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REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

Relief and Landscapes of the Amut Depression (Northeastern Cisbaikalia)

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Abstract—A generalized description of a modern geomorphologic structure—the landscapes of the Amut Depression as one of the elements of the rift system of northeastern Cisbaikalia—is given for the first time. The main features in the relief formation of the depression are outlined and the principal factors are determined. This study has revealed the predomination of fluvial, lacustrine, and cryogenic processes in the modern morphogenesis of the depression. Special attention is paid to the study of lakes. Modern methods of bathymetric surveys are used to determine the main parameters of the basins of the major lakes in the depression: Amut, Malan-Zurkhen, Balan-Tamur, and Churikto. It has been revealed that ancient glaciers and tectonic movements were involved in the formation and configuration of the lake basins. The current shape of the shore zone depends on the geological structure, in which a special role is played by thermoabrasion and thermodenudation. Since the study area is assigned to the Dzherginskii State Nature Reserve with its principal mission to preserve natural systems, landscape investigations have been performed. The medium-scale map of the depression and surrounding mountains is based on the concept of geosystems by Academician V.B. Sochava and compiled with the use of classical methods of studying the plant cover complemented by images taken by an unmanned flying vehicle and data from remote sensing of the Earth. The salient features of the modern status of landscapes in the study area are highlighted. The main role in the structure of the landscapes is played by mountain–taiga and mountain–depression larch geosystems with mature moss–lichen cover. At higher hypsometric levels, a greater area is occupied by subshrub–lichen sparse larch communities.

Keywords: depression, relief, exogenous processes, landscapes, bathymetry of lakes

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INTRODUCTION

Small basins or depressions that still have not been comprehensively studied are widespread in the Baikal rift zone, along with the main large basins (Barguzinskaya, Verkhneangarskaya, Muisko-Kuandinskaya, etc.). The urgency of the study of such forms of topography and their nature is obvious, which has been pointed out in the works by E.V. Pavlovskii [1], N.A. Florensov [2], V.P. Solonenko [3], G.F. Ufimtsev [4, 5], and V.B. Vyrkin [6]. One of them is the Amut Depression, located in the upper reaches of the Barguzin River to the northeast of the northern tip of the Barguzin Depression (Fig. 1). A combination of features—size, age, morphological formation rate, and seismic regime—enables it to be assigned to the embryonic type of basins (depressions) of the Baikal type (according to V.P. Solonenko [3]). Small depressions located within uplifts are characterized by G.F. Ufimtsev [5] as surrounding or accompanying rift valleys. The Amut basin is formed at the junction of the Ikat and the Southern Muya ranges, and there are similar Kovyli and Turaki depressions not far from it.

The aim of this work is to characterize the modern relief and landscapes of the Amut Depression, which is located in the Dzherginskii State Nature Reserve, the scientific tasks of which include the study and preservation of natural diversity, socioethnic heritage, and ecological cleanliness of this unique region of northeastern Cisbaikalia.

MATERIALS AND METHODS

This work is based on materials obtained by V.B. Vyrkin [6, 7] in 1981–1982 during terrain geomorphologic and bathymetric studies and the results of their analysis supplemented in 2020 by the study of the relief and landscapes of the depression and of the morphology of lakes by the staff of the Sochava Institute of Geography, Siberian Branch, Russian Academy of Sciences.

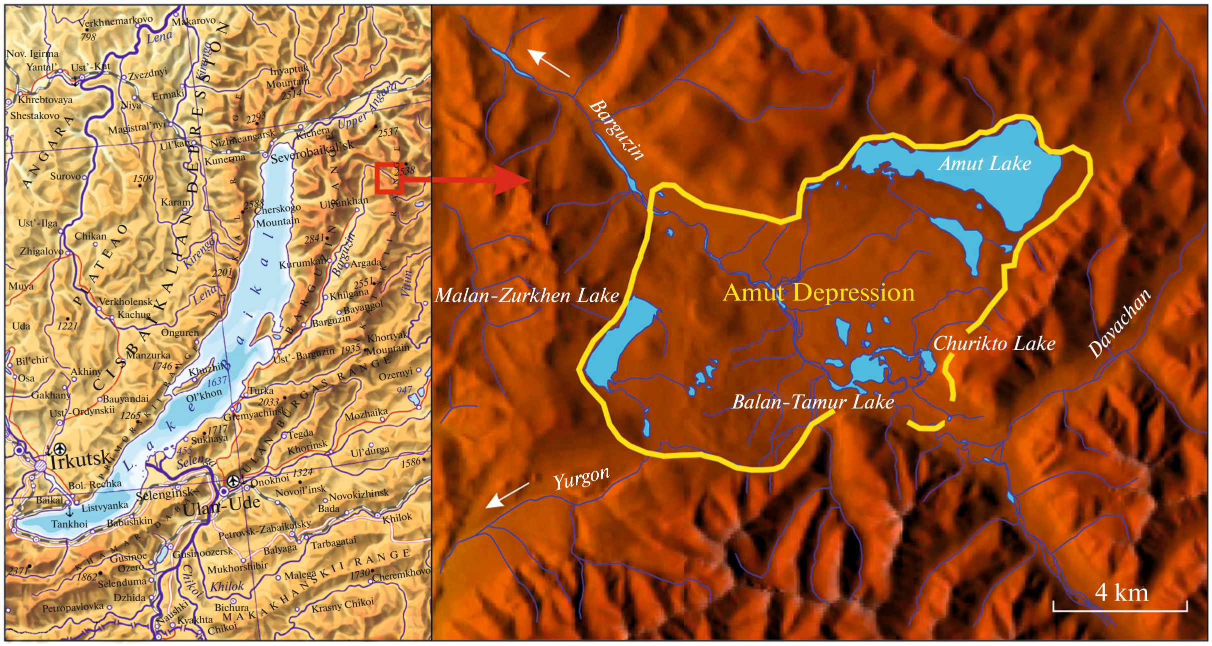

Fig. 1. Location of the Amut Depression in northeastern Cisbaikalia.

Special attention was paid to the research of the morphology of lakes using a Deeper Smart Sonar PRO+ echo sounder. The configuration and altitude of the shorelines of the lakes were determined during the compilation of bathymetric maps of the lakes of the depression—Amut, Malan-Zurkhen, Balan-Tamur, and Churikto—using aerial photography from a DJI Mavic 2 Pro unmanned aerial vehicle equipped with a Hasselblad L1D-20c camera. Orthophotoplans, depth measurements, and digital models were built as a result of image processing in Agisoft PhotoScan Professional and AutoCAD programs with the subsequent export of raster and vector data. The shoreline and isobaths were distinguished in the QGIS3.16 software package.

The term landscape in this paper is a synonym of the term geosystem (and not of macrogeochora according to Academician V.B. Sochava), because it is widely used in published scientific geographical works [8].

Some features of the spatial structure of landscapes in the Amut Depression were considered by researchers [9–11], but these were mainly small-scale surveys that did not reflect the organization of geosystems at the topological level. Comprehensive expedition studies were performed by the Institute of Geography, Siberian Branch, Russian Academy of Sciences, in order to obtain up-to-date information about the structure of local natural systems and modern dynamic processes in this area.

The structure of geosystems in the depression was examined by a combination of conventional methods for studying plant cover [12] and natural complexes [8] supplemented by photography from an unmanned aerial vehicle and by data of remote sensing of the Earth (Landsat satellite images).

RESULTS AND DISCUSSION

The Amut Depression of 140 km^2 in the area is located in the upper part of the Barguzin River basin and is assigned to the depressions of the Baikal type at the initial formation sage [13]. It stretches for 16–17 km from the southwest to the northeast and for 8–9 km from the southeast to the northwest and is located at the junction of the Ikat and the Southern Muya ranges at the intersection of the northeastern part of the Barguzin rift with the rift of the upper reaches of the Barguzin River. The steep and high southeastern side of the Amut Depression coincides with the northeastern rift, to which the neighboring Kovyli and Turaki depressions are allocated.

The Amut Depression is located at the intersection of the Barguzin River Valley with a rift and formed in the area of Upper Proterozoic granitoids; there are two remnants of them in its southwestern part, to the east of the Malan-Zurkhen Lake. The basin is mainly composed of the Upper Quaternary glacial and fluvioglacial deposits—boulders, pebbles, gravel, loam, sandy loam, and sands—and of Holocene alluvium along the valley of the Barguzin River. The altitude of the central lowered part of the basin is 1210–1240 m above sea level, and that of surrounding mountains is 1700–2400 m. The floodplain and two above-floodplain terraces of the Barguzin River are distinguished here. Pleistocene terminal moraine ridges are located in the northeastern and southwestern parts of the basin at the altitude of 1400–1470 m above sea level.

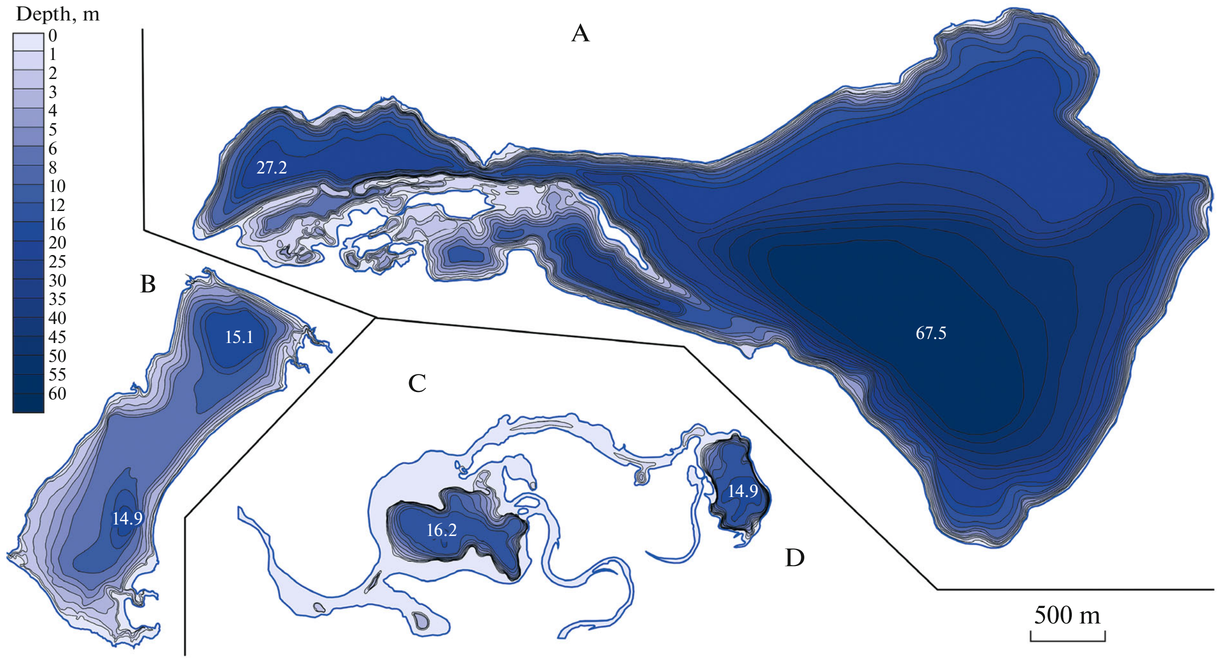

Fig. 2. Bathymetric maps of lakes in the Amut Depression.
Lakes: (A) Amut, (B) Malan-Zurkhen, (C) Balan-Tamur, and (D) Churikto.

Moraine deposits 100–200 m thick are represented by unsorted boulder–blocky and boulder–pebble–gravel material with a yellowish brown sandy–clay filler and with a large amount of glacial fine earth, which is carried out of moraine strata by temporary watercourses.

A large amount of insufficiently researched lakes is a distinctive feature of the depression. Our studies of 1981, 1982, and 2020 enable us to characterize the main features of topography of the largest lakes: Amut, Malan-Zurkhen, Yakondykon, Balan-Tamur, and Churikto.

The largest lake in the depression—the Amut Lake—located between its northeastern slope and the moraine ridge and the Yakondykon Lake located between two moraine ridges are connected with the Barguzin River by the Amut Channel (Fig. 2). The drainless Malan-Zurkhen Lake in the southwest of the basin is bordered in the north by a terminal moraine ridge. The elevation of the peaks of the ridges over the edges of the lakes is 10–50 m. A system of lakes Balan-Tamur–Churikto is located in the southeast of the basin. The Barguzin River enters the flowing Balan-Tamur Lake from the east and flows out of it in the west. The lake is connected with the Churikto Lake, which is related with the Barguzin River by a temporary channel during high water, in addition to its connection through the Balan-Tamur Lake. Besides large lakes, there are many small moraine lakes here allocated to the axial parts of terminal moraine ridges with hilly–basin topography, as well as thermokarst lakes in the central lower part of the depression.

The largest lakes (Amut, Yakondykon, and Malan-Zurkhen) are of moraine-barrier genesis. However, tectonics could also participate in the formation of particular parts or basins of these lakes, of the deepest Amut Lake in particular. The role of ancient glaciers in the formation and configuration of the basins of the Balan-Tamur and Churikto lakes is significant; however, they may be of tectonic genesis, taking into account their location at the intersection of the main rift of the depression with the graben valley of the Barguzin River. The bathymetric survey of four lakes was performed by us in 1982 and 2020 (Fig. 2). The total area of the water surface of all the lakes of the depression reaches 17 km^2 or 12% of the area of its bottom.

Lakes Yakondykon, Churikto, and Malan-Zurkhen are assigned to the profundal–littoral morpholimnic type, and the Balan-Tamur Lake is of the littoral-profundal type [7]. A significant part of the Balan-Tamur Lake is not deep, in bays in particular. Depths more than 10 m are only recorded in the central part and in the area near the southeastern shore. There is only one deep basin on the lake bottom, surrounded by a littoral with abundant large granite boulders (to 5 m) of glacial origin. The underwater eastern slope of the lake is steep and filled with sandy material brought by the Barguzin River. The large mean depth of the Yakondykon and Churikto lakes is determined by the morphology of their basins with small areas of shallow waters of the narrow shore strip. All lakes are characterized by the shift of maximal depths to one of the shores. This is well pronounced for the Yakondykon Lake, where the inclination of the underwater southwest shore is great and the depths are 15–20 m at a distance of 30–80 m from the shore line. Northern and eastern underwater slopes are less steep.

The relief of the bottom of the Malan-Zurkhen Lake is represented by two depressions separated by an elevation under alternated subaquatic and subaerial conditions due to great fluctuations in the lake level. The recorded depths are 5–7 m in the center and the southwest of the lake and 14 m in the northeast.

The shores of Balan-Tamur and Churikto lakes and the channels connecting them are formed under the impact of thermal abrasion and thermal denudation. These processes are most intense on the southern bank of the channel composed of lacustrine and lacustrine–marsh sediments with a network of polygonal structures. Cracks located parallel to the coastline favor shore destruction. The annual rate of coastal retreat in some places reaches 1 m. The entire system of the lakes is flowing, so the level of lakes and channels rises by several meters during floods on the Barguzin River. Water, flooding low banks, stagnates in many places and contributes to the thermokarst activation.

Microlevees reaching 10 cm in height, seen in places on the shores of the Amut and Malan-Zurkhen lakes composed of sand and gravel, are often half-destructed by aeolian processes. There are several such levees on the northeastern shore of the Malan-Zurkhen Lake, formed due to long-term fluctuations in its level (to 3 m). Blocky and sandy sediments predominate over clay ones in the shore strip of the bottom. Higher aquatic vegetation is well developed in the littoral zone to a depth of 3–4 m.

The Malan-Zurkhen Lake is characterized by significant fluctuations in the level recorded by the dendrochronological method. They reached 4 m during the past 30–35 years, which is determined by the belts of differently aged forest stands. The long-term dynamics of the amount of precipitation is the most probable factor in these fluctuations. Variations in the lake water volume reached 9 million m^3 from the late 1950s to the early 1980s (the lake volume in 1982 was 11.7 million m^3); i.e., the maximal volume was about 20 million m^3. There are 10- to 11- and 20- to 22-year-long cycles in the fluctuations of the lake level. Small undrained lakes of the region are characterized by the amplitude of level fluctuations of 1–2 m. The level of the Balan-Tamur and the Churikto lakes rises by 1.5–2 m during high floods on the Barguzin River.

The main features of lake relief-forming processes in the Amut Depression are typical for the mountain regions of Cisbaikalia and Transbaikalia. Only the Malan-Zurkhen Lake is distinguished by many specific features which are not typical for the rest of the lakes in the basin and neighboring areas due to the absence of constant surface runoff from it. It is characterized by significant fluctuations in its level from year to year (to 5–6 m) and in the composition of the fauna, in which only one species of fish was found: the Siberian bearded stone loach (according to an oral report by A.N. Matveev).

Rather inactive lake processes of substance transportation in the terminal and intermediate sedimentation basins result in its shift from subaerial to subaquatic conditions. The bottom sedimentation is slow, and the manifestation of shore processes is very diverse. Clay and sandy sediments accumulated in them are mainly transported to the lakes by fluvial and slope processes and less often are input as a result of the shore destruction (the ratio between these processes is opposite in some cases). The shores of many lakes of the depression are stable; only some parts of the Balan-Tamur and Churikto lakes composed of frozen loose sediments are relatively dynamic due to intensive thermoabrasion and thermokarst.

Thermokarst and the formation of heave mounds are of primary importance among the cryogenic processes of local substance transportation in the depression. Thermokarst is developed on the depression bottom and in the valley of the upper Barguzin River and of some of its tributaries. The main thermokarst forms include subsidence basins filled with water (lakes) and funnels. The size of thermokarst lakes differs, but shallow ones with a diameter to 200 m prevail.

The morphology of thermokarst forms is closely related to the ice content in loose sediments. The process is poorly developed in case of low ice amount in the upper horizons of alluvial, fluvioglacial, and other deposits. It is more common in the center of the Amut Depression in the areas of lacustrine and lacustrine–marsh deposits with high ice content. An area of several square kilometers between the Barguzin River and Balan-Tamur and Churikto lakes is characterized by local subsidence of the surface as a result of thermokarst. Ridges and hills 5–10 m high here alternate with hollows and depressions with cracks and sliding soil blocks on the slopes. Trees lean in the middle part of the slopes of ridges and fall in their lower part. The thermokarst development in this area is enhanced by layers of lacustrine–marsh sediments (clays and peat) with high ice content.

Thermokarst is also developed along polygonal–wedge ice on the floodplain and above-floodplain terraces of the Barguzin River at the altitude of 1250–1280 m. Tetragonal, pentagonal, and hexagonal polygons with a side size of 10–30 m formed as a result of frost cracking are now being destructed. Cracks located along the slope inclination undergo thermal erosion. These elements represent a mature form of destruction of polygonal-wedge structures by thermokarst developed along repeated-wedge ice. This area on the map of the distribution of repeated-wedge ice in the Soviet Union [14] is assigned to the zone of relict repeated-wedge ice (2–5% of the area), but the formation of a modern one is also possible here [15].

One of the most probable reasons for thermokarst development over the repeated-wedge ice of the Amut Depression is related to fires in the second half of the

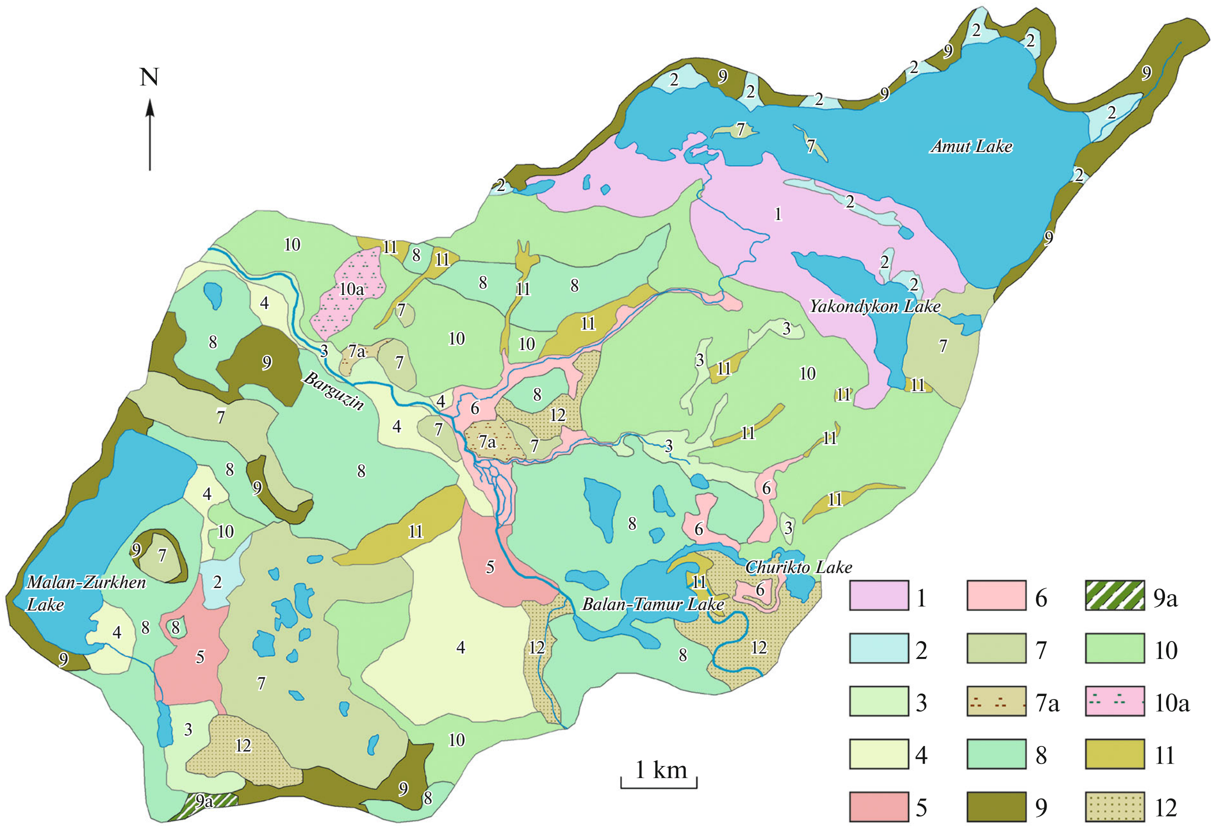

Fig. 3. Landscapes of the Amut Depression.
Groups of facies: (1–12) are given in the explication.

20th and at the beginning of the 21st century, which changed the hydrothermal regime of soils. However, although thermokarst forms are now at different development stages here, most of them are at the stage of surface subsidence and of deepening and expansion of depressions, while a smaller number is at the stage of stabilization or degradation. Trunks of dead and dying trees on the bottom of the lakes testify to the fact that their shores remain unstable. Modern thermokarst forms intensively appear in large areas as a result of climatic changes during the last 100-year period. Fires contribute to local thermokarst development. Based on a dendrochronological study of the coasts of Lake Baikal, G.I. Galazii [16] revealed climate warming in the last 50-year period. Changes in temperature parameters in the Baikal region in the 20th century caused the initial melting of underground ice and the formation of cryogenic forms.

A complex of soils typical for the goltsy and taiga belts formed in the studied area is related to specific features of the geological and geomorphologic structure and climatic regime. According to soil-geographical zoning, the soils of the basin are assigned to the high-altitude Barguzin–Upper Angara region of lithozems, petrozems, mucky carbolitozems, soddy–podzols, podzols, gleezems, and typical and coarse-humus podburs [17].

According to the physical-geographical zoning, the research area is located within the Baikal-Dzhugdzhur mountain–taiga physical-geographical area [8], which is characterized by prevailing mountain structures of ancient orogenesis with the domination of light coniferous forests with a well-developed shrub layer. The altitudes of the basin and the severe climate cause the formation of communities of low biodiversity and insignificant variants of geosystems.

Based on the results of the terrain research, a medium-scale (1 : 100000) map of landscapes of the Amut Depression has been compiled (Fig. 3). Groups of facies are the main unit of mapping; they are combined into four geoms assigned to one type of natural environment with the specification of the subcontinent and the physical-geographical area.

Explication for the landscape map of the Amut Depression (northeastern Cisbaikalia) on a scale of 1 : 100000

A. NORTH ASIAN BAIKAL-DZHUGDZHUR TAIGA GEOSYSTEMS

I. Dwarf pine subgoltsy (Pinus pumila (Pall.) Regel) geosystems

(1) Tops of moraine ridges with dwarf pine and dwarf shrub (*Ledum palustre* L., *Empetrum nigrum* L.,

Vaccinium vitis-idaea L.)—lichen (*Cladonia* ssp.) communities, often with patches of dwarf birch (*Betula nana* ssp.) and sphagnum (*Sphagnum* sp.) swamps in the upper part of the mountain taiga belt at an altitude of 1400–1600 m above sea level on thin stony mountain soils; hypothermal.

II. Geosystems of shrub mountain depressions

(2) Mountain depressions and plains with dwarf birch (*Betula nana* ssp.)—willow (*Salix krylovii* E.L. Wolf and *S. glauca* L.) herb (*Bergenia crassifolia* (L.) Fritsch, *Festuca altaica* Trin., *Poa pratensis* L., *Carex* sp.) communities of near-river habitats at an altitude of 1300–1400 m above sea level on stony thin-profile mountain soils in combination with short-herb meadows on rocks of different composition; medium-hydromorphic and hypothermal.

(3) Plain shrub (*Salix krylovii* E.L. Wolf, *Betula nana* ssp., *Pentaphylloides fruticosa* (L.) O. Schwarz) and dwarf-shrub (*Ledum palustre* L., *Vaccinium vitis-idaea, V. uliginosum* L.)—sedge (*Carex* sp.) thin swampy communities; hypothermal.

III. Geosystems of dwarf shrub—swamp mountain depressions

(4) Gentle slopes and bottoms of poorly drained mountain depressions with dwarf shrub (*Andromeda polifolia* L., *Ledum palustre*)—moss (*Sphagnum* sp.) communities with thin larch (*Larix dahurica* Turcz. ex Trautv) forests with dwarf pine on permafrost peaty soils; cryohydromorphic.

(5) Plain dwarf shrub (*Chamaedaphne calyculata* (L.) Moench, *Ledum palustre*, *Oxycoccus palustris* Pers., *Vaccinium uliginosum*)—lichen—sphagnum communities with rare dwarf birch on permafrost—marsh peat soils; cryohydromorphic.

(6) Lowland habitats and depressions with marshy forbs (*Comarum palustre* L., *Eriophorum* ssp.)—sedge (*Carex* sp.) communities; hypothermal.

IV. Mountain—taiga and mountain—depression larch (Larix dahurica) geosystems

(7) Flat top surfaces of goltsy leveling with shrub (*Betula nana* ssp.) and dwarf shrub (*Ledum palustre*, *Vaccinium uliginosum, V. vitis-idaea, Rhododendron aureum* Georgi)—lichen (*Cladonia* ssp.) thin larch forests with dwarf pine.

(7a) Young dwarf shrub—lichen larch communities on burnt plots.

(8) Gentle foothill slopes of wide valleys with shrub dwarf shrub—lichen larch communities, often in combination with areas of sphagnum swamps on thin soddy—podzolic soils on deluvial—collivial deposits; slightly hydromorphic, hypothermal.

(9) Slopes of medium steepness with dwarf shrub—lichen dwarf pine thin larch communities on stone fields.

(9a) Young dwarf shrub—lichen dwarf birch thin larch communities on burnt plots.

(10) Gentle slopes in the upper part of the mountain taiga belt with dwarf shrub (*Ledum palustre*, *V. vitis-idaea*, and *Arctous alpina* (L.) Nied.)—lichen larch communities, often with the participation of dwarf pine on thin soddy—podzolic soils; slightly hydromorphic and hypothermal.

(10a) Young thin dwarf shrub—lichen larch communities.

(11) Valley dwarf shrub—herb—moss shrub larch communities on soddy—podzolic stony soils; hypothermal.

(12) Plain habitats of the depression bottom with dwarf shrub—moss shrub larch thin communities on thin soddy—podzolic soils; slightly hydromorphic and hypothermal.

Daurian larch (*Larix dahurica*) is a forest-forming tree species within the bottom and sides of the Amut Depression in well- and medium-drained habitats. No other tree species were revealed during the terrain work. Dwarf shrub—lichen larch communities with dwarf pine in the undergrowth are the most widespread. Single trees of spruce (*Picea obovata* Ledeb.) were recorded only outside the Amut Depression, downstream of the Barguzin River.

A detailed analysis of landscapes in the Amut Depression reveals some differences between the northeastern (Amut) and southwestern (Malan-Zurkhen) parts, separated by the Barguzin River. For example, dwarf pine communities are most pronounced in the Amur part of the basin, where they occupy the upper parts of moraine ridges.

Gentle southeastern slopes in this part of the depression with permafrost soils are occupied by shrub and dwarf shrub—moss—lichen thin larch facies, which are not widespread in the southwestern part of the depression. Slightly inclined wide swampy valleys are more pronounced here.

Plain habitats near the Malan-Zurkhen Lake are mainly represented by willow dwarf shrub—lichen—sphagnum communities. Closed shrub—forbs—dwarf shrub larch forests occupy the lake-depression surface of the moraine. In other areas, in the northeastern of the depression in particular, thin sphagnum—lichen larch forests predominate.

Waterlogged shrub and sphagnum communities are widespread on low elements of topography, in depressions between ridges, and in slope hollows on permafrost soils throughout the depression. Meadow communities are mainly allocated to the wide valley of the Barguzin River, where swampy sedge communities are formed on alluvial deposits, often in combination with willow cenoses.

The plant cover may be generally characterized as rather monotonous with respect to the species and community diversity. The spectrum of species in forest and nonforest communities is mainly identical.

The disturbance of the geosystems of the area is low: traces of fires within the basin are sporadic, and old burnt areas are small with intensive restoration processes.

CONCLUSIONS

The main features of the relief and landscapes of the Amut Depression are typical for the mountainous regions of Cisbaikalia and Transbaikalia. Only the undrained Malan-Zurkhen Lake is characterized by many specific features not typical for the rest of the lakes in the depression and in the neighboring mountain–taiga and goltsy areas.

The depression is mainly characterized by hilly–basin and ridge topography formed by glaciers in a small tectonic depression of the Baikal type in the Upper Pleistocene. The relief is now transformed under the effect of fluvial, lacustrine, and cryogenic processes.

Despite numerous types of habitats, the spatial structure of geosystems in the Amut Depression is relatively simple due to severe ecological and climatic conditions. Predominating larch communities, which are typical for mountain depressions of the entire physical-geographical region, are located here at the southwestern limit of their distribution. This makes them a promising object for monitoring evolutionary-dynamic processes in the natural complexes of Cisbaikalia related to global climate changes.

The landscape diversity of the area is caused by local differences in the relief of the depression and surrounding mountains, lithological composition and mesoclimatic conditions, and temperature features of the edaphic medium.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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