ГЕОМОРФОЛОГИЯ, 2022, том 53, № 3, с. 128–133

СЕДИМЕНТОЛОГИЯ, ПАЛЕОГЕОКРИОЛОГИЯ, ПАЛЕОГИДРОЛОГИЯ

УДК 551.4 072:551.435.5 (470.56)

МОРФОЛОГИЯ И СОВРЕМЕННОЕ ФУНКЦИОНИРОВАНИЕ МЕЛОВЫХ ПОЛИГОНОВ ОБЩЕГО СЫРТА, ЮГО-ВОСТОК ВОСТОЧНО-ЕВРОПЕЙСКОЙ РАВНИНЫ

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Поступила в редакцию 30.03.2022 г.
После доработки 10.04.2022 г.
Принята к публикации 15.04.2022 г.

На меловых породах юго-востока Восточно-Европейской равнины в условиях континентального климата отмечается развитие специфического ландшафта, называемого меловыми полигонами. Для него характерен полигональный микрорельеф и пятнистость, внешне напоминающая медальоны тундры. Объект является уникальным и практически не изученным ландшафтным комплексом. Проведенные исследования выявили комплекс реликтовых криогенных признаков: полигональный рельеф со стороной полигона в среднем 5 м; грунтовые клинья, приуроченные к ложбинообразным понижениям между полигонами; криотурбированность почвенного профиля, и палеокриотекстуры. Полученные данные позволили впервые обосновать палеомерзлотный генезис полигонов. Установлено, что меловые полигоны являются разновидностью реликтового криогенного микрорельефа, сформировавшегося в валдайский криохрон в условиях криоаридного климата, многолетней мерзлоты, морозобойного растрескивания грунтов и роста полигонально-жильных льдов.

Ключевые слова: неоплейстоцен, реликтовая криогенная морфоскульптура, псевдоморфозы, криотурбации, морозное пучение

DOI: 10.31857/S0435428122030130

1. INTRODUCTION

Chalk and chalk-like marls are widely distributed on the territory of the East European Plain. They are part of the sediments of the upper cretaceous system and stretch as an almost continuous strip from the western border of Russia to the southern spurs of the Ural Mountains. The genesis of the upper cretaceous rocks is associated with the lithogenesis of carbonate deposits, the formation of which occurred during the extensive marine transgression of the Late Cretaceous age. Such rocks are exposed or laid close to the surface on the territory of the Srednerusskaya, Kalachskaya, Privolzhskaya and Podol'skaya Uplands, the Obshchy Syrt, and the Podural'skoe Plateau forming a special type of lithogenic landscape called “chalky landscapes“ by V.B. Mikhno (1993). They are diverse in structure, genesis, and forms of relief. They are characterized by chalky mountains, canyons, chalky wastelands with sparse calciferous vegetation, chalky forests, karst lakes and swamps, industrial quarries, etc.

Specific landscape complexes widespread on the territory of the Obshchy Syrt and the Podural'skoe Plateau, in the areas of surface occurrence of upper Cretaceous rocks of the Maastrichtian tier (Cr_2m) represented by white chalk, are of the particular interest. These landscape complexes are called “chalky polygons” for their external similarity to the medallion spots in the permafrost zone. They present themselves as an alternation of isometric microhighs having the shape of polygons and hollow-shaped microdepressions separating them and forming a polygonal network. A feature of the chalky polygons is the presence of the white spots of chalky rock with a diameter of ~2 m in the central part. These landscape complexes are unique for the steppe zone; they are practically unexplored in many aspects, and their genesis is still insufficiently studied and it remains debatable. Polygonal microrelief was explained by the seasonal cryogenesis combined with dissolution and mechanical destruction of limestone rocks by ground water, as well as by swelling of clay after seasonal moistening (Mikhno, 1993; Chibilev et al., 2000; Kliment'ev et al., 2001). Both hypotheses were based on the external configuration of polygonal microrelief without examination of the internal structure.

This article presents the results of a field study of chalky polygons carried out to clarify their genesis and modern functioning.

2. MATERIALS AND METHODS

Comprehensive field studies were conducted at the Starobelogorsky key site located 6 km southwest of the village of Staraya Belogorka in the Novosergeyevsky district of the Orenburg region (52°5′16.98″ N, 53°8′59.05″ E). The key site covers an area of about 3 ha on the gentle concave slope of Buzuluk River at an abs. height of ~250 m a.s.l. (fig. 1, a, b).

The territory is located in the extreme South-East of the East European Plain. This part of the Obschesyrtovo-Preduralskaya Upland steppe province belongs to subboreal continental East European dry-steppe landscapes (Voskresensky et al., 1980; Problemy..., 2010). The site is confined to the close occurrence from the surface of Upper Cretaceous rocks of the Maastrichtian stage (Cr_2m) widespread within the Starobelogorsky graben (Mikhno, 1993). A characteristic feature of the Upper Cretaceous deposits is the development of an eluvial layer in the upper part of the section, which is a gruss with fragments of chalk, fossilized remains of marine fauna, and chalks "flour". With a depth, eluvium represents itself as an array of gravelly debris, which then turns into dense monolithic chalk.

The climate of the area is continental. The mean annual air temperature is +4°C. Winter is cold and severe (average January temperature is −15°C), summer is dry and hot (average July temperature is 22°C). The mean annual precipitation is ~350 mm. The frost-free period lasts about 140 days. The depth of winter freezing is 1.2–1.4 m; the height of the snow cover of about 0.3 m (Geograficheskii atlas..., 2020).

Zonal soils are represented by textural-carbonate chernozems characterized by complex soil and vegetation covers. The vegetation cover is represented by sparsely herbaceous fescue and feather grass steppes and their edaphic variants, which are currently almost completely plowed. Forest vegetation is abundant only on river floodplains, syrts, and small valleys (Geograficheskii atlas..., 2020).

Field studies were carried out in 2020–2022. Morphometric (diameter, length, width, relative exceedences, and slopes of microrelief elements: polygons, chalky spots, and hollow depressions) and morphographic (shape and profile, intensity in relief) parameters of chalky polygons were studied. The features of the site's position in the mesorelief (absolute pitch, slope, surface exposure, etc.) were revealed, and the characteristics of the vegetation cover (species composition, projective cover) were recorded.

The soils were studied in a trench laid along with the profile between adjacent patches of Cretaceous rocks, with a length of ~3 m and a depth of 120 cm. Detailed soil morphological description was carried out together with the sketches and photo fixation. Soil and rock samples were collected for analytical investigation in the laboratory. The depth of free-zing, the iciness of rocks, and cryotextures in soils and sediments were determined and recorded during winter studies. Additionally, the high-resolution satellite images of Google Earth resources for this area were examined.

3. RESULTS

The landscape structure of the key site is represented by a series of isometric microhighs in the form of polygons (pentagons or hexagons) separated by elongated microdepressions (fig. 2, a, b). The average size of polygonal microrelief is ~5 m with the height about 0.1–0.15 m. There are white spots without vegetation with up fo ~2–3 m in diameter in the center of the microhighs. White spots are the dense fine-dispersed crusts of disintegrated limestone with scattered inclusions of hard limestone gravel and belemnite fragments, covered with salt efflorescence.

The white chalky spots were broken into segments separated by the network of lowered strips with vegetation. In the dry period, the surface of chalky spots was very dense and hard, broken by a network of desiccation cracks forming polygons with a side of 0.1–0.15 m.

The hollow-shaped depressions, with the depth 0.1–0.15 m and 0.6–0.8 m width, separating the chalky polygons were poorly expressed in relief, however, the polygonal network was clear due to a thicker and brighter vegetation. The chalky polygons were arranged in the relief in a strictly ordered manner, forming a polygonal-spotted pattern.

The internal structure of the chalky polygons was studied in a trench, which was dug across the microrelief (fig. 3, a, b). Lithological discontinuity was revealed with two layers, disturbed by wedge-shaped structures in the central part of the trench under the hollow-shaped depressions and ascending intrusions of chalky eluvium that reached the surface.

The upper layer was represented by a grayish-brown compacted loam with fine platy structure. The boundary with the underlying layer was sharp, cryoturbated, with mutual intrusions of the layers. From a depth of 0.61 m, finely dispersed chalky material with abundant inclusions of hard chalky fragments of various sizes occurred. In the lower part of the trench, large fragments of chalk formed a solid mass, almost devoid of chalky flour. Ferruginous interlayers, spots, and coating forming a grid were found.

We also identified a ground vein in the central part of the trench in the microdepression between the microhighs with white spots. It differed from the surrounding material by the color and was clear identified

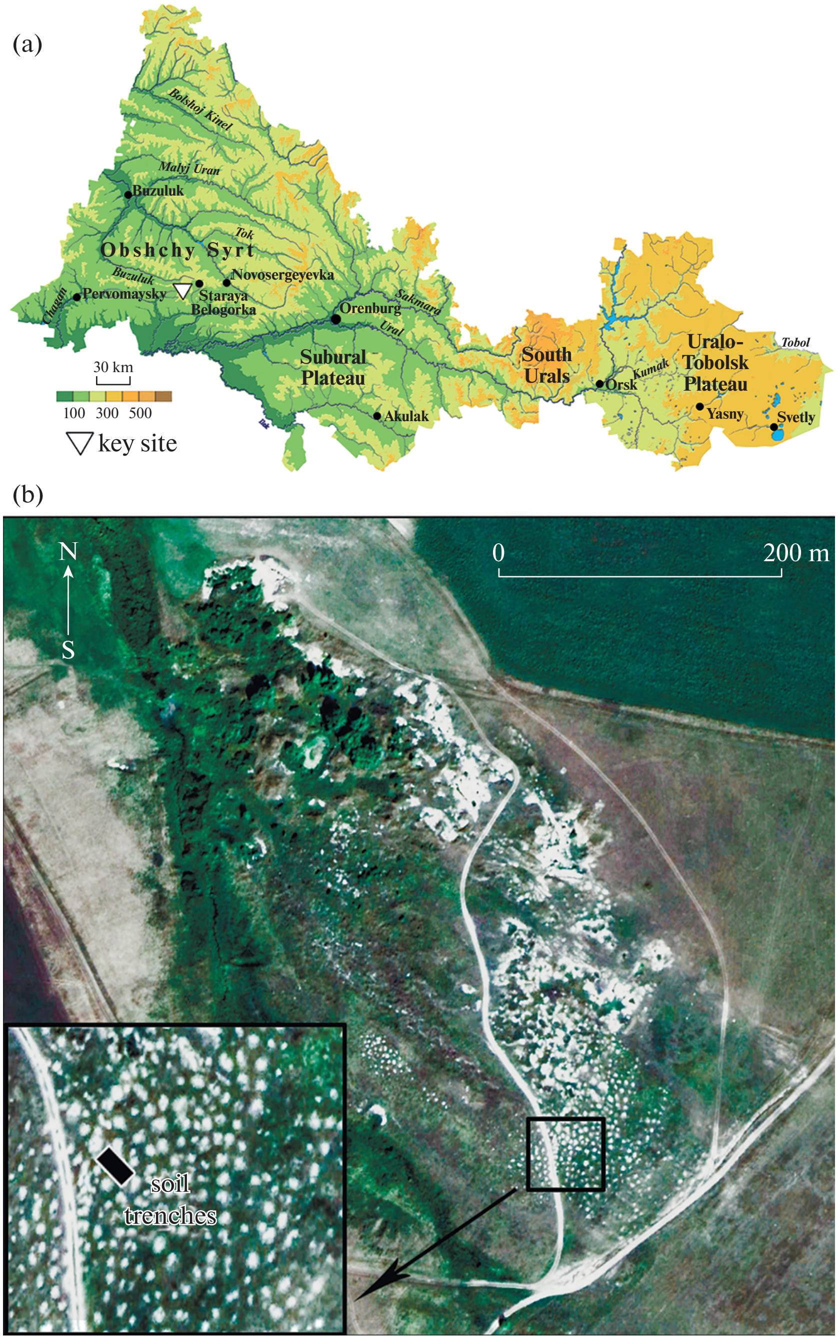

Fig. 1. (a) – Location of Starobelogorsky key site in Orenburg region. (b) – The fragment of the satellite image with a polygonal-spotted microrelief in Starobelogorsky key site (Google Earth).

Рис. 1. (a) – Карта Оренбургской области с расположением ключевого участка. (b) – Фрагмент космического снимка участка Старобелогорский с полигонально-пятнистым микрорельефом (Google Earth).

by the composition. The vein consisted of light gray loose powdery loam, dessicated by open vertical cracks and was very prominent on the background of dense grayish-brown loam. The vein had a two-tiered structure: the upper expanded part 1.2 m wide at the top narrowed to 0.48 m at a depth of 0.5 m, below in the chalky rock it turned into a thin hair-like open crack that went below the trench level. On the southern wall of the trench, the earth vein had several endings or "tails".

A characteristic feature of the studied section was intrusions of chalky material, rising almost vertically towards the polygon centers. The intrusions across the whole soil profiles which reached the surface were marked by the formation of the surface chalky spots.

Fig. 2. (a, b) – Chalky spots among steppe grasses in Starobelogorsky key site (photo by A.G. Ryabukha).

Рис. 2. (a, b) – Меловые пятна среди степной растительности на участке Старобелогорский (фото А.Г. Рябухи).

The intrusions consist of finely dispersed chalky material of a slab structure (the thickness of the tiles increases with a depth of 2–4 to 8–10 mm) with inclusions of chalk rubble of various sizes.

In winter, chalky polygons experience the processes of ice formation and heaving in the central parts of chalky spots. Ice lenses form within finely dispersed chalky spots only. Layered and layered-reticulate pattern of the cryogenic texture of the upper horizons was created by the formation of fine ice lenses 1–1.5 mm thick repeating every 3–4 mm. The distance between the ice lenses increased up to 5–6 mm with depth (fig. 4). The cryotexture is massive in the rocks composing micro-depressions. It connects with their better drainage and slower freezing.

Deep winter freezing resulted both in differentiated frost heaving of the microhighs tops and upfreezing and cryogenic sorting of coarse fragments. Micromounds with a height of 0.02–0.03 m and a diameter of about 0.01 m were found on the surface of chalky spots as a result of the frost heaving.

Fig. 3. (a) – Southern wall of the trench across the microrelif at the Starobelogorsky key site. (b) – Northern wall of the trench across the microrelif at the Starobelogorsky key site (photo by A.G. Ryabukha).

Рис. 3. Южная (a) и северная (b) стенки траншеи на участке Старобелогорский (фото А.Г. Рябухи).

4. DISCUSSION

Soils exposed by a trench cutting through a polygonal microrelief revealed a complex of cryogenic signs, which is not surprising in conditions of a sharply con-

Fig. 4. Layered cryotexture in the top of the chalky spots on the Starobelogorsky key site (photo by A.G. Ryabukha, 14.12.2021).

Рис. 4. Слоистая криотекстура верхних горизонтов меловых пятен участка Старобелогорский (фото А.Г. Рябухи, 14.12.2021).

tinental climate, low snow cover, and deep seasonal soil freezing. However, the formation of some cryogenic features cannot be explained by the modern climate; it indicates a more severe climate and the presence of rocks in a permafrost state in the past. These cryogenic signs were formed, apparently, in the Late Pleistocene.

Ground vein to inter-polygonal depressions are relics of frost cracking, which is confirmed by their two-tier structure, with an expanded upper part, the thickness of which indicates the depth of the seasonal-thawed layer in the past, characteristic numerous "tails" formed in the permafrost layer and features of the introduction and filling of soil structures. The ground wedges are partially filled with overlying sediments and fragmented rocks, and are rich in organic matter. Thus, the upper expanded part of the vein is enriched with finely dispersed chalk flour, which gives the wedge a whitish hue. It probably flowed into the wedge from chalky spots during spring thawing. Similar forms in permafrost conditions are the result of cryogenic cracking, and the destroyed rocks are products of cryogenesis. The two-tiered wedge-shaped structures, according to A.I. Popov, is a reliable sign of the existence of paleofrost, with soil temperatures no higher than −3°C (Popov, 1967).

Large swirls, folds and bends uncovered in the trench correspond to cryoturbations formed during deeper, compared to modern, seasonal freezing and thawing of rocks and reflect the result of seasonal movement of soil mass in a wet-plastic state due to the alternation of freezing and thawing, which led to mixing and penetration of horizons into each other. In the central parts of the polygons as the most weakened zones, cryoturbations of chalk material reached the surface and poured out, forming spots of chalk rock.

Spots and layers of ferruginization in Cretaceous rocks mark cryogenic waterproof layers, and filamentous inclusions of iron forming a grid may indicate the existence of cryogenic textures in the past.

Thus, the morphology of chalky polygons, their size and ordered location in plan, the shape of the wedge-shaped structures (ground wedges), the vertical changes of the attributes of the chalky material with depth indicated the role of relict cryogenic processes in their genesis and allow us to assume that a relict cryogenic microrelief has been uncovered in this case.

Literature data confirm that permafrost existed in the study area in the past (Butakov, 1983; Vandenberghe et al., 2014). Analysis of the data on the Eurasian subaerial cryolithozone suggests that the formation of chalky polygons most likely corresponded to the Yaroslavl cryogenic horizon with the most active stage or maximum cooling about 20–15 thousand years ago. It reflected the most severe low-temperature cryomorphogenic conditions when the thickest ice veins (ground wedges) were formed. It was at that time that the Late Pleistocene cryogenic area of the Northern Hemisphere reached its maximum. The Yaroslavl cryogenic horizon was characterized by the permafrost of the so-called "Siberian type". This type was characterized by the widespread development of permafrost, relatively low temperatures (generally no higher than −3 ... −5°C), and wide development of polygonal relief (Velichko, 1973; Butakov, 1983).

Based on A.A. Velichko's doctrine about the relict cryogenic microrelief and the stages of its development, it can be assumed that in the process of its formation, the microrelief of chalky polygons passed three main stages (Velichko, 1973). The first stage corresponds to the stable position of the layer of seasonal frost and permafrost: the main relief-forming processes associated with sharp and deep freezing of soils were frost cracking with the formation of polygonal relief and the filling of cracks with ice or soil. Cryoturbation of rocks took place within the relict seasonal-thawed layer. Because of cryogenic processes, the external appearance of the surface and the internal structure of soils significantly changed.

The second stage is associated with a sharp change in climatic conditions during the transition from the Pleistocene to the Holocene about 10 thousand years ago, because of which the permafrost gradually degraded. The thawing of polygonal-vein ice and ice inclusions in the soil mass took place. Secondary structures appeared in place of vein ice – pseudomorphoses along ice veins or ground wedges. There was a consolidation ("conservation") of the fractured polygonal microrelief by the soil and vegetation cover and its transition to a relict state.

The third stage is the period of existence of the microrelief in a relict state in the conditions of a moderately humid Holocene climate, under the influence of modern exogenous processes. Nowadays, cryogenic processes that cause excessive ice release and frost heaving of chalky spots on the surface of polygons and sorting of material, impact actively the microrelief of chalky polygons. The condition for the formation of ice lenses is additional moisture. Polygonal microrelief is a factor of intra-soil redistribution of moisture and differences in the hydrothermal regime of soils of microhighs and depressions. In the soils of the polygons, intra-profile moisture goes from the depressions to the surface of chalky spots, which contributes to the more active formation of seasonal ice and cryogenic texture in them. It can be assumed that modern seasonal cryogenic processes are the leading factor that prevents the overgrowth of chalky spots and supports the morphological structure of chalky polygons to the present time. In addition, the salinization of chalky material and the absence of nutrients support the existence of a central spot without vegetation in polygonal structures.

5. CONCLUSION

The microrelief of chalky polygons is a kind of relict cryogenic morphosculpture, universally detailed and studied by A.A. Velichko on the territory of the East European Plain (Velichko, 1973). The studied microrelief, although relict, is "not buried" and is well preserved on the ground.

Paleocryogenic structures (soil wedges, cryoturbations, post-cryogenic textures) found in the section, and the characteristic polygonal paleorelief are evidence of the existence of frozen rocks with temperatures up to –3°C and below in the late Pleistocene on the territory of the region.

Currently, the microrelief of chalky polygons is supported by modern cryogenic processes associated with the freezing and thawing of fine chalk mass in the central parts of the polygons that lead to the destruction of chalky rocks to a clay fraction, ice formation and frost heaving of chalky spots.

Thus, chalky polygons are forms of microrelief unique to the steppe zone, which combine relict and modern cryogenic features.

Morphology and Modern Functioning of Chalky Polygons in Obshchy Syrt, Southeastern East European Plain

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Specific landscapes defined as chalky polygons can be found formed on chalky rocks under a continental climate across the south-east of the East European Plain. Theses landscapes are characterized by polygonal microrelief and spotting, outwardly resembling tundra medallions. Such landscape complexes are unique and practically not investigated. Our investigation showed a number of relict cryogenic features: polygonal relief with the polygon side averaging 5 m; ground wedges associated with hollow-like depressions between polygons; cryoturbation of soil profiles, and paleocryotextures. The results suggested the paleofrost genesis of chalky polygons. Chalky polygons were found to be a kind of relict cryogenic relief formed in the Valdai Cryochron in conditions of cryoarid climate, permafrost, frost cracking of soils and the growth of polygonal-vein ice.

Keywords: Neopleistocene, relict cryogenic morphosculpture, pseudomorphs, cryoturbations, frost heaving

ACKNOWLEDGEMENTS

This research was funded as part of Institute for Steppe Research Theme No. AAAA-A21-121011190016-1, RFBR grant 20-05-00556 and Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University titled "Future Planet and Global Environmental Change" No. 121051100164.

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