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MODERN AND PALEO-CRYOGENIC FORMATIONS ON OLKHON ISLAND

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For the first time, complex geocryological investigations have been fulfilled on the northern coast of Olkhon Island, Baikal Lake, near the southern borderline of permafrost. The island landscapes belong to a very arid desert-steppe type. Information on the contemporary cryogenic and postcryogenic phenomena has been obtained. The morphologic and morphometric characteristics of the permafrost relief and the results of the automatic hourly geotemperature observations have been described. The influence of microlandscape conditions on the dynamics of permafrost in the steppe areas has been analyzed. Different variants of the impact of the cryogenic factor on the slope processes have been considered.

Sporadic permafrost, arid climate, cryogenic factor, slope processes

INTRODUCTION

During the season of 2012–2013, the researchers of the Sergeev Institute of Environmental Geoscience, RAS, the Institute of Applied Mechanics, RAS, the Institute of Earth Crust, SB RAS, conducted complex geocryological studies of the north-western steppe part of Olkhon Island. In terms of geocryology, this territory has been poorly investigated, with just a few studies published on this subject. The schematic geocryological map composed by *F.N. Leshchikov and N.E. Zarubin* [*1967*] assigns the island territory to the area of sporadic permafrost soils with the temperatures of –0.2...–0.5 °C and thickness of the permafrost strata varying in the range of 9–30 m. Two points with the permafrost thickness of 23 and 30 m have been found on the island. The relief, the map control, the method of obtaining the data, and the source of information were not provided by the authors [*Leshchikov and Zarubin, 1967*]. Yu.K. Vasilchuk identified peat frost mounds there [*Vasilchuk et al., 2013*]. In the southern part of the island, pseudomorphs have been described along ice veins in the cross section of the Zagli Bay [*Mats et al., 2001*].

In total, permafrost areas are found in the area in question as lenses up to 10 m thick and up to 100 m and longer in diameter, located on the bottoms of swamped valleys and on northern slopes. Frozen loams and sandy loams primarily have laminated cryogenic structure, the lens size reaching 10 mm. When thawing, soils become soft and very soft, with significant collapses observed [*Leshchikov and Shats, 1983*]. In the lake valleys, there are frost mounds of two types: pingos and frozen salses. The former ones are related to freezing of the entire under-lake talik as a whole system, and the latter ones are caused by inhomogeneous freezing of certain parts of the talik [*Bazhenova, 2013*].

O.I. Bazhenova [*2011*] relates the area in question to steppes with maximum aridity, with the annual precipitation rate being 210–220 mm, and the annual air temperature being –0.6...–1.0 °C. However, despite the dry climate, local wet peat areas with associated permafrost soils are quite common on the island. These territories are known for their high sensitivity and a quick response to climate changes and to human production activity. On the southern borderline of their occurrence, permafrost soils are in an unstable thermodynamic balance and are characterized by significant formation and degradation rates. Under such conditions, the cryogenic factor exerts considerable influence on the behavior of the environment, which accounts for the theoretical and practical significance of the studies carried out in the area. During the works conducted, the authors were able to reveal and investigate the area of current occurrence of permafrost soils, to see their structure and to elucidate the role of the cryogenic factor in the formation of the environment and in the dynamics of the exogenous processes. Post-cryogenic formations of different scales and different ages were described and classified.

THE AREA OF INVESTIGATION

Olkhon Island is situated in the middle part of Baikal Lake and is a component of an inter-depression bridge, Akademichesky ridge, dividing Severobaikalskaya and Srednebaikalskaya depressions of the lake. Neotectonically, the island is part of the Olkhon elevation and has inclination of 2–8°; in north-west, the inclination reaches 20°. The studies were conducted on the north-western coast of the island, on the gently sloping ground covered with small bays formed by processing of loose Neogene-quaternary sediments. The materials were obtained in 2012–

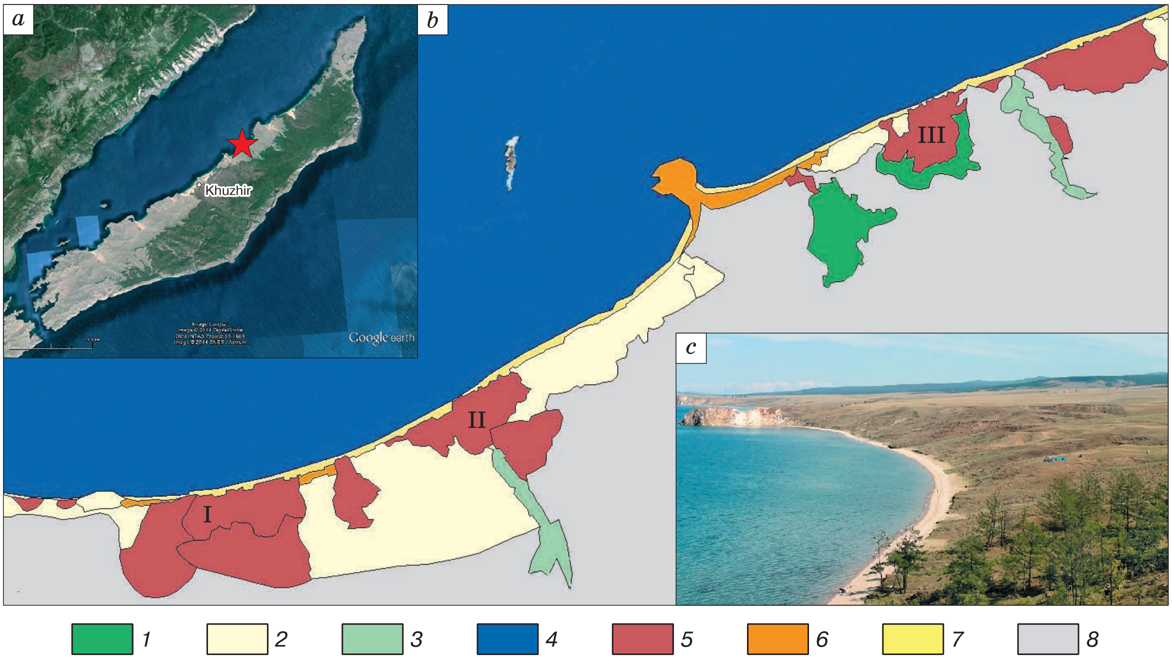

Fig. 1. The location (*a*), the general view (*c*) of the area under study on Olkhon Island (http://www.maps. google...) and a schematic map of the types of the territory identified (*b*):

1 – swamped valleys; *2* – slopes with creep, solifluxion and landslide formation; *3* – narrow ravines; *4* – Baikal Lake (Minor Sea – Maloye More); *5* – landslide bodies; *6* – cliff debris and rock outcrops; *7* – beach; *8* – low-inclined surfaces. Areas of engineering-geological monitoring: I – an area of hummocky-pitted microrelief; II – a narrow hollow; III – a wide hollow.

2013 during field works on the coast of Olkhon Island in the area of the village of Kharantsy (Fig. 1). The territory in question in the central part of the island is morphologically non-homogeneous. An area from 20 до 200 m wide and with the slope angle varying from 8–10 to 70–80° is situated on the shore of the lake, where a large variety of the sloping processes is observed. In the middle of the lake, there is a non-forested plain, with a gentle slope of 3–5° rising towards the central part of the island. Both zones are crossed by hollows (Fig. 1).

PALEOCRYOGENIC FORMATIONS

Modern permafrost and paleocryogenic formations are widespread in the territory of the Baikal region. Primary ground veins with the size of the polygons 2.0 × 2.5 mm and the depth of 0.5–0.7 m are most common [*Soil..., 2011*]. According to *F.N. Leshchikov* [*1989*], frost-formed polygons sized from 0.3 to 7.0 m are well-developed in almost all the relief elements. In the Baikal region, larger forms of the relief related to melt-out of thick polygonal-veined ice (PVU) in the Holocene are well developed [*Molodykh, 1958; Leshchikov, 1978; Vorobyeva, 1980; Kuzmin, 1988; Kozlova, 2006*]. Alternating mounds and round dishes form polygons sized 20 × 30 m; the difference between the mound tops and dish bottoms is about one meter. Pseudomorphs caused by PVU are situated on the dishes. As noted, pseudomorphs along ice veins on Olkhon Island have been described in one location of the cross section of the Zagli Bay in the southern part of the island [*Mats et al., 2001*]. We were unable to find any modern perennial cryogenic formations, like perennial frost mounds, PVU, etc., in the territory investigated, although we would consider it too early to deny their existence on the island. We found and studied post-cryogenic polygonal formations. Three generations of polygonal forms related to frost-caused cracking were identified.

1. Polygonal forms sized 0.5 × 1.5 m. They are widespread on dividing surfaces, gentle slopes, and dish bottoms. They are visible on the surface as dishes up to 10 cm wide (Fig. 2, *a*). In the outcroppings, they are associated with a system of ground veins of a dark color up to 1 m thick (Fig. 2, *b*).

2. Polygonal forms sized 1.5 × 3.0 m. They are formed by alternating mounds and dishes. These formations are best seen on the gentle slopes and on the edges of valleys having different degrees of drainage (Fig. 3). The width of the dishes is 0.3–0.5 m, and their depth is 0.2–0.3 m. In addition to the isometric polygons (Fig. 3, *b*), there are also polygons elongated along the slope (Fig. 3, *a*). On wetter slopes, the dishes are covered by peat, while the elevations are covered by grassy vegetation. In the dry areas, the elevations are

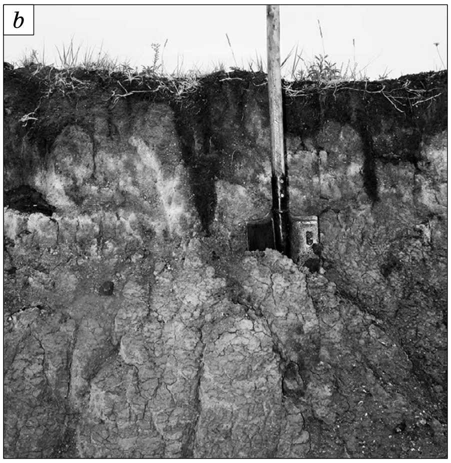

Fig. 2. Polygonal forms sized 0.5 × 1.5 m (the photograph provided by A.N. Khimenkov):
a – micro-relief; *b* – ground ice veins corresponding to the polygon borders.

dried up, the vegetation is scarce or absent, and the depressions are covered by grassy communities.

3. Polygonal forms of large sizes (10 × 20 m and larger). The polygon contours on the flat surfaces of the water divides and valley bottoms are poorly visible on the relief but can be traced by the change of vegetation and in small linear depressions. The clearly seen hummocky-pitted microrelief was found in the littoral area. Here, in the middle part of the slope 5–10° steep, extending to the shore of the lake, a flattened area about 200 m long and 100 m wide is located. It is characterized by alternation of low mounds and depressions forming specific topography (Fig. 4). Rounded mounds sized 15 × 20 m (more rarely 20 × 30 m) rise over the adjacent dishes to the height of 3–5 m. The width of the dishes varies from 3–5 to 10–15 m. Sometimes hummocky-pitted microrelief forms the shapes extending along the slope. On the dishes smaller polygons sized 2 × 3 m are found. The area with the hummocky-pitted microrelief is situated at the altitude of about 20–25 m above the lake level. Some flattened areas are found at this altitude in the other parts of the lake shore. Although they are separated from each other by ravines, depressions, and landslide formations, they form a single geomorphological level. Its height corresponds to terrace III above the lake, identified on the entire shore of Baikal Lake [*Mats et al., 2001*]. The terrace is of a pediment type; deluvial loams up to 5–7 m thick are underlain by Jurassic clays or limestone. The loam mass is sometimes underlain by a sandy horizon with pebbles and detritus. According to *V.D. Mats et al.* [*2001*], the cross section of terrace III includes three climatic horizons: the cold horizon (Zyryan glaciation, early Wurm), the warm horizon (Kargin glaciation, middle Wurm), and the cold horizon (Sartan glaciation, late Wurm, age 15–16 ka by ^{14}C). The finishing phase of the terrace formation corresponds to severe climatic conditions of the Sartan time, which accounts for development of large PVU.

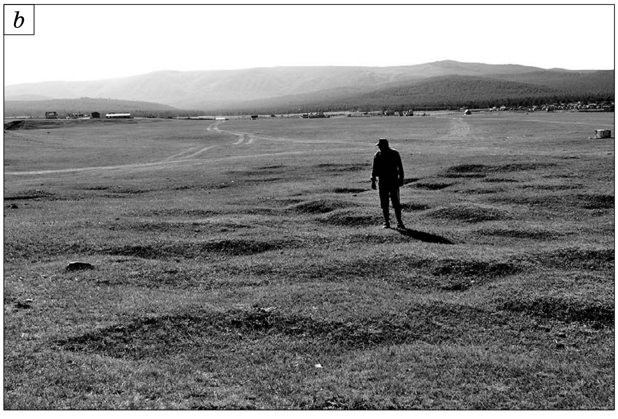

Fig. 3. Polygonal forms sized 1.5 × 3.0 м (the photograph provided by A.N. Khimenkov):
a – extended; *b* – isometric.

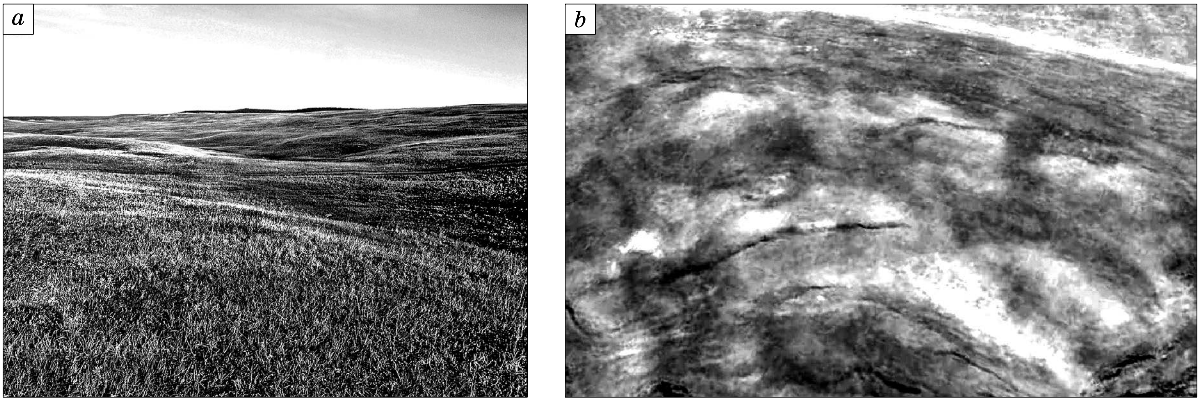

Fig. 4. Polygonal forms of large sizes (10 × 20 m and larger).
a – the photograph by A.N. Khimenkov; *b* – a satellite image of Olkhon Island (http://www.maps.google...).

MODERN CRYOGENIC FORMATIONS

In the steppe territory with an arid climate under study, swamped areas may include bottoms of hollows, primarily oriented in the latitudinal direction, and small local depressions of the relief. As a rule, the bottoms of the wet depressions are covered by peaty hummocks; the sizes of the swamped areas vary from several dozens to several hundreds of meters. These constitute the most probable areas of permafrost development, the presence of which is indicated by *F.N. Leshchikov* [*Leshchikov and Zarubin, 1967*]. The borehole bored in the center of the swamped area of the valley (Fig. 5) revealed a permafrost stratum at the depth of 1.7–1.9 m (an unthawed layer of season-

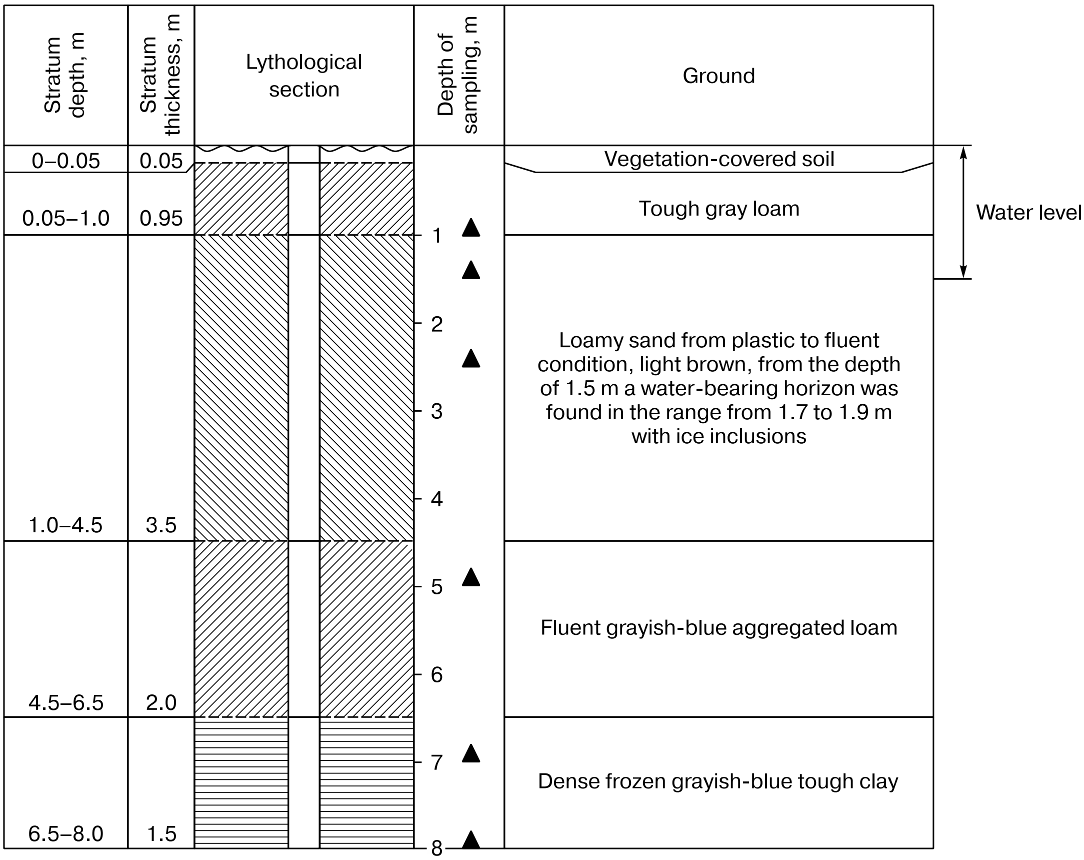

Fig. 5. The axial section of borehole 1 (the peat-covered bottom of the hollow, with the total depth of 8 m).

al freezing). Its cryotexture is laminated, with the thickness of the ice lenses reaching 2 cm. Below, at the depth of 6.5 m, there is a sandy-loamy-loamy horizon of fluid consistency, underlain by frozen clays with micro-lens cryostructure. The opened intrapermafrost water had lift, which accounted for its outflow onto the surface. The data obtained agree with the observations of *F.N. Leshchikov and M.M. Shats* [*1983*], which demonstrated that the areas with non-merging permafrost, corresponding to the stage of permafrost degradation, are quite widespread in the territory of the southern Baikal region. In particular, they indicate the presence of frozen soil lying at the depth from 4 to 6 m at the foot of gentle slopes formed by argillaceous deposits. The temperature in them may be below −0.2 °C, whereas the ice content varies in a broad range [*Leshchikov and Shats, 1983*].

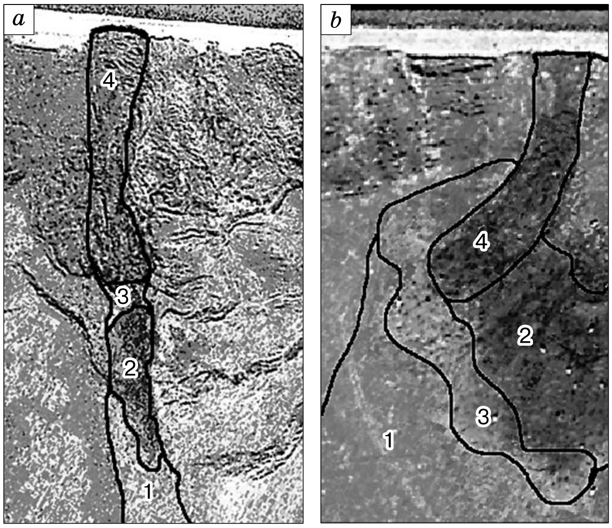

Fig. 7. Micro-relief zonality of the composition of the narrow (*a*) and wide (*b*) hollows on Olkhon Island (Fig. 1).

1 – the zone of dried peat-covered hummocks; 2 – the zone of wet peat-covered hummocks; 3 – the zone of depressions and ruptures adjacent to the bench; 4 – the zone of landslides of dilution-flow. A processed satellite image (http://www.maps.google...).

THE STUDIES OF THE TEMPERATURE REGIME OF THE ROCKS

The studies of the temperature regime of the rocks carried out in 2012–2013, as well as automated hourly temperature observations, were conducted in a pit (RU_04_Olkhon-Pit). Temperature measurements were conducted with the sensors HOBO® U12-008 (manufactured by Onset Computer Corporation), which were installed at the depths of 0.5, 1.0, 1.5, 3.65 m, after which the pit was filled. The annual temperature data are shown in Fig. 6.

THE CRYOGENIC FACTOR IN THE DEVELOPMENT OF EXOGENOUS PROCESSES

Among the numerous exogenous processes occurring in the territory in question, one group should be specially indicated, which is directly or indirectly accounted for by the cryogenic factor. Despite the sporadic character of their occurrence, modern permafrost rocks exert essential influence on the intensity and diversity of the exogenous processes. During the field works, we investigated two areas located on the wetted valley bottoms, where the influence of the cryogenic factor on development of the slope processes is most expressed (Fig. 1).

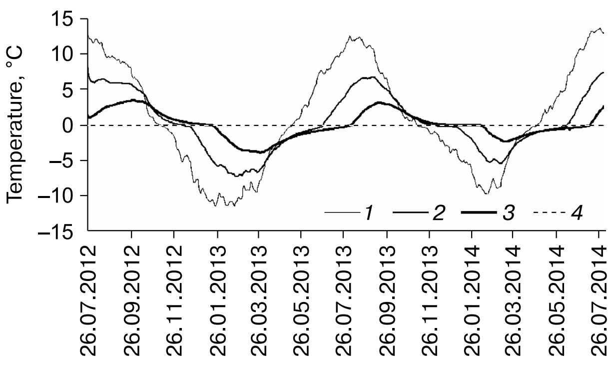

Fig. 6. Plots of the ground temperature change in a pit on Olkhon Island (RU_04_Olkhon-Pit).

Depths: *1* – 0.50 m (average annual temperature T_{av} = 0.01 °C); *2* – 1.0 m (T_{av} = −0.31 °C); *3* – 1.5 m (T_{av} = −0.21 °C); *4* – 3.65 m (T_{av} = 0 °C).

Fig. 8. A bench separating the sagging zone and the zone of the dilution-flow landslides on a wide hollow (the photograph provided by A.N. Khimenkov).

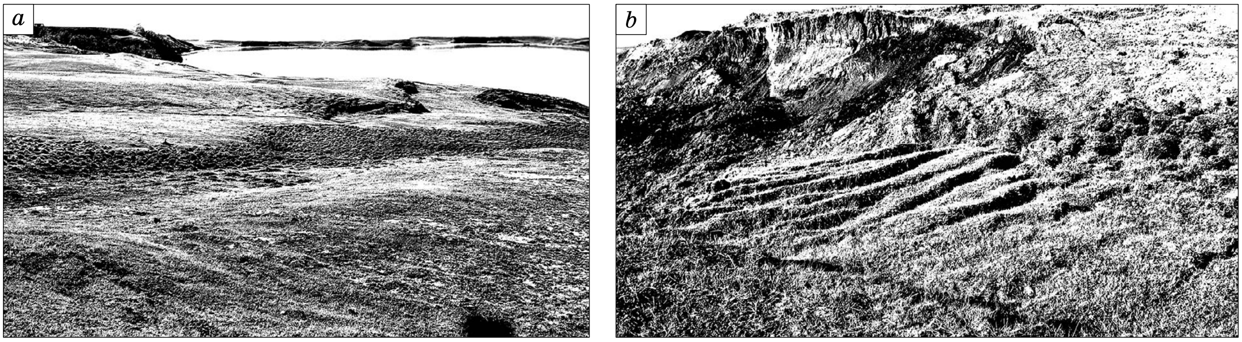

Fig. 9. The micro-relief conditions of the narrow hollow on Olkhon Island.

a – zones of dried (light color) and wet (dark color) hummocks; *b* – the zone of separation cracks in the lower part of the wet hummocks (the photograph provided by A.N. Khimenkov).

One area (Fig. 1, III) is located on the bottom of a depression about 200 m wide in its diameter (Fig. 7, *b*). The incline of the bottom towards the lake was about 3–5°; zonality of the micro-relief structure of the depression bottom was distinct (Fig. 7, *b*). At the distance of approximately 150 m from the shore, dry surface covered by grassy vegetation with traces of degraded hummocks is replaced by wetted peaty hummocks covered with moss. The change of the micro-relief conditions corresponded to gradual transition from the rocks having positive temperatures to frozen rocks. Down the slope, at the distance of approximately 100 m from the shore, the hummocks are replaced by the zone of the hummocky-pitted micro-relief (Fig. 3, *a*; the polygon dimensions vary from 2 × 3 to 3 × 5 m). The width of the zone varies from 1–2 to 10–15 m; it is formed due to melt-out of the upper part of the permafrost without mixing of the ground. This zone ends with a bench rising to 0.5 m (Fig. 8). Below the slope, up to the lake, there is a watered area with the traces of ground flow. The relief is uneven, with small water bodies appearing on the surface sized from 0.5 to 2–3 m, one can see breaks in the turf cover and traces of the ground flow. The flow of the water-saturated ground is caused by thawing of the permafrost.

Another area is located in a narrow hollow (about 50 m in diameter) (Fig. 1, II). The slope of the surface in the upper pat does not exceed 5°; here, too, zonality in the relief structure has been revealed (Fig. 7, *a*).

At the distance of about 300 m from the shore of Lake Baikal, the dry surface covered by grassy vegetation with traces of degraded hummocks is replaced by wet hummocks (Fig. 9, *a*). The height of the hummocks reaches 20–40 cm, their diameter is 30 × 40 cm, the length of the zone of green hummocks is about 70 m. Borehole 1 (Fig. 5) was drilled in the zone of the hummocks, which indicated the presence of unmerged permafrost and a 2.5-m water-saturated horizon lift.

Near the lower edge of the hummocks, a bend is evident. The slope angle of the depression bottom varied from 5–10 to 20°. In the depressed area about 15 m long, a series of crosswise cracks was observed (ground block separation cracks) up to 1 m deep, 20–30 cm wide and 3–5 m long (Fig. 9, *b*). The spread zone of the spread of the ground block separation cracks finished with a bench about 2 m high.

Farther below, up to the lake itself, there was a watered area of the ground material flow movement, with traces of the flow limited by the side edges. The length of this area was about 100 m. In the lower part, the ground flows reached the beach and entered the zone of the lake's wave abrasion.

The above areas of wetted hollows with permafrost occupy a small part of the territory under study. Here dry surfaces composed of thawed rocks and covered by grassy vegetation are mostly common. Development of ground fissures as cracks oriented along the slope is observed everywhere (Fig. 10). The width of the cracks is 30–40 cm, and their length may

Fig. 10. A series of ruptural deformations of the annual thawed layer on the slope (Olkhon Island) (the photograph provided by A.N. Khimenkov).

reach 10–15 m. Sometimes they form a sort of steps, with the height of the steps being several dozens of centimeters. No large slip blocks or traces of ground flow in these areas were found.

DISCUSSION OF RESULTS

Cryogenic geosystems of the southern permafrost zone. The southern borderline of the permafrost zone presents an excellent opportunity for studying the conditions of the initial stage of permafrost development. It is here that the specific features of the new component of the lithosphere, a cryogenic geosystem, corresponding to a certain moment in development of the natural environment, are revealed [*Khimenkov and Brushkov, 2006; Khimenkov, 2013*]. Abduction of heat from the Earth' surface results in self-organization of the local geosystems, the main component of which is ice, determining their structure and properties. Complex feedforwards and feedbacks emerge among different components and parameters of the environment (soil mass, vegetation, relief, soil temperature, soil moisture content, etc.), which result in differences in the trends and dates of development of frozen strata when exposed to equal environmental impacts.

Under conditions of the southern zone of permafrost spread, where even insignificant local natural or anthropogenic impacts (the dynamics of the land drainage and vegetation) result in critical changes of the geocryological and exogenous processes, these ties are revealed most distinctly. Local permafrost islands are very sensitive to any, even very weak, external impacts; therefore they are a convenient object for studying the response of the frozen strata to their changes. Formation of permafrost under these conditions is always determined by relief and micro-relief conditions. Given the same climatic characteristics and geological conditions, non-frozen strata may be located next to the area of permafrost formation or, on the contrary, degradation. Small frozen areas are of large environmental significance, influencing the composition of the vegetation covering the land, intensifying or weakening the dynamics of the exogenous processes on the slopes. For this type of frozen strata, the environmental factor prevails over the climatic one. The climatic parameters only are insufficient to cause formation of permafrost. In these cases, in accordance with the assumption of *Yu.L. Shur and M.T. Jorgenson* [*2007*], an "ecosystem-driven permafrost" develops. This assumption is important for evaluating the dynamics of the southern part of the cryolithozone, given different scenarios of climate change.

In the territory in question, the influence of the micro-relief changes on the permafrost conditions can be easily seen. For the upper parts of the hollows, development of the fields of dried peat hummocks with well-expressed polygons is characteristic, indicating wide occurrence of permafrost in the past. The degradation of wetted hummocks may be caused both by climate warming and by intensified anthropogenic impact, related to uncontrolled pasture of cattle and to increased tourist activity. Observed in a narrow hollow (Fig. 1, II) permafrost degradation and formation of the residual thaw layer here are primarily caused by the pasture of cattle and the related destruction of vegetation. A similar situation is observed in the other regions of the southern borderline of the permafrost zone. In the steppe areas of the hollow of Hubsugul Lake situated in the north of Mongolia, intense pasture of cattle results in degradation of vegetation and in subsequent melt-out of permafrost. In the undestroyed areas, the thickness of the annual thawed layer is 1.4 m, while in the areas of intense pasture, it increases to 4.8 m [*Baastyn Oyungerel, 2011*].

The hummocky-pitted microrelief on the slope is related to the mechanism proposed by *A.I. Popov* [*1960, 1962*]. In this case, resulting from irregular formation of the cracking system due to exogenous processes, relief is formed, reminding of an erosion network with the main riverbed and tributaries, which has not tree-like branching but a bent structure with rectangular articulation (Fig. 4, *b*). Such a type of interblocking is formed on comparatively steep (more than 2–3°) slopes. Interblocking depressions are formed by overlapping of the processes of thermokarst thawing, solifluxion or substrate deluvion and outflow of material along the formed polygonal system of frost cracks [*Popov, 1962*]. Another mechanism of development of hummocky-pitted microrelief, also proposed by A.I. Popov for thawed soils with large depth of freezing and thawing, is possible. Formation of thick ground veins is characteristic of these conditions. In the thawing period, infiltration of atmospheric water takes place along the cracks, as well as suffusion of silt. Sagging occurs, which is especially significant at crossings, or rectangular junctions of frost cracks. This is the way hollows are formed, connected by less deep and less wide depressions, which in total form polygonal forms. Due to sagging of the crack strips and partial drifting of the soil to the hollows at the edges, the blocks themselves seem convex, often dome-like. Due to the largest depth of the hollows in the junctions and crossings of the cracks, often an impression of a relief looking like close kettle holes is formed. This type of a mesorelief is very common in the regions with a seasonal inland climate, which is relatively dry climate with little snow, causing deep seasonal freezing, frost cracking and deep summer thawing (Transbaikalia, Eastern Siberia). Both variants of forming the hummocky-pitted microrelief under conditions of sporadic permafrost often occur under similar surface conditions [*Popov, 1960*].

The influence of the temperature regime of the annual thawing layer of steppe areas on the slope processes. Analysis of the geothermal data indicates deep seasonal freezing of the soil (Fig. 6). The average annual air temperature (from August 2012 to July 2013 was −1.07 °C), the extremely small amount of snow, scanty vegetation, and a small moisture content of the soil contribute to deep freezing. The thawing rate in summer is rather high: in 2013, the upper half a meter's layer of the soil got thawed already by May 14, while the one meter's layer was ready for landslide drifting by June 27. The freezing front was at the depth of 1.5 m on August 6, while complete thawing of the seasonally frozen layer occurred only on the first ten days of December, under conditions when the first half a meter of the upper soil layer already got frozen. Given the high drifting rate of the phase transition zone, the wetting regime of the soil becomes very important, which, on the one hand, depends on the amount of atmospheric precipitation and, on the other hand, is controlled by the position of the frozen aquiclude. In the argillaceous ground, the processes of ice segregation are accompanied by intense migration of moisture both in the thawed and frozen regions. Under such conditions, different variants of moisture distribution in the thawing (able to drift) layer may form in different years.

Formation of the areas of breaks and benches oriented along the slope is related to the characteristic features of seasonal thawing (Fig. 10). During the entire summer season, there is a weakened wetted zone between the increasing thawing layer and frozen layer. When certain thickness is reached, which depends on the composition of the soils and the ice content of the frozen horizon, the soil block moves, and a series of cracks and benches is formed on the slope. The dry climate and a low moisture level of the soils in the seasonally thawing layer do not allow the soil block to drift to large distances. Thus, the characteristics of the temperature regime and of the moisture level of the steppe areas on Olkhon Island determine the character of development of the slope processes. These include practically complete absence of erosion forms and extensive cracking on the slopes composed of thawing soils.

Exogenous processes in the areas of permafrost degradation. The greatest variability of the exogenous processes caused by the cryogenic factor is observed in the areas situated on the hollow bottoms. Close connection has been noted between the change of micro-reliefs and the exogenous processes, caused by a change in the geocryological conditions. Formation of permafrost masses under wetted peat-covered areas of hollow bottoms consolidates the soil mass and ensures its relative stability. Degradation of peat covers, irrespective of its causes, results in thawing of permafrost and intensification of the slope processes. In this case, two main forms of movement are observed: slow shifting along the water saturated horizon of the seasonally frozen layer and a flow of water saturated ground waters.

Formation of benches dividing the region of development of the processes of dilution-flow from the above bottom takes place in the valleys reaching the shore. These benches are of different heights (from several dozens of centimeters to 2 meters); sometimes the forming pattern of the bench reminds of thermal denudation circuses, characteristic of northern regions, when frontal degradation of rocks with a high ice content takes place. Two types of paragenetically related changes in the micro-reliefs of permafrost conditions and exogenous processes were revealed.

In the wide hollow, permafrost areas are located on the peat-covered wet hummocks (Fig. 7, *b*, 8). Near the bench, where the conditions for the outflow of surface and ground wasters improve, the peat-covered layer begins to degrade. The moss cover gets replaced by grassy vegetation. Irregular sagging of the ground takes place, and a zone of polygonal relief is formed. The soil mass remains stable. Below the bench, intense melt-out of the underground ice occurs, and a zone of the dilution-flow landslides is formed [*Postoyev, 2013*], which can be seen up to the lake edge.

In the narrow hollow, in the area of development of wetted frozen hummocks, there are signs of the beginning of degradation (destruction of the moss cover, appearance of grassy vegetation, etc.) (Fig. 9). These changes result in directed thawing and formation of sporadic permafrost recorded during drilling. Stability of the soil massif decreases. The bottom of the valley begins to shift down. These displacements can be seen on the surface as a series of subparallel cracks 3–5 cm wide and 3–5 m long, situated across the hollow, and a series of associated cracks in the lower areas of the valley edges. The associated cracks are at an angle of about 30° to the seam. The width of ruptures varies from 2–3 to 5–10 cm, their length is 2–3 m; and the distance between them is 3–5 m. The observed ruptural deformations indicate the first stage of the soil mass's movement. Near the bench, the possibility of the outflow of ground waters rises. The movement accelerates and enters the second stage, forming a series of large parallel separation cracks and soil sagging (Fig. 9, *b*). Here further thawing of frozen soil takes place, as well as discharge of ground water at the bench foundation and acceleration of the soil material's movement as separate blocks. The third, most dynamic, stage occurs as a series of landslides of liquefaction, when watered soil masses flow. At least two or three cycles of flow formations are identified.

Reflecting the general sequence of the change of geocryological conditions and exogenous processes, the above examples of paragenetic complexes of the exogenous processes related to permafrost thawing have certain differences.

In the wide valley, thawing mostly occurs on the side of the formed bench. The thawing rate is significant, which does not allow a rather wide zone of permafrost degradation to be formed. Above the bench, the frozen mass is stable; below it, a water-saturated ground flow is formed, up to 1 m wide.

In the narrow valley, degradation of the peat-covered hummocks occurs before it approaches the bench. Thawing of large areas from the top and formation of sporadic permafrost takes place. The soil mass becomes unstable and begins to creep along the thawed water saturated layer. Near the bench the ground waters are discharged and further melt-out occurs, with deep separation cracks formed, accompanied by total sagging of the surface. In the zone of the dilution-flow landslides, individual soil blocks with the area of dozens of square meters and over 2 meters thick are observed, transported to the distance of about 100 m.

The considered examples of the impact of the cryogenic factor on the slope processes are characteristic of wet hollows. In dry hollows, where destruction of the peat-covered horizon and soil thawing have already taken place, the moss cover is replaced by grassy vegetation. The slope processes are much less dynamic here than in the wet hollows with permafrost. Smoothened traces of the past dynamic processes (landslide benches, flow forms, separation cracks) can be seen on the surface; cracks develop also in the ground, related to the peculiar features of the regime of the seasonally thawing layer.

CONCLUSIONS

1. Cryogenic and post-cryogenic phenomena on Olkhon Island are widespread. Three generations of post-cryogenic polygonal formations reflecting the intensity of the impact of the cryogenic factor on the lithosphere in the past have been identified.

2. The areas of modern permafrost exert significance influence on the dynamics of the environmental development of the steppes of Olkhon Island. Their formation stabilizes slope processes and increases the biodiversity of the local landscapes due to development of wet areas. Permafrost degradation results in dramatic intensification of the complex of the slope processes, destruction of wet micro-reliefs and reduction of the area's biodiversity.

3. In the territory of Olkhon Island, formation and degradation of modern permafrost are determined by micro-relief conditions, which ensure the possibility of formation or degradation of the moss cover. Two types of permafrost have been revealed: continuous permafrost related to development of wet peat-covered hummocks and sporadic permafrost formed in the areas of degrading hummocks. Degradation of the moss cover is related both to natural and anthropogenic impacts.

4. The annual cycle of the temperature studies resulted in establishing the parameters and values of the temperature regime of the annual thawed layer. The revealed thickness of the annual thawed layer is 3.65 m, which essentially exceeds the previously recorded values (2.8 m at the Uzur meteo station) [*Trofimova, 2006*]. Thawing of the annual thawed layer takes place till the first ten days of November, when the top layer of the soil already begins to freeze. The lengthy period of thawing ensures sliding of the soil blocks along the frozen foundation, resulting in the wide distribution of cracks in the soils of the annual thawed layer on the slopes.

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