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Ecological-Geographical Aspects of Soil Complex Types Allocation at the Ukok Plateau Using Remote Sensing Studies

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Abstract—This paper considers the possibility of creating mesoscale soil maps of the natural systems of the Ukok Plateau on the basis of remote sensing studies, principles of landscape zoning, landscape-indicator interpretation methods, and integrated analysis of the spatial-temporal characteristics of natural environment objects.

Keywords: intermountain basins and highland plateaus, soil cover structure, remote sensing studies

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Fundamental and applied problems of state and functioning of mountain ecosystems both in our country and abroad are attributed to a number of policy objectives for conservation and sustainable use of mountain landscapes [1–4]. The need to study natural resources and monitoring of mountain geosystems are conditioned not only by their high importance for the regional economy but also by the fact that they play an important role in maintaining biosphere functions and conservation of global biodiversity. In the context of general problems, preservation of the integrity of the soil cover in connection with its leading role in shaping the diversity of terrestrial ecosystems is an urgent theoretical and practical problem [5].

The results of the study of the soil cover of the Altai Mountains with a wide range of diversity of altitude zones of mountain ranges, intermountain basins, and upland plateaus can be used for addressing many theoretical and practical issues of soil science on both the local level and at the level of large regions.

Historically, intermountain basins and high plateaus have been centers of economic life of the Altai Mountains. However, unlike the steppe and forest steppe low- and middle mountain valleys and basins of the region, which became natural resources earlier than others, the ecosystems of basins and plateaus can be regarded as conditionally native (primary), most appropriate to natural factors of their formation [6], that is, as assessment categories in identifying the features of the natural or anthropogenic transformation of the soil cover in areas of similar origin.

The soil cover of the Ukok highland plateau (2200–2400 m) still remains unexplored due to inaccessibility of the area. Data on properties of soils and soil-forming processes in conditions of extreme continental climate (absolute extremum is –60°), high-altitude zonation (contact of dry steppes with highland alpine-tundra zone), and extensive development of glacial formations in relief (stages of limno-glacial complexes) are very rare in the scientific literature. Study of the structure of the soil cover of the Ukok Plateau was carried out in order to develop the principles of allocation of soil complex types on the basis of remote sensing studies and integrated analysis of digital layers of spatial-temporal characteristics of the natural environment objects. The study materials were used to create a map layout of soil complexes of the Ukok Plateau [7].

OBJECTS AND METHODS

According to geomorphological zoning, the Ukok Plateau is a vast depression between the South Chu ridge and the northern roots of the high mountains of the Southern Altai, Saylyugem, and Tabyn-Bogdo-Ola. Its northern boundary is on the lower level of the Dzhazator river valley that is adjacent to the South-Chu Ridge. In the east, the plateau includes upper reaches of the Dzhazator Valley and Tarkhata Basin. The southern boundary runs along the northern slope of the Southern Altai Ridge, Tabyn-Bogdo-Ola mountain range, and the Saylyugem Ridge. In the west, the boundary is drawn by the Karaalakha Mountains, including landscapes of the Samakha steppe [8].

Key areas were selected on the basis of the principles of landscape zoning, which allows recognizing, classifying, and mapping the landscape and differentiating factors, components of the landscape, a regional landscape structure as a whole and its dynamic characteristics [9, 10]. The method is based on the adjoint

Basic patterns of organization of soil cover of Altai Mountains and adjacent areas

Consecutive number	Soil cover structure type	SCS characteristic, soils	Literary source
	Altai Mountains (in the Asian part of the former USSR)		
1	Densely dendritic unordered and densely dendritic expositionally differentiated mesostructures	Finely-contoured alternation of moraine hills and intermoraine closed depressions with superimposed erosion network	[23]
	South-eastern province of Altai Mountains:		
	Zone of highlands	At an altitude of 1800–3500 m—mountain-meadow and mountain-tundra ones; 1300–2000 m—mountain-forest-tundra (fragments)	[11]
2	Interzone mountain soil areas of high-, medium-, and low mountains: intermountain basins, highland plateaus, river valleys	At an altitude of 1400–2600 m—mountain meadow-steppe chestnut and chernozem ones; 1300–2500 m—dark chestnut, mostly chestnut, and light chestnut	
	Mongolian Altai		
3	Altitude-exposition	At an altitude of over 3500 m—rocky and tundra and turf-humus-gley ones; 1600–3000 m—highland alpine steppe coarse-humus ones combined with alpine meadow ones, in the lower part of the zone—with mountain chernozems; less than 1600 m—highland steppe coarse-humus, which are directly transferred into the zone of chestnut and light chestnut soils.	[21]

analysis of regional structures that are objectively reflected on satellite images and are fixed on the landscape-typological maps. The landscaped areas are allocated by the traits of a landscape structure, are characterized by development of a dominant type of terrain, and are distinguished by natural composition of structural elements and clearly deciphered in terms of natural and anthropogenic factors of differentiation of the soil cover.

As sources of information on the objects of the environment that define specific features of soil formation, the study uses general geographic maps to determine degrees of fragmentation of the territory and as a base for the geographic adjustment of satellite images; thematic soil, geomorphological, and geobotanical maps: Schematic distribution of main soils of Gorno-Altai Autonomous Region, scale 1 : 500000, 1973 [11]; Vegetation map of southeastern West Siberia, scale 1 : 100000, 1960 [12]; Intermountain steppe vegetation map of Toi-Samakha, scale 1 : 500000 [13]; Geomorphic schematic map of Bertek depression, scale 1 : 500000, 1998 [14]; Natural complexes of Ukok Plateau, scale 1 : 500000, 1962. [15] For objective partitioning of borders and spatial distribution of the soil complexes, a digital terrain model of the Ukok Plateau was created.

Medium-scaled soil maps of the key areas were created using landscape-indication decoding of the Landsat satellite images. Spectral image classification in the Erdas Imagine software environment with subsequent vectoring in ArcGis served as the main method of interpretation of the satellite images. As a result of digital raster processing and adjustment of boundaries and information content of their basic mapped units, digital thematic layers were obtained: natural complexes, vegetation, limno-glacial complexes, and soils, which served as the basis for the allocation of the soil cover structure types.

Typological principle of SCS partitioning in mountainous regions. The leading role of soil complexes in the structure of the soil cover of different mountain ranges is noted by many researchers. Within the Altai-Sayan mountain country and on the neighboring territories that are characterized by extracontinental conditions of soil formation, typology of soil complexes is covered in papers [16–19, etc.]. At the study area, to allocate forms of the soil cover structure, we followed the principles of systematization of the soil cover structures (SCS) that were stated in the fundamental monographs [11, 20]. In the group of interzone soil regions for highland basins, plateaus, and river valleys (at altitudes of 1100–2500 m), an approach that was developed for small areas of lowland areas of the adjacent Mongolian Altai was put in the basis of partitioning SCS types [21].

According to the taxonomic classification system of soil cover structures that was designed by V.M. Fridland, the SCS type characterizes the territory, for which processes and factors that determine the main geographical patterns of soil distribution are united [22, 23]. The structure of the soil cover of the Ukok Plateau, according to studies that were carried out to varying degrees of detail, is defined by the presence of vertical zonation—mountain tundra and mountain-meadow soils of highlands and interzone areas of highlands (see table). For regions of intermountain-

depression-type of zoning, a peculiar combination of contrasting environmental conditions is noted, which leads to appearance of soils that are typical for different latitudinal zones and subzones (appearance of chestnut soils in the mountain-steppe zone).

Of considerable interest is the approach to the study of the structure of the soil cover that is built on the basis of combining the zoning regioning principle by types of soils and the geomorphological one by types of soil combinations. The literature has accumulated significant material on the study of the soil cover of the mountains of South Siberia using the typological principle, at which apportionments similar in its features are grouped into one type regardless of their spatial location [24, 25]. For example, one type of SCS in Darkhat basin includes complexes of steppe soils, soils of the lake shaft, lake-marsh, and steeply sloping undulating plains [26], that is, formation of combinations—contrasting combinations with large ranges of soil—is frequently observed. For the soil cover of the Ukok Plateau, contrasting combinations of the complex of mountain-steppe and mountain-tundra soils are typical, in which boundaries between elementary soil ranges are very sharp, and transitions between them can be less than 1 m.

Main factors of soil cover differentiation. The selection of one type of the soil cover structure does not preclude the formation, within this type, of different soil combinations that are distinguished by a quantitative ratio of components or presence of some minor components that occupy small areas but that have an independent environmental significance. The specific nature of the soil cover structure of the Ukok Plateau, in which all the selected combinations of soils vary in component composition, is conditioned by the characteristics of environmental conditions of soil and altitude zones and interzone mountain areas, as well as local differences in terms of vegetation cover, soil-forming rocks, and types and forms of ice and lake topography (Fig. 1).

Zonation of soil and vegetation cover. In the profile of the South-Eastern Altai, the zone of forest soils is completely dropping out, since woody vegetation in the area is presented in fragments, and in some places is completely missing. Anomalies in the distribution of soils are expressed in the fact that tundra soils in terms of altitude location often occur lower than the steppe ones, occupying basins with permafrost soil-forming rocks. Low temperatures and stagnant water lead to extensive development of marsh-forming processes. The complex combination of soil-forming factors conditions the formation of soils in terms of morphology and properties—from primitive spotted moss-lichen soil formations to mountain-tundra, mountain-meadow alpine, mountain-meadow subalpine, and mountain meadow-steppe soils that have a developed profile.

Soil-geographical zoning. According to the Scheme of Soil-geographical Zoning, the territory of key areas can be considered as part of the zone of mountain-tundra and mountain-meadow highland soils (at the altitude of more than 1600–2000 m and up to 2600–3500 m) and interzone mountain soil regions, high-, medium-, and low mountains.

Regioning of vegetation cover. According to the regioning schemes of vegetation cover, the Bertek Basin kea area refers to the Chui-Ukok highland-steppe district of the Mongolian province and is divided into two areas—Saylyugem barren-tundra-steppe and Ukok tundra-dwarf birch-steppe. The region boundaries include the western and central spurs of the Saylyugem Ridge, Tarkhata Basin, and Ukok Plateau. The key area of the Samakha steppe refers to the Chui-Argut nival-highland-taiga-forest-steppe district of the Altai province, Chu-Argut forest-steppe region, which includes the Samakha steppe and the Dzhazator River valley [27].

Influence of ice and lake morpholithogenesis. Exogenous and resulting processes (glacial, fluvioglacial, fluvial, limno-glacial, permafrost ones, and weathering) were the main factors of relief formation at the last geological stage of development of the Ukok Plateau. Forms of accumulative relief, primarily moraines, have the greatest development in the study area. In the Bertek Basin, intense-hilly, hilly, and smoothed types of moraine relief are distinguished [28]. The intense-hilly relief is formed in the frontal part of glaciers and is usually associated with finite-moraine complexes. The hilly moraines have a more chaotic disordered structure of hills and tree location, and troughs are filled with fluvioglacial deposits. The smoothed moraines are more ancient and have worse preservation of moraine relief. The limno-alluvial plains are formed as a result of emergence of dammed lakes.

Soil cover map layout. Hilly depressions of the Ukok Plateau form two dominant depressions—Tarkhata and Bertek. The Bertek Basin is divided into two depressions: the east—Kalguta; the west—Akalakha. The investigation of the soil cover features and soil properties was carried out in terms of the soil complexes taking into account specificity of their limno-glacial topography. The Tarkhata Basin is a sublatitudinally elongated depression, the general decline of the bottom of which is more than 50 m to the east. In the basin, a complex of glacial and fluvioglacial formations is expressed, which forms hilly moraine topography. For drained meso-rises, combinations of small-turf grass steppes are characteristic, under which finely contoured complexes of chestnut low power strongly gravelly soils are formed (Fig. 2). Mountain-tundra turfy-meadow soils are formed in humid areas of inter-hilly depressions of moraine-hilly relief under shrub-grass-sedge tundra. Turfy-meadow soil and turfy-meadow with buried humus horizon were allocated on solifluction-difluction relief elements.

Within the Kalguta depression, a marshy meadow ancient-lake glacial flat plain is allocated, which was formed at the location of Mid- and Upper Quaternary

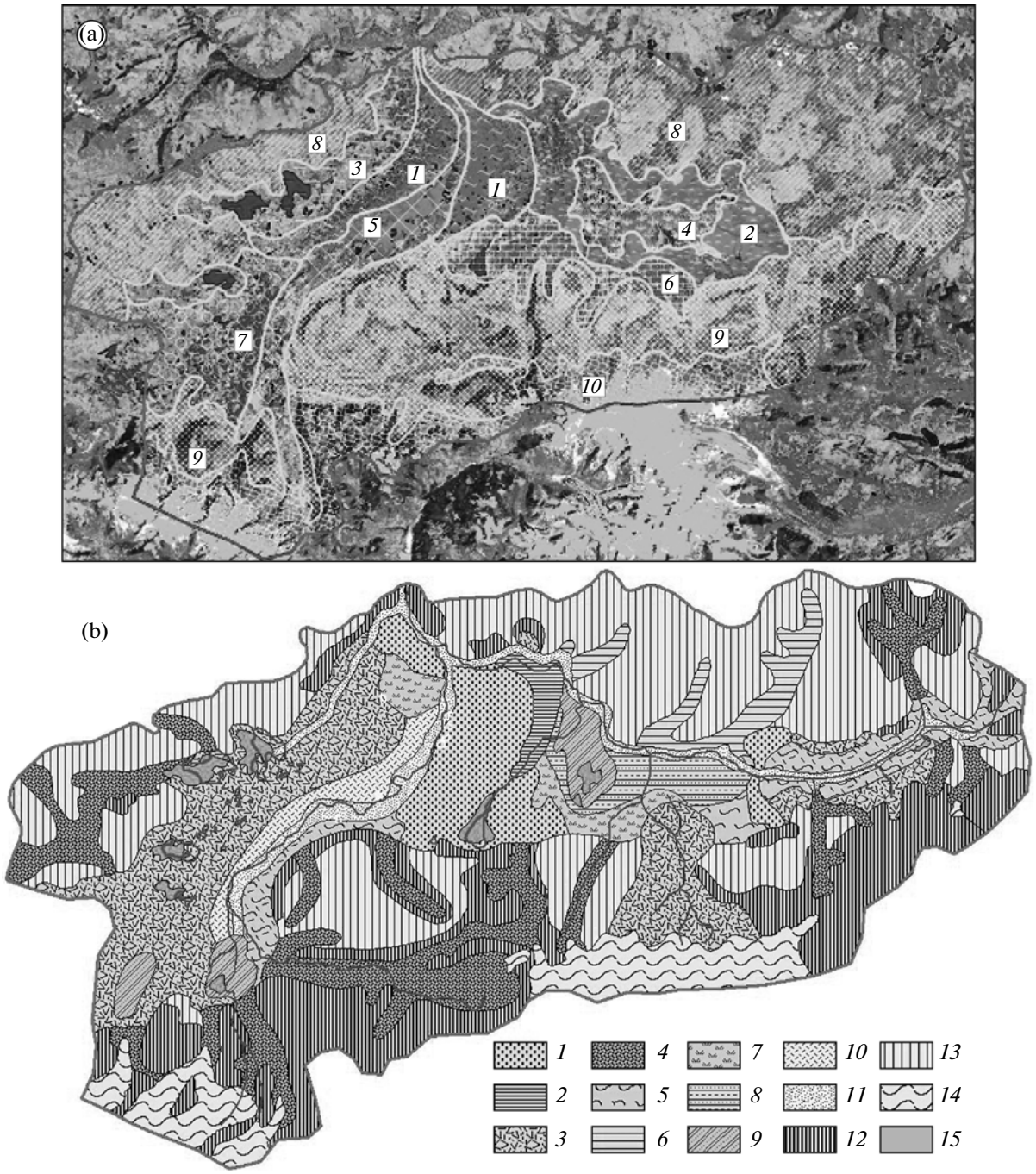

Fig. 1. Digital layers: (a)—natural complexes of Ukok Plateau [15]; (b)—geomorphological scheme of Bertek intra-mountain depression. [14]

(a): *1*—tundra-steppe hilly plain; *2*—steppe sloping undulating fluvioglacial plain; *3*—tundra-steppe ancient-lake sloping-hilly plain covered with moraine; *4*—marshy meadow ancient-lake glacial flat plain; *5*—meadow-steppe valley; *6*—tundra moraine slightly dissected plateau; *7*—tundra upland plain; *8*—surfaces of alignment and gentle slopes; *9*—steep slopes devoid of unconsolidated sediments; *10*—lakes.

(b): *1*—hilly-ridge-depression (intensively-hilly); *2*—gently-hilly ridge-depression (smoothed); *3*—hilly-undulating (hilly); *4*—trough valleys; *5*—gently-undulating slightly inclined surface of fluvioglacial plains; *6*—sloped broad river valleys filled with fluvioglacial deposits; *7*—gently-hilly undulating lake plain; *8*—flat slightly dissected lake-alluvial plain; *9*—finely-mid-hilly surface of lake plain; *10*—large- and finely-hilly surface of floodplain; *11*—finely-hilly surface high floodplain; *12*—steep slopes; *13*—surfaces of leveling and gentle slopes with solifluction-difluction relief; *14*—glaciers; *15*—lakes.

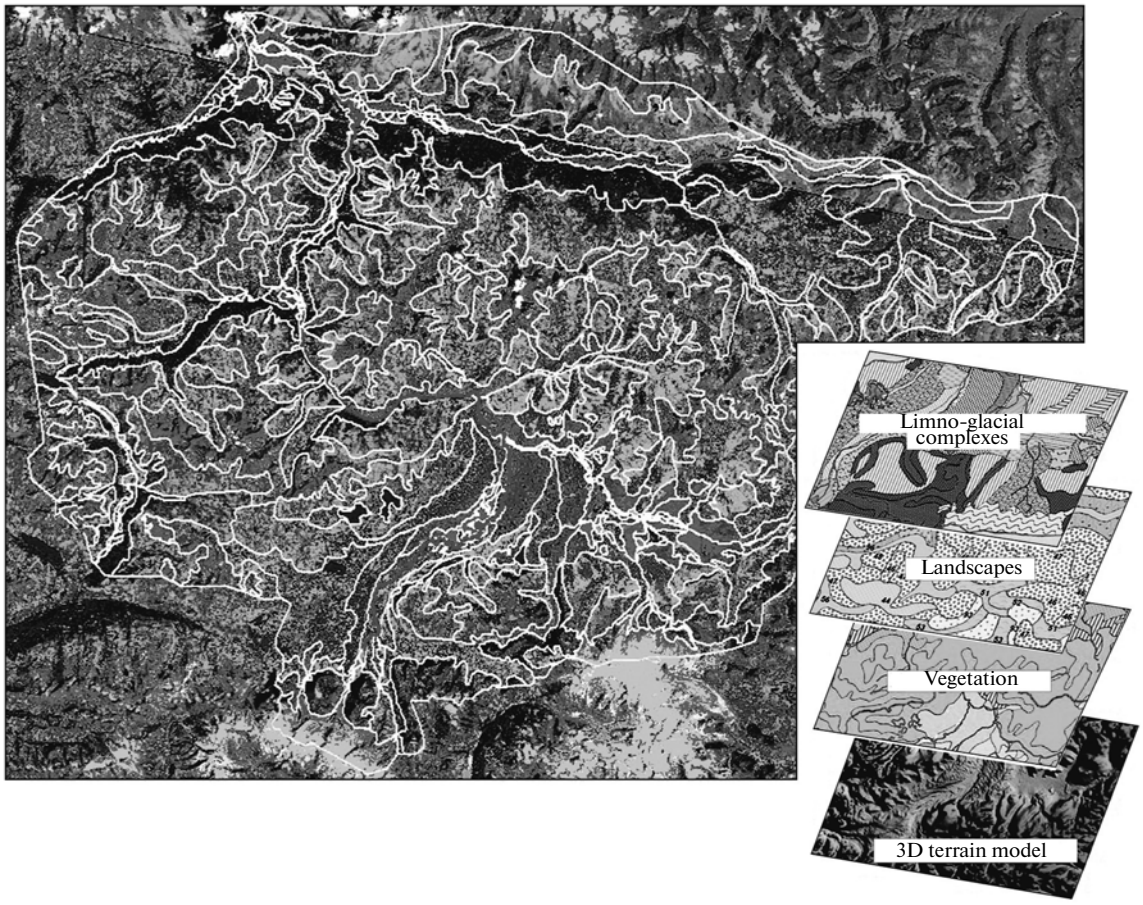

Fig. 2. Soil map layout of natural complexes of Ukok Plateau created on the basis of remote sensing studies and integrated analysis of digital layers of spatial-temporal characteristics of natural environment objects.

glacial lakes, on the bottom of which belt clays, sometimes interbedded with coarse-grained sand and loams, were deposited. There are many lakes, marshes, and rivers on the surface of the plain. The rivers meander very much, they are embedded only by 1–2 m. Altitude relative fluctuations do not exceed three meters. Flat plains that are occupied by marshes or marshy meadows are tract-dominants. Extensive shallow microdepressions of the plain are occupied by marshes, very wet sedge and grass-forb meadows in meadow-marsh and alluvial-meadow soils.

The tundra-steppe hilly-undulating moraine plain, which is located in the central part of the plateau, is composed of pebbles and boulders that are cemented by whitish and yellowish-brown loam. Moraine hills, which are covered with grassy steppe and depressions with thermokarst lakes and sedge-kobresia meadows, are tracts-dominants of this natural complex. The depressions are covered by swampy meadows on the meadow-marsh soils. The grass steppe on dark-colored mountain-steppe soils dominate on the hills. In general, the soil cover of the plain represents a complex mosaic of highland steppe and tundra soils, which creates a kind of tundra-steppe complex.

The steppe sloping undulating fluvioglacial plain is composed of sand and pebble fluvioglacial rocks. Weak dissection of the relief promotes development of fairly homogeneous soil-vegetation cover. The surface of the plain is almost entirely covered with highland turfy-grass bluegrass steppe on mountain-steppe dark-colored soils. Sedge meadows on alluvial-meadow soils occurred along riverbeds of rivers.

The Samakha steppe is located at altitudes of 1500–1600 m, stretches from the south-west to north-east, and is adjacent to the Argut valley from the north. The extended central area of Samakha Basin is blocked by a moraine shaft of a length of approximately 4.5 km and a width of 700–800 m, which rises above the steppes by 60 m or more. On the slopes of the moraine shaft with numerous boulders, low power chestnut soils are formed under sparse cinquefoil-sagebrush steppes. The northern slope of the moraine shaft is woody. The turfy weakly podzolic soils form small contours under fragments of park larch stands

and turfy-podzolic soils form small contours under cedar-larch moss forests.

The boundaries and information content of the soil contours in the key areas are corrected with the use of digital thematic layers: vegetation, limno-glacial relief, soil-geographical zoning, and natural complexes of the Ukok Plateau. Currently, the map layout of the soil complexes of the Ukok Plateau contains 14 legend units.

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