Mapping of geosystems in the south of the Yenisei Siberia for environmental assessment

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Abstract. Landscape mapping of the southern regions of Middle Siberia within the territory of the planned complex investment project "Yenisei Siberia" on collateral economic development of 3 regions (Krasnoyarsk Territory, Republics of Khakassia and Tyva) is carried out. Works were performed with using uniform geosystem classification based on systemic hierarchical approach to identification of a taxonomy of landscape units. It considers positioning of concrete territories and typological ranges of regional geosystems in the system of physical geographical regionalization. The technique of mapping was based on the V.B. Sochava's doctrine about geosystems and the principles of creation of hierarchical structure of geomers by integration of structural and structural-dynamic indicators. Own ideas of authors of geosystems classification received from experience of landscape mapping of other regions in the South of Siberia by drawing up the map are used. As a result of research a big variety of geosystems is revealed on the map through display of spatial differentiation of areals of distribution of geomers of a rank of group of fatsias is revealed. The complexity of landscape structure is caused by position of the territory of researches of a joint of four landscape regions.

1. Introduction

The territory of the planned complex investment project "Yenisei Siberia" for joint economic development of the Krasnoyarsk Territory, the Republics of Khakassia and Tyva [1] comprises the basin of the upper and middle Yenisei (Nazarovskaya, Kanskaya, Minusinskaya, and Tuva depressions and their mountainous surroundings). The region is characterized by diverse natural conditions and abundant natural resources. Geographical location, remoteness from the seas and oceans significantly determine its climatic conditions and landscape diversity.

Elaboration of the classification of geosystems in the south of the Yenisei Siberia during their mapping was based on the principles proposed by V.B. Sochava [2, 3-5]. It is based on a system-hierarchical approach to identifying the subordination of landscape taxa and evolutionary-dynamic interpretation of the mapped units, and the structure of the map legend takes into account the positioning of the territory and the typological spectrum of geosystems in the planetary system 2, 6, 7.

A wide variety of geosystems was identified and mapped as a result of landscape studies (figure 1).

As the lowest mapped unit of geomers, a group of facies was selected, and more than 200 such groups were identified in the territory of the research region. They were clustered into facies and geom classes. In total, 13 geom classes belonging to three groups were distinguished: North Asian goletz and taiga, North Asian forest-steppe and steppe, Central Asian mountain-tundra, tundra-steppe and steppe.

According to the signs of the landscape structure, the Yenisei Siberia is assigned to three physical and geographical areas: Ob-Irtysh (OIA), Central Siberian (CSA), South Siberian (SSA), each of them...
has its own special landscapes [4, 5]. In our opinion, the southernmost part of the studied region belongs to the fourth region - Central Asian (CAA).

Figure 1. Geosystems of the south of the Yenisei Siberia. Central Siberian (CSA): 1 – taiga, 2 – subtaiga; Ob-Irtysh (OIA): 3 – taiga, 4 – subtaiga; South Siberian (SSA): 5 and 6 – goletz and subgoletz, 7 – mountain taiga, 8 – taiga, 9 – subtaiga, 10 – forest-steppe, 11 – steppe; Central Asian (CAA): 12 – subgoletz, 13 – dry-steppe.

2. Geosystems of the OIA and CSA
The northwestern part of the studied region belongs to the OIA which are characterized by the predominance of planed surfaces and latitudinal zonality. In the geological structure, the region is an epigercin platform with a general tendency to bend throughout the Meso-Cenozoic [5]. 14 groups of facies were identified on the territory, combined into 4 classes of facies and 2 geoms (Ob-Irtysh taiga...
and subtaiga), which are characterized by a variety of dark coniferous forests on podzolic, sod-podzolic and gray forest (often gleyous) soils, sedge-sphagnum forested swamps and pine mixed with birch subshrub-moss forests in combination with subshrub-sphagnum bogs.

The landscapes of the CSA, covering the northeast of the study area, were formed on the ancient high Siberian Precambrian platform with a predominance of common and differentiated uplifts and denudations, accompanied by trappean volcanic eruptions, during the Mesozoic-Cenozoic geomorphological stage. The elevated-flat relief dominates in the territory, as a result of which thin deposits with fragments of bedrock serve as the prevailing soil-forming substrate. The 18 facies groups identified and mapped here belong to the 6 facies classes of 2 geoms (Central Siberian taiga and subtaiga). Landscapes of high plains, belonging to the southern taiga class of facies, dominate in the region and they are characterized by dark coniferous bilberry-grass-green-moss forests on sod-podzolic and gray forest soils; bilberry-green-moss pine forests are found on podzols.

3. Geosystems of the SSA

The physical-geographical areas described above include relatively small areas. The main part of the study area is occupied by the SSO, which is a mountainous region. The region includes Western and Eastern Sayan, Kuznetsk Alatau, Tuva Plateau, Western and Eastern Tannu-Ola and Tsagan-Shibetu ranges. It is characterized by a wide variety of hollow landscapes and mountainous frames - from goletz to steppe. 162 facies groups, 50 facies classes, and 7 geoms (southern Siberian alpine, subalpine, mountain taiga, taiga, subtaiga, forest-steppe and steppe) were identified in the region.

The goletz and subgoletz Southern-Siberian geom includes three groups of facies forming part of three classes of facies: the goletz alpine-type class, the goletz tundra class, and the subgoletz tundra-meadow-subshrub class. The facies of this geom are situated in Kuznetsk Alatau, Western and Eastern Sayans, on the summits of the ranges Shapshal’skii, Tsagan-Shibetu, Tannu-Ola, and Akademik Obruchev, and Sengilen highlands, in conditions of low temperatures and considerable precipitation amounts. The geosystems of the first two classes of facies are situated on summit and near-summit surfaces of goletz planation, and those of the third class are on the slopes and goletz planation surfaces. For the geosystems of the goletz and subgoletz Southern Siberian geom, vertical zonality is more pronounced (compared to the others).

Goletz alpine-type geosystems are represented by scree debris, with alpine meadows in the lower part. Shrub thickets cover mosaically the area at their lower boundary, and subalpinitypic meadow geosystems in more humid habitats. Yerniks and tall grass meadows often descend far into the forest belt. Subgoletz tundra-meadow-subshrub are represented by subalpine meadows, which alternate with tundra (moss, moss-lichen and subshrub) and lower with sparse forests (fir, spruce and larch).

Typically the groups of facies of sparse forest form a narrow strip. The upper limit of the distribution of tree species depends on the sum of active temperatures and soil temperature, which are at the same heights higher in drier conditions (especially on insulated slopes). Therefore, the height of this border varies from 1400-1800 m above sea level in Kuznetsk Alatau, Western, Eastern Sayan and northeastern Tuva up to 2200 m on the southern slopes of Tannu-Ola. The lower border of the forest also rises in a drier climate, therefore, in some places on the southern slopes of Tannu-Ola and everywhere on the Mongun-Taiga ridge, mountain steppes directly transit into alpine meadows and tundra [8].

At lower levels, the geosystems of the goletz and subgoletz Southern-Siberian geom are immediately adjacent to the groups of facies of the mountain-taiga Southern-Siberian geom which consists of several classes of facies, particularly of reduced, limited, optimal development and low mountain. Groups of facies with sparse forests of middle-mountain dark-coniferous reduced development occur everywhere across the mountainous territories of the study region (Kuznetsk Alatau, Eastern and Western Sayans and mountainous territories of Tuva), being transitional from goletz to the taigaones, but they occupy the largest area in regions with increased precipitation amounts. In drier regions, the upper border of the forest is more pronounced, but there are exceptions, e.g., sparse forests are well manifested on the plateau-like peaks of western Tannu-Ola.
A next stage includes geosystems of the class of middle-mountain dark-coniferous facies of limited development which are widespread in the mountainous territory of the study region. Compared to the steppe geom, vertical zonality is clearly pronounced in this mountain-taiga geom. The northern slopes of Western Sayan with a rather cold climate and significant precipitation amounts are typified by fir and Siberian stone pine-fir true-moss with a scanty composition of young forest and grass mantle. The contribution from Siberian stone pine is usually not large, but it increases as the upper forest line is approached. The predominance of fir in the tree layer is promoted by the favorable soil conditions. Siberian stone pine starts to dominate on the more lithomorphic habitats in areas with a substantial intensity of erosion processes. The southern slopes of Western Sayan are the home to the widespread groups of facies of larch, Siberian stone pine-larch forests, in some places with the inclusion of spruce, and with a mixed young forest, subshrub-moss.

Downward the slopes, in places up to an altitude of up to 600 m, the area nearer to the Minusinskaya depression is dominated by geosystems of dark-coniferous optimal development of the mountain-taiga Southern-Siberian geom. Compared to the preceding geosystems, the class of facies of optimal development is significantly richer in composition of young forest and grass-subshrub vegetation, and the soil cover is larger in thickness. The largest areas on planed surfaces of the summits and gentle slopes are occupied by Siberian stone pine-fir (with spruce) small-sized-grass-subshrubtrue moss forests on mountain-taiga podzolic soils.

Among forest geosystems, larch one of optimal development and dark-coniferous of limited development are dominated, because of an increase in the degree of lithomorphism and moisture, which increase the competitive ability of Siberian pine [6]. Dark-coniferous moss associations on humus taiga soils are located mainly in the eastern, more moistened part of Tuva. A rather significant array of larch forests alternating with swamps occupies the bottom of the Todzhinskaya depression at heights of 1000-1500 m. Larch trees surrounding the Tuva basin are of a different nature. The steppe larch and birch-larch forests on soddy soils are confined mainly to the slopes of northern exposures; on the other, depending on macro exposure, dry or meadow steppes are common [9].

Of significantly widespread occurrence are low-mountain slope of intramountain depressions dark-coniferous bilberry-grass-green-moss and mossy on sod forest, sod-podzolic, light gray forest soils and low-mountain light-coniferous subshrub-grass-green moos, grass-lingon-herbaceous on grass-soddy, soddy- forest and light gray forest soils.

Valley geosystems of the mountain-taiga class are represented by spruce with birch, larch or Siberian stone pine tall-grass and forb-sedge swampy in places, birch forb-sedge, sedge-sphagnum swampy facies and bogs as well as by forb-grasses meadows. The distinguishing feature of the valley groups of facies is the presence of low-level and high bogs.

Of significantly widespread occurrence in the foothill areas are the geosystems of the subtaiga Southern-Siberian geom especially subtaiga one; it is characterized by a wide distribution of lowmountain light-coniferous, mixed and deciduous groups of facies. Small tracts of natural forage lands protrude far away into the subtaiga zone and the arable agrolandscapes are situated on planed and gentlysloping surfaces of the intermontane depressions on common, leached chernozems and in the place of meadow vegetation and forests.

Valley geosystems of the taiga and subtaiga Southern-Siberian geom are represented by meadow-birch-pine steppizated, birch-willow forbs-grass and riverbed shrub, forbs-grasses and steppe meadows in alluvial meadow, meadow-boggy, boggy, gray forest gley and sod-podzolic gley soils [10].

The North-Asian forest-steppe and steppe group of geoms of the study territory includes two geoms: the forest-steppe geom and the steppe geom. The geosystems of the forest-steppe geom along the eastern margin of the Minusinskaya depression, represented by a broad strip, are situated on low spurs of the mountain ridges (largely of the northern aspect) of Eastern Sayan, protruding to the largest distance within the depression. The terraces of the Yenisei and the terraces of the old valleys of its tributaries are characterized by the presence of alluvial surfaces. A characteristic of this territory is the
occurrence of sands which produce dune-hillocky topography. They are concurrent with groups of facies of planed surfaces and gentle slopes.

Facies of the steppe Southern-Siberian geom occur just in the central parts of depressions. Nearer to the forest-steppe are the geosystems of the low-mountain and foothill classes of facies. The plain and gently-sloping territories of the study region are dominated by scanty forb-grasses shallow-soddy, grass-wormwood steppes combined with steppizated halophytic meadows on chernozems as well as by their digressional modifications.

In the Tuva depressions, steppe Southern-Siberian geosystems are distributed up to a height of 1000-1400 m. As in the Minusinsk depression, they are represented mainly by real steppes with the dominance of xerophytic cereals on low humus chernozems and dark chestnut soils. A smaller area is occupied by meadow steppes, confined to depressions and slopes of northern expositions.

Considerable tracts of the geosystems of the forest-steppe and steppe geoms are arable lands, and the other territory of the steppe, meadow-steppe and steppizated-meadow groups of facies is used as natural forage lands.

4. Geosystems of the CAA
The northern part of the Central Administrative Area enters the south of the study region along the border with Mongolia. The most characteristic are subalpine tundra-steppe geosystems on mountain-tundra, mountain-steppe coarse-humus soils and dry-steppe mountain-depression soils on light chestnut, sometimes saline, sometimes slightly saline, sandy and sandy and brown semi-desert soils [11, 12].

The Central Asian group of geomes includes geosystems of deserted steppes of depressions, highland steppes and thickets of xerophytic shrubs. They prevail in the Ubsunur depression, and are found in the Tuva depression. Mountain steppe geosystems are spread along the southern slopes of the Tannu-Ola, Sengilen, Mongun-Taiga and Tsagan-Shibetu ranges, reaching 2500 m high, i.e. significantly higher than the upper border of the forest in East Tuva. The southern macroscope on Tannu-Ola and the northern frame of the Khemchik depression are characterized by a pronounced boundary between the steppes and forests, which is stable in time. Central-Asian geosystems are most characteristic of the lower part of proluvial loops near Lake Ubsu-Nur with halophyte-feather grass associations on light chestnut soils (desert steppe). The landscapes of the Tes-Khem river valley are peculiar with the alternation of riverine forests and thickets of bushes, moist floodplain meadows (often on solonchak soils), steppe meadows and desert steppes, due to differences in soil moisture.

5. Conclusion
Thus, as a result of research of the territory of the Yenisei Siberia, its landscape structure was characterized, the geosystems of the upper and middle Yenisei basin were mapped (Nazarovskaya, Kanskaya, Minusinskaya and Tuva depressions, as well as their mountainous surroundings), a unified classification was developed for all selected physiographic regions based on system-hierarchical approach, taking into account the positioning of the territory that was used to create the legend of the map of geosystems.

More than 200 groups of facies united into classes of facies, geoms, and groups of geoms have been identified and characterized. The territorial differences of the typological spectra of regional geosystems are revealed, which are manifested in the complexity of the horizontal structures of the plain and mountainous territories in their landscape relief: the plains are characterized by a high uniformity of structure and large areas of landscape contours, and the structure of the mountainous geosystems is significant in complexity and contrast, therefore, the regional specificity of the altitudinal zonality of mountain geosystems was taken into account especially carefully. The boundaries of the physical and geographical areas (OIA, CSA, SSA, and the Central Administrative area) are clarified.
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