures. Signs of diagenesis are reflected in crescent pits (fig. 6, (e, f)) and etched zones on quartz grains.

The dominant class of roundness in PS-1AS is I and II, glossy and quarter-matt grains. Quartz grains in the PS1-AS are characterized by a pitted surface (fig. 7, (a, b)) with silica films, large and small conchoidal fractures (fig. 7, (c, d)) and crescent pit (fig. 7, (b, e)). Split grains with etched zones (fig. 7, (f)) and "fresh" grains are not uncommon (fig. 7, (g)). In horizon Bk, compared to other horizons of paleosols, the maximum number of perfectly matt grains was found. These grains belong to the III class of roundness (fig. 7, (h)). The entire paleosol also has a high content of glossy grains.

The dominant class of roundness in PS2-AS is I and II, quite a lot of grains with quarter-matt and glossy surface. A significant number of grains with semi-matt surface. Quartz grains in PS2-AS are characterized by particles having two parallel grooves and conchoidal fractures. The number of roundness class 0 grains increases, glossy grains are noted with V-shaped pits (fig. 8, (a)), grains are often split in half (fig. 8, (b)), "fresh" grains are noted (fig. 8, (c)), grains with large conchoidal fractures (fig. 8, (e)). In the Ak horizon, the percentage of class IV grains increases. In a small amount, particles with aeolian characteristics are noted: with flat and crescent pits (fig. 8, (d)), grains with a micro-pitted surface (fig. 8, (f)).

In the PS3-AS paleosol the maximum number of grains of the 0, I roundness classes and completely angular grains are recorded in the entire profile. The humus horizon ABk of the PS3-AS is also characterized by a high content of grains of class II; grains of class III and IV are also recorded in a small amount. The grains in this soil are angular (fig. 9, (a)), with a pitted surface (fig. 9, (b, c)). Often there are grains with glossy potholes (fig. 9, (d, e)), parallel grooves (fig. 9, (f)) and single deep grooves filled with silica (fig. 9, (g)). Conchoidal fractures and flat pits are numerous. Grains with signs of chemical etching on the surface are registered (fig. 9, (h)).

The processes of diagenetic transformation of material in all paleosols are clearly identified: V-pits (fig. 10, (a)), dense silica precipitations (fig. 10, b, c), as well as filling of pits with silica (fig. 10, (d)), etching zones (fig. 10, (e)) are marked on the surface of the grains. Newly formed gypsum crystals (fig. 10, (f)) are also noted in paleosols PS2-AS and PS3-AS. Abundant carbonate coatings are recorded on grains not treated with acid.

3.4. Spore-pollen analysis. In the PS1-AS paleosol, 180 grains were found in the sample collected from Bk horizon. Tree and shrub pollen is absent, grass pollen predominates 67.4%: Cyperaceae 22.6%, Poaceae 5.5%, Artemisia 5.5%, Chenopodiaceae 4.4%, *Plantago* 7.7%, *Urtica* 6.0%, single *Ephedra,* Asteraceae, Rosaceae, Fabaceae and other representatives of forbs were identified. The number of spores is 32% of the total number of counted grains. Spore plants are represented by a variety of Polypodiaceae, club-mosses and non-vascular mosses. In the BCk horizon, the number of pollen grains and spores is 198 units. *Salix*, *Quercus*

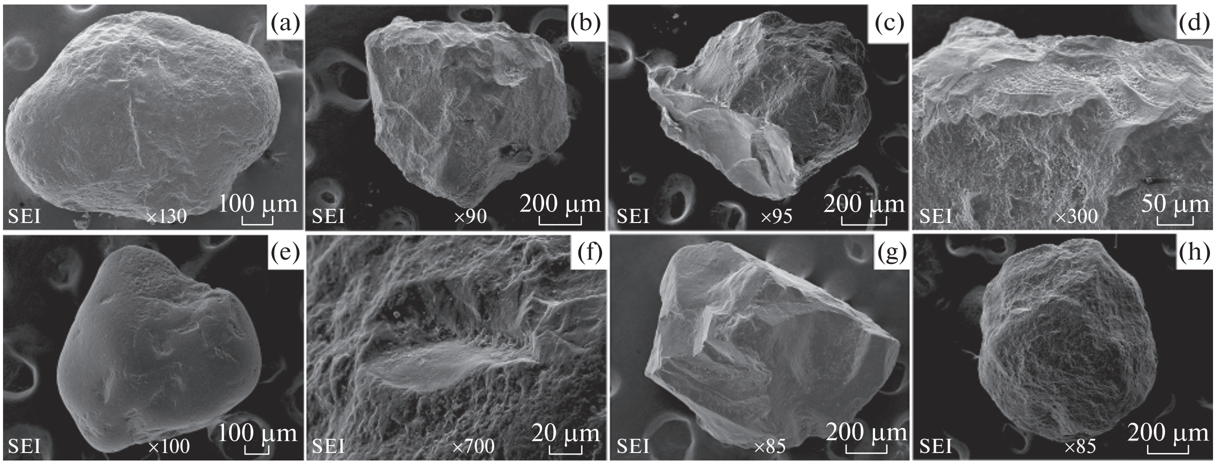

Fig. 7. Quartz grain morphoscopy in the PS1-AS paleosol: (a) – grain with pitted surface; (b) – pitted surface and conchoidal fractures; (c) – large conchoidal fractures (grain split in half); (d) – conchoidal fracture; (e) – crescent pit; (f) – etched zones and potholes; (g) – "fresh" grain; (h) – grain with pitted surface of III class of roundness.

Рис. 7. Морфоскопия кварцевых зерен палеопочвы PS1-AS: (a) – зерно с ямчатой поверхностью; (b) – ямчатая поверхность и раковистые изломы; (c) – крупный раковистый скол (зерно разбито пополам); (d) – раковистый скол; (e) – серповидные ямки; (f) – зона травления и выбоина; (g) – "свежее" зерно; (h) – зерно с мелкоямчатой поверхностью III класса окатанности.

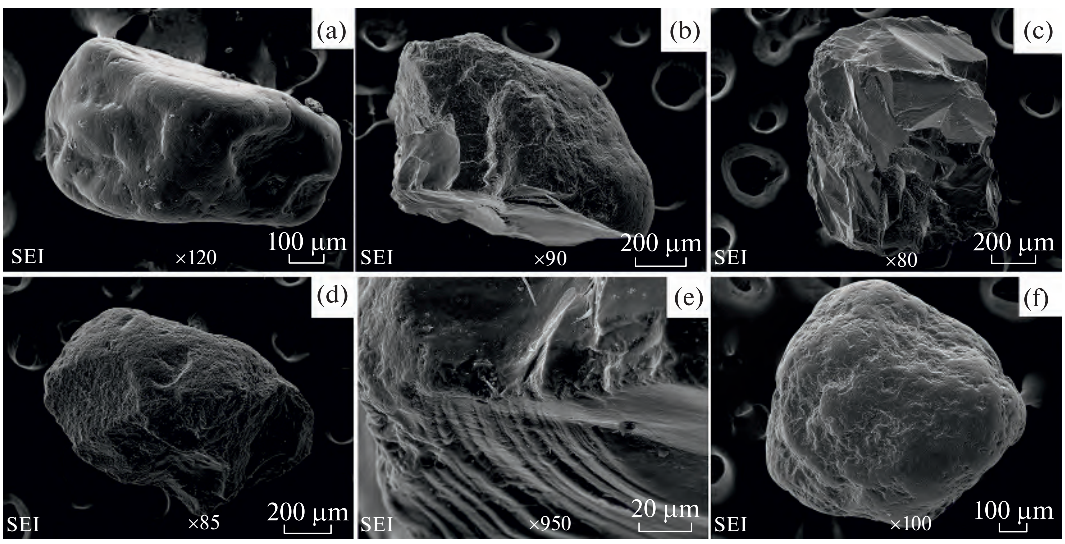

Fig. 8. Quartz grain morphoscopy in the PS2-AS paleosol: (a) – glossy grain with V-shaped pits; (b) – grain with conchoidal fractures (grain split in half); (c) – "fresh" grain; (d) – flat and crescent pits; (e) – conchoidal fracture; (f) – grain with micropitted surface.

Рис. 8. Морфоскопия кварцевых зерен палеопочвы PS2-AS: (a) – глянцевое зерно с V-ямками; (b) – зерно с раковистыми сколами (зерно разделено пополам); (c) – не окатанное "свежее" зерно; (d) – плоские и серповидные ямки; (e) – раковистый скол; (f) – зерно с микро-ямчатой поверхностью.

were noted among single woody 2.0%. Grass pollen prevails 73.7%, among which Poaceae 39.9%, Cyperaceae 24.7% and single pollen grains of *Plantago*, *Urtica*, Chenopodiaceae, Asteraceae, Polygonaceae, Rosaceae, Fabaceae. The number of spores reaches 24%, among which Polypodiaceae and *Lycopodium* are noted. In the lower part of the BCk horizon, 195 grains were counted. Among them, the pollen of *Salix* and *Ulmus* trees is single 1.5%. The amount of grass pollen 57.7% and spores 46.6% are approximately the same. Herbs are dominated by Poaceae 11.4%, Cyperaceae 7.6%, *Urtica* 8.7%, *Plantago* 6.1%, *Rumex* 5.6%. The largest number of spores was noted in the sample, among which spores of Polypodiaceae 15.3%, *Lycopodium* club-mosses 14.8% and non-vascular green mosses *Bryales* 13.3% predominate.

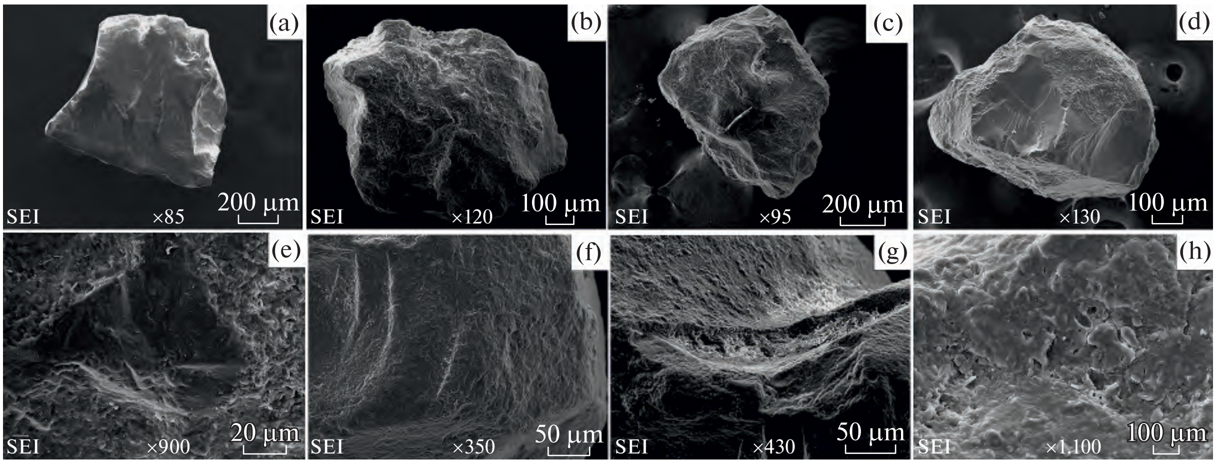

Fig. 9. Quartz grain morphoscopy in the PS3-AS paleosol: (a) – angular grain; (b, c) – pitted surface; (d, e) – glossy potholes; (f) – parallel grooves; (g) – deep grooves filled with silica; (h) – chemical etching on the surface.

Рис. 9. Морфоскопия кварцевых зерен палеопочвы PS3-AS: (a) – не окатанное зерно; (b, c) – зерна с ямчатой поверхностью; (d, e) – глянцевые выбоины на поверхности зерна; (f) – параллельные борозды; (g) – глубокая борозда, заполненная кремнеземом; (h) – зона травления.

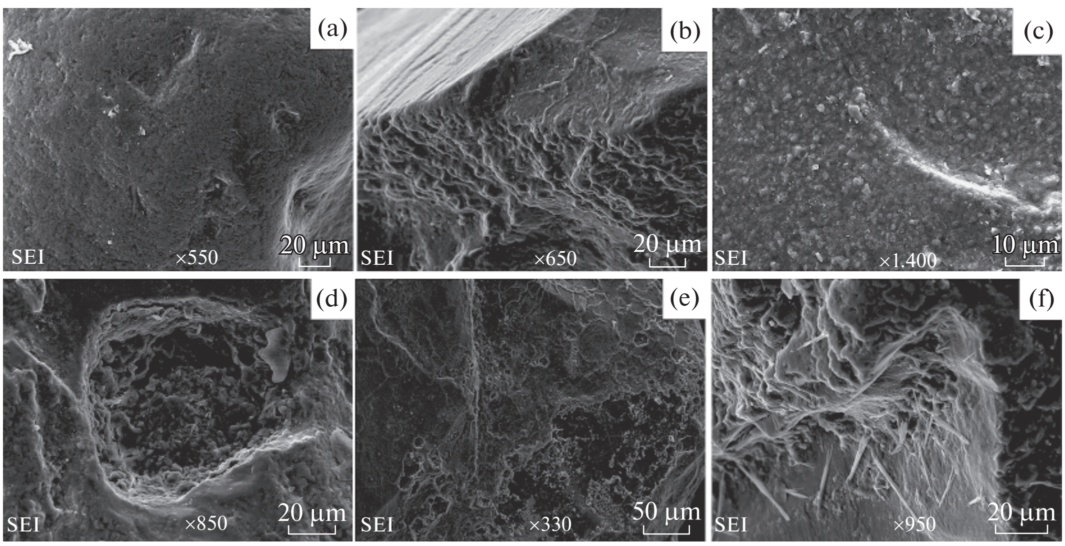

Fig. 10. Signs of diagenetic transformation of quartz grains surfaces: (a) – V-pits (horizon Ckg of the PS2-AS); (b) – silica precipitations (horizon Ckg of the PS2-AS); (c) – silica precipitations (horizon ABk of the PS3-AS); (d) – filling of pits with silica (horizon BCk of the modern soil); (e) – chemical etching on the surface (horizon BCk of the modern soil); (f) – gypsum crystals (horizon Ckg of the PS2-AS).

Рис. 10. Признаки диагенетического преобразования поверхности кварцевых зерен: (a) – V-ямки (горизонт Ckg палеопочвы PS2-AS); (b) – кремнеземистые пленки (горизонт Ckg палеопочвы PS2-AS); (c) – кремнеземистые пленки (горизонт ABk палеопочвы PS3-AS); (d) – ямки, заполненные кремнеземом (горизонт BCk современной почвы); (e) – зоны травления (горизонт BCk современной почвы); (f) – кристаллы гипса (горизонт Ckg палеопочвы PS2-AS).

In the PS-2AS paleosol, the sample from the upper part of the Ak horizon contains 184 grains, of which arboreal pollen contains 7.6% (*Salix*, *Ulmus*, *Quercus*), grass pollen 73.9%, among which Cyperaceae 12.5%, Poaceae 11.4%, *Urtica* 13.9%, *Rumex* 6.5%, *Plantago* 5.9%, Asteraceae 5.9%, Chenopodiaceae and other herbs. The number of spores reaches 18.4%, among which spores of Polypodiaceae predominate.

In the sample from the lower part of the same horizon, 220 grains were counted, woody – 5.4% (*Salix*, *Ulmus*, *Quercus*), herbaceous – 92.2%, dominated by Poaceae, Cyperaceae, *Rumex* 10.4%, *Urtica* 15.4%, single *Ephedra*, *Artemisia*, Chenopodiaceae. The amount of spores is small – 2.2%. The smallest amount of pollen and spores was found in the sample from the BCk horizon (104 grains). The pollen of woody plants is single 1.9%, contains grains of *Salix* and *Quercus*. Among herbs 76.9% dominated by Cyperaceae 19.2%, *Urtica* 14.4%, Polygonaceae 5.7%, *Plantago* 4.8%, *Rumex* 4.8%, Chenopodiaceae 4.8%, etc. The number of spores of *Bryales*, Polypodiaceae, *Lycopodium* reaches 21.1%.

The PS-3AS paleosol is characterized by the largest amount of pollen and spores. In the sample collected from upper part of the ABk horizon were found 272 grains. Here the pollen of woody plants is single 7.3%: *Ulmus* 5.5% and other (*Quercus, Carpinus*). Grass pollen prevails 89.3%, represented by a variety of *Varia*: *Ephedra*, Poaceae, Cyperaceae, Caryophyllaceae, Chenopodiaceae, Asteraceae (13.2%), *Rumex* 9.1%, *Plantago* 5.5%, *Urtica* 18.7%, *Potentila* 6.6%, etc. There are few spores – 3.3% of Polypodiaceae. In the lower part of horizon ABk, 232 grains were found. Among the pollen of woody plants, 10.7% were grains of *Betula*, *Salix*, *Carpinus*, *Ulmus*, *Quercus*. Grass pollen 77.5% is represented by Poaceae 4.3%, Cyperaceae 4.3%, *Rumex* 6.4%, *Plantago* 8.1%, *Urtica* 12.9%, Fabaceae 10.3%, Polygonaceae 4.3%, few pollen grains Asteraceae, Rosaceae and other herbaceous plants. Among the spore plants, 11.6% were spores of *Lycopodium* 5.1% and Polypodiaceae 4.3%.

4. DISCUSSION

4.1. Genesis of paleosols. The modern soil of the Alchak-Sedlovina section is carbonated, the humus horizon is well distinguished, however, the low values of magnetic susceptibility, even in the Ak horizon, are associated with a strong profile erosion. According to the results of the granulometric composition, the clay fraction is carried down the profile. Low-rounded quartz grains (I and II classes) with a parallel grooves, characterize the prevailing processes of water transport of particles. A small number of well-rounded grains (III class) with a micropitted surface indicates a slight aeolian transport of redeposited particles. The transport of particles by water was weak since the features weakly affect the surface of the grains, and there is no layering in the profile structure, which is typical for water erosion (Krinsley, Doornkamp, 1973). Signs of the soil-forming process, namely the action of soil solutions, are clearly visible on quartz grains; these are crescent pits and etching zones on quartz grains, confined mainly to fractures. The presence of carbonated concentrations, specific brown color and morphology allows us to attribute this soil to the Calcic Cambisol.

The PS1-AS paleosol is strongly carbonized in the lower part of the profile and eroded since the humus horizon is absent and the magnetic susceptibility increases towards the bottom; apparently, the BCk horizon was previously surfaced. It is possible that the absence of a humic horizon is associated with intense slope erosion of soils and the removal of surface horizons. According to the results of granulometric analysis and morphological description, lessivage processes were actively proceeding in this soil, which is recorded in clay coating. According to the results of morphoscopy, the largest number of grains of II and III classes of roundness is noted, among which there are a large number of particles with a glossy surface, which indicates an active introduction of fresh material by water (Krinsley, Doornkamp, 1973). Grains with a quarter-matt surface, on which micropits are fixed, indicate a weak aeolian winding of the material. A small amount of fresh grains (class 0) indicates the influence of slope processes. Grains with cracks of varying degrees about the secondary transformation of the soil under the influence of freezing (Krinsley, Doornkamp, 1973). Soil formation took place under different conditions: the lower horizons were formed under more humid warm conditions, then the conditions changed towards aridization and cooling, as evidenced by the data of spore-pollen analysis. Apparently, this paleosol developed according to the Calcic argic Cambisols type. The PS1-AS paleosol was formed under transitional vegetation from forest-steppes to cereals-sagebrush-motley.

In the PS2-AS paleosol, according to the MS results, humus ABk and transitional horizons BCk are clearly distinguished. The paleosol was formed with the participation of the processes of accumulation of clay and silty fractions, as well as stagnic conditions. The paleosol contains an abundance of new carbonate formations, which indicates an arid climate. The results of morphoscopy of quartz grains indicate the input of material with the participation of water flows (classes I and II) and the active input of unrounded material by slope processes: the number of grains of roundness class 0 increases, “fresh” and glossy grains are noted in the horizon, grains with V – shaped pits and conchoidal fractures. The aeolian transfer was insignificant: grains of III and IV classes with a quarter-matt and semi-matte surface are present in an insignificant amount. Often the grains are split in half, such signs are recorded after the deposition of material, which may be due to seasonal freezing (Krinsley, Doornkamp, 1973). Given the above, the PS2-AS paleosol was formed during waterlogging, possibly there was a stagnation of fluvial flows, as evidenced by the gray shade of the profile and gravel interlayers, which were introduced by water flows. Later, the climate became drier and warmer, the soil began to acquire signs of dry steppe soils. The PS2-AS paleosol can be attributed to the Gleyic Cambisols. The paleosol PS2-AS has a hydromorphic type of development and was formed under the transitional type of vegetation: from forest-steppes to cereals-grassland steppes in a temperate-warm climate.

Two MS peaks are in the PS3-AS paleosol: the first small peak in the humus horizon is associated with soil formation, and the second peak in the BCk horizon is associated with weak ferrugination. In this paleosol, in contrast to the overlying paleosols, the granulometric composition becomes lighter, the content of the sand fraction increases towards the BCk. Carbonate concretions in the paleosol are concentrated in a small amount in the upper horizons, thin Fe-Mn coatings are clearly traced to the bottom, such signs are associated with seasonal high soil moisture. The intensity of soil formation processes is recorded on the surfaces of quartz grains in the form of etching of fractures, silica powder, crescent pits (Krinsley, Doornkamp, 1973). Crystalline gypsum is recorded not only in the morphological description, but also on the fractures of quartz grains, similarly to the PS2-AS. Grains with signs of freezing are also noted. In the PS3-AS, according to the results of the morphological description of the section, the amount of gravelly material increases. This indicates an intensive supply of material. It is also confirmed by the morphoscopy of quartz grains, here the largest number of unrounded and slightly rounded glossy grains (0, I and II classes). Grains with parallel grooves, characteristic of water transport, and grains with a quarter-matt surface are recorded, which indicates a weak eolian processing. Large potholes on quartz grains also indicate high transfer and impact rates (Velichko, Timireva, 1995). Similar to the overlying the PS2-AS paleosol, grains could be processed and come with a fluvial flow. The PS3-AS paleosol was formed under conditions of dry warm steppes with periodic moistening, under mosaic-type vegetation: to cereals-grassland steppes, forests of the Mediterranean type and woodlands of birch. Given the above, it can be assumed that this soil belongs to the Cambisols type.

4.2. The age correlation of paleosols. On the territory of Crimea, paleosols of reddish hues are found mainly in Pliocene deposits (Veklich, Sirenko, 1976; Panin et al., 2019b). In the Alchak-Sedlovina section, the LPS is underlain by the V Perchem terrace, the age of which makes it possible to correlate the studied paleosols to the Pleistocene period, starting from MIS 17 and younger one. On the territory of the East European Plain, paleosols of this age with a reddish color are associated with the Vorona pedocomplex (MIS 13/15) (Veklich, Sirenko, 1976; Velichko et al., 2009a; 2009b; Panin et al., 2019a; 2019b). In the Platovo section of Rostov region, Lebedeva (1972) identified the V Platovo Chaudian terrace, which is covered by red-colored paleosols. Velichko et al. (2009a) compared these paleosols with the Vorona pedocomplex. Taking into account that the V Perchem terrace correlates with the V Platov marine terrace, it can be assumed that the paleosols of the Alchak-Sedlovina section can also belong to the Vorona pedocomplex. The data of spore-pollen analysis can serve as an indirect confirmation of the age of these paleosols. Where in paleosols, with a high degree of conditionality, the reconstructed vegetation is compared with the Lubny stage identified in Polesia and Carpathian foothills (Sirenko, 2017), which correlates with the Muchkap Interglacial. Sirenko and Turlo (1986) also distinguished the reddish-brown paleosols in the Lubny horizon of the Central Black Sea region.

The paleosols of the Vorona pedocomplex in the LPS of the Sea of Azov (Velichko et al., 2009b; Panin et al., 2019a) developed under more humid conditions than in the Crimea. Since in their profiles, in contrast to paleosols of the Alchak-Sedlovina section, there are plentiful Fe-Mn nodules and there are no gypsum crystals (Panin et al., 2019a), which are one of the main signs of an arid climate (Minashina, Shishov, 2002).

5. CONCLUSIONS

Based on the correlation of the age of the V marine terraces of the Black Sea and the Sea of Azov, the Alchak-Sedlovina LPS is presumably assigned to MIS 13/15. The soils of Alchak-Sedlovina belong to the Vorona pedocomplex, taking into account the age of the Perchem sea terrace and comparison of data obtained from the multi-proxy analysis of the Alchak-Sedlovina LPS, and the LPS of the Vorona pedocomplex of the Sea of Azov and the Lubny stage in the Steppe Crimea and the Black Sea region.

The investigation of the LPS of the Alchak-Sedlovina showed that in the mountainous part of the Crimea, the paleosol sequence is quite distinctly preserved, represented by paleosols of the Cambisols type, two automorphic soils and one hydromorphic soil. In the MIS 13/15 (Early Pleistocene), paleosols were formed under conditions of warm steppes or forest-steppes with periodic moistening and often local stagnation of moisture; in the cold season, there was slight freezing of the surface. During the formation of the lower part of the LPS profile (PS2-AS, PS3-AS), coarse clastic material was introduced. Later, the climate became drier and warmer, steppe, similar to the modern one; during the formation of the PS1-AS, such a climate dominated for a much longer time, but erosion processes were activated, which removed the humus horizon of the soil.

During soil formation, the stability of sedimentation was preserved. The main agent for the formation of the LPS was aeolian transport as a source of silty material, according to granulometric analysis data. According to the morphoscopy data of quartz grains, slope processes and temporary streams were the agents of sandy material. An insignificant number of grains with eolian signs and traces of eolian processing indicates the stabilization of eolian processes during the redeposition of the material. The predominant unrounded and slightly rounded grains of sandy material with glossy and quarter-matte surface types indicate that during the formation of the LPS, additional material was introduced from a nearby source, there is only one such source near the section – a mountain range.

THE STRUCTURE AND FORMATION CONDITIONS OF THE EARLY PLEISTOCENE PALEOSOLS IN THE LOESS-PALEOSOL SEQUENCE OF THE ALCHAK-SEDLOVINA SECTION (REPUBLIC OF CRIMEA)

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Paleosols are one of the main paleoecologic indicators that record changes in the environment in loess-paleosol sequence. Understanding the peculiarities of the structure of paleosols and the natural processes that caused them makes it possible to reconstruct the landscape and climatic conditions in the desired territories. The article presents new studies of the loess-paleosol sequence of the Alchak-Sedlovina section located in the mountainous area of the southern part of the Crimean Peninsula. The section exposed two automorphic paleosols (PS1-AS and PS3-AS) and one hydromorphic paleosol (PS2-AS), which we correlate with the paleosols of the Vorona pedocomplex (MIS13/15). This assumption is based on data obtained from the results of a comprehensive analysis, including a morphological description of paleosols and their physical-chemical parameters. It has been established that the loess-paleosol sequence of the Alchak-Sedlovina section under study was formed on deposits of V Perchem marine terrace, which corresponds to the MIS 17 interval. The paleosols PS2-AS and PS3-AS developed according to the Cambisols under conditions of warm steppes or forest-steppes with periodic moistening and often local moisture stagnation; during the cold season, a slight freezing of the surface was observed. The PS1-AS paleosol profile also corresponds to the Cambisols, but it was formed in a drier climate under steppe vegetation similar to the modern one. In the study area, during periods of accumulation of loess material and soil formation, they were accompanied by constant erosion processes. As a result, in the loess-paleosol sequence of the Alchak-Sedlovina section, layers of large rock fragments are fixed, and the surface horizons of paleosols are eroded. The obtained material allowed us to take a fresh look at the development of the paleosol cover in the mountains of Crimean Peninsula. The revealed characteristics of the paleosols of the Alchak-Sedlovina section can later be compared with other paleosols of the Crimean Peninsula to interpret their age and formation conditions.

Keywords: soil morphology, marine terrace, morphoscopy of quarts grains, Pleistocene, Muchkap interglacial

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