Cryogenic processes in soils of chalky landscapes in steppe zone south of the Orenburg region

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Abstract. Specific microrelief marked by white chalky spots at the soil surface was studied in Volga-Ural region. The microrelief was described and soil features were studied in a soil trench across the microrelief including morphology and further micromorphology in the thin sections with the aim to better understand the genesis and functioning of chalky polygons, and to testify the hypothesis of their cryogenic origin. Wide range of cryogenic features was found both at macro- and microscale. Some are expected to be relict, while the other features are supported or formed by modern cryogenic processes. The further investigation of the temperature regime is planned to investigate the spatial diversity and role of winter freezing in the modern squeezing of wet powdery chalky material to the soil surface.

1. Introduction
Chalky landscapes and soils formed on the eluvium of the Cretaceous landscapes are common in the central-southern part of Russia including Belgorod, Voronezh, Lipetzk, Orenburg, Volgograd regions in Russia, and adjacent territories of Kazakhstan. These landscapes and soils look different comparing with surrounding typical soils and landscapes, and are attributed to the specific territories [1].

Some chalky landscapes, at least, in Volga-Ural region and Pre-Urals plateau have a specific attribute named “chalky polygons”. These chalky landscapes are complicated by convex or flat white spots of chalky material on the soil surface. Some of these convex geomorphic microunits have surface morphology very similar to the polygonal cryogenic microlief widespread in the permafrost area in the eastern part of Russia, i.e. in Yakutia and Buryatia. Meanwhile, Volga-Ural region is situated out of the permafrost area, though being characterized by continental climate with severe winters and deep winter freezing of soils.

The genesis of chalky polygons is not completely understood until now. According to the earlier suggested hypotheses chalky polygons are supposed to have been formed by modern cryogenic processes in winter period, or by shrinking-swelling processes resulted from alternating drying and wetting during the warm period [2].

The aim of our investigation was to better understand the genesis of chalky polygons on a base of their external and internal morphology and to identify the role of cryogenic processes in their formation.

2. Materials and Methods
2.1. Study area
External and internal morphologies of chalky polygons were investigated at the key site situated in the Akbulak district in Orenburg region (51°08'10” N, 55°37'16” E). Chalky polygons usually occupy the rounded areas with flat or slightly convex surfaces in the trans-accumulative parts of gentle slopes and could be identified by the white spots of chalky material on the surface (figure 1).

![Figure 1. White spots on the soil surface indicating the chalky polygons: satellite image (left) and landscape view (right).](image)

Chalky polygons and soils are formed under continental climate (mean annual air temperature 4 °C, cold winter with mean air temperature in January of -15 °C and deep freezing up to 140 cm, hot summer with mean air temperature in July of 21 °C, mean annual precipitation of 260-390 mm) and steppe vegetation on the loamy material underlined by chalky eluvium and hard Maastrichtian chalk.

2.2. Methods
The key-site was chosen based on the study of satellite images as an example of very clear network of chalky polygons.

Soils were studied in the soil trench about 4 m long across the microdepression between two chalky microhights with an amplitude of about 30 cm. Four vertical pit walls were described with most detailed description of the front wall. Additionally, two horizontal cuts were fixed in the trench at the depths of 30 and 60 cm, and supplemented by a number of shallow pits of 40-60 cm depth around the trench.

Soils were described in the field [3] and sampled for the further analytical investigation in the laboratory. Additionally, the undisturbed samples were taken for the micromorphological analysis in the thin sections using microscope. Undisturbed oriented blocks were impregnated with polysynthetic resin, mounted on glass slides 4x4 cm size, polished to 30 μm thickness and covered by glass for micromorphological description of thin sections according to Stoops [4]. Optical examinations of microfabrics were performed using an Olympus BX51 polarizing microscope with an Olympus DP26 digital camera and Stream Basic software under plane (PPL) and crossed-polarized (XPL) light modes at magnifications of 25x to 100x.

3. Results and Discussion
3.1. External morphology of chalky polygons
Two types of chalky polygons were identified at the key-site. Both types have similar morphological elements: white chalky spots on the soil surface 2-3 up to 4 m in diameter. The first type includes the flat polygons without microrelief, while the second type includes the polygons with microrelief when
white chalky spots occupy the microhighs and are separated by microdepressions. The surface amplitude can reach up to 50-60 cm.

The chalky polygons of second type (i.e. with microrelief) are very similar morphologically to the cryogenic microrelief, which is common in our days in Yakutia, and which resulted from the melting of last glacial ground ice wedges (figure 2)

Figure 2. Similar external morphology of chalky polygons in Orenburg region (left) and cryogenic microrelief in Yakutia (right).

3.2. Internal morphology of chalky polygons
Clearly seen differences in morphology were found between four soil profiles from the front, left, right and back walls of the trench. The four walls of the soil trench have individual morphology, do not have similar horizonation and do not repeat each other. In fact, the normal horizonation was found in the back wall of the soil trench only, while the three other profiles had various kind of disturbances, involutions, and turbations. The front wall of the trench has especially strongly turbated morphology and mosaic profile. Detailed investigation of profile and horizons revealed the set of features interpreted as cryogenic ones and discussed below.

3.2.1. Cryogenic features in soil profiles and horizons. Large surface wedges filled with dark humus material were found in the middle of the front and back walls (associated with microdepression) going down to the depth of about 110-120 cm. The wedges were up to 50 cm large at the surface and became narrow and curved in the subsoil. On the front wall the bottom part of the wedge became narrow at a depth of 90 cm, and terminated with a set of narrow fissures, while in the back wall of the trench the wedge became sharply narrow at a depth of about 50 cm and continued as a very fine fissure below (figure 3).

Other macrofeatures interpreted to be cryogenic are the vertical and inclined diapirs and turbated structures, which were found in all four walls of the trench (figure 3). White diapir and white turbated zones consist of crushed chalky material. The have clear abrupt contacts with the hosting soil material, and are usually delineated by small rounded fragments of hard chalk (figure 4A). The abundance of rounded fragments increase and their size decrease from the bottom to the surface of soil profiles, which is indicative for the increased rotation process.

We also detected the result of cryogenic sorting process, such as the accumulation of hard chalk fragments in the profiles and in the fresh intrusions at the surface of the microhighs (figure 4B). Simultaneously the splitting and shattering of coarse chalk fragments into the smaller ones also occur (figure 4C).
Figure 3. Front wall (A) and central part of the back wall (B) of the soil trench. The horizontal (plane) cuts at a depth of 30 and 60 cm confirmed that the cracks in the front and the back walls of the trench were interconnected and formed a single network, which is apparently cryogenic.

The inclined diapirs are connected with microhighs and are the channels for chalky material movement towards the surface of microhighs. As a result of turbations and diapirs the normal soil horizonation is truncated and disturbed, and the profile becomes mosaic, which is typical both for cryogenic and shrinking/swelling soils. The last process is hardly possible in the studied soils. The preliminary field investigation revealed that soils are not sticky (i.e. they have not much swelling clay minerals) and are not clayey.

A number of subhorizontal and inclined thin fissures in the soil mass are interpreted as schlieren texture. The schlieren texture changes from coarse to fine one having the periodicity from 4-5 cm up to 1-2 mm, and is resulted from ice formation in the soil mass (figure 4D).

3.2.2. Cryogenic features in the thin sections. The micromorphological study in the thin sections revealed a number of microscale cryogenic features. In addition to microschlieren texture, rotation, splitting and intrusions, we found the wedge-shaped, angular-blocky, platy and granular (globular) aggregates, common for cryogenic soils, evidence of cryogenic sorting, and fragmented black organic matter, which is normally typical for cryoarid soils (figure 5A-D). The formation of these microfeatures is usually explained by the cryogenic processes, namely by the frost and ice impact, and they are known as frost-induced microstructures [5].
Figure 4. Cryogenic features in soil profile: A – Coarse-schlieren texture to the left from the chalky inclined diapir; B – Coarse fragments at the microhigh surface as a result of cryogenic sorting; C acute-angled fragments resulted from splitting and shattering of coarse hard chalk; D – Rounded fragments of coarse and medium hard chalk resulted from cryogenic rotation.

The pedogenic transformation of initially hard chalk is very clear in the thin sections, and is helpful for the understanding of the intrusion mechanism and diapir fabric. Figure 6 A-B demonstrate the microstructure of the chalky material, when it reaches the subsurface (figure 6A) and occurs in the surface (figure 6B) of microhigh. The pressure and friction forces transform the primary dense Maastrichtian chalk into a powdery mass, which can be very plastic in the moist state, and can be squeezed up by the action of ice when it freezes in the moist state in the wintertime.
Figure 5. Microfeatures of soils of chalky polygons in the thin sections. A – inclined platy microstructure; B – granular aggregate integrated into play microstructure; C – angular-blocky microstructure; D – fine fragmented black organic material including tissue remains; E – strongly fragmented chalky material filling the fissures between the more stable chalky fragments.

Figure 6. Microfeatures of soils of chalky polygons in the thin sections. A – inclined platy microstructure; B – granular aggregate integrated into play microstructure; C – angular-blocky microstructure; D – fine fragmented black organic material including tissue remains; E – strongly fragmented chalky material filling the fissures between the more stable chalky fragments; F – homogenous desiccating plastic carbonated micromass from the microhigh surface crust after drying.
4. Conclusion
The morphological and micromorphological investigation of the soils of chalky polygons in Orenburg region supported our initial hypothesis about the cryogenic origin of the chalky polygons. A number of cryogenic features was found both at macro and micro levels i.e. in soil profiles in the trench, and in the thin sections, which makes the studied soils similar to the cryogenic soils of permafrost area.

This means the possibility of the formation of cryomorphic soils out of the permafrost zone and poses a question if these features are modern or relict? We believe that soils of chalky polygons represent the combination of modern and relict features. The cryogenic network apparently could be formed during the last glaciation, and we believe the cryogenic wedges marked at present time by microdepressions are relict. Simultaneously, it is quite evident that most above mentioned cryogenic attributes are active at present time, including the diapir structures, cryoturbations and the squeezing of plastic chalky material towards the soil surface.

We believe that this happens when winter freezing occurs in soils with certain moisture contents, due to the strong and uneven pressure of the growing ice on a wet and plastic soil mass compressed between the frozen soil surface and hard primary Maastrichtian chalk in the bottom.

The further investigation of the winter soil temperature regime is planned to better understand the freezing process in studied chalky polygons.

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