Transformation of geosystems of the Baikal natural territory (research and mapping)

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Abstract. The article deals with modern ideas about the transformation of geosystems and offers methodological foundations of its study. We considered the geosystem transformation in the context of changes in essential properties as a result of manifestation of transformative dynamics and geosystem evolution. It was revealed that the main trend of their transformations is largely determined by the impact of neotectonic processes. Singularities in the changes are assessed against the background of natural transformations of geosystems in the Late Cenozoic, when systemic connections, similar to modern ones, began to form. We noted that in most of plains and low-mountain areas of the area under study, a potential analogue of the natural complexes transformation in the Pliocene is currently being formed due to the development of aridization processes. We cite an instance of geosystem transformation of the Baikal natural territory. The methodology of mapping the transformation of geosystems, which is based on the mapping of system connections, transforming dynamics and evolution of geosystems, is considered. The research is based on information synthesis of data about the territory of Siberia, on the results of long-term ground route observations using the methods of complex physical and geographical research, comparative geographical, genetic, cartographic and GIS.

1. Introduction

It is generally accepted that climatic and geobotanical factors are leading in identifying the features of the transformation of geosystems. But it is controversial to base only on this fact, when it is necessary to establish the geosystem transformation sites located near the centers of tectonic activity. The study is of particular relevance for the area of the Baikal natural territory (BNT). The target of research is the geosystems of the Baikal natural territory. This territory combines a variety of geodynamic regimes: an ancient platform, the Baikal rift and pre-rift zones, and the Sayan mountainous region. Previously, paleogeographic, neotectonic, geobotanical and landscape studies were carried out here, but the specifics of the geosystem transformation have not been practically disclosed. Knowing these transformations will help mitigate the negative environmental impact of BNT. The principal task of the study consists in the conceptualization of geosystem transformation in geodynamically active territories. The work is based on the materials of long-term observations of the geosystems of Siberia. Synthesis of published data on the tectonic structure, development of the territory and climate change was taken as a principle while identifying the nature of geosystem transformation in the Late Cenozoic. Scientific research used the methods of complex physical and geographical research, comparative-geographical, cartographic, field route observations and interpretation of space images.
When analyzing the impact of thermal endogenous flows on the geosystems in this area, we were guided by published information on the results of measuring temperatures in wells and determining the values of geothermal gradients [1].

2. Concept of the transformation of geosystems
The location of the area on the border of geodynamically active zones necessitated the comprehensive reconstruction of geosystem transformation taking into account both climatic and tectonic transformations. In this context, special attention is paid to the works, in which the results demonstrate the dependence of mean temperature on the continents on the relief and orography. The study is based on the idea of geosystem as the earthly space of all dimensions, where individual natural components are in systemic connection with each other and as certain integrity interacts with the space sphere and human society [2, 3]. Geosystems belong to the class of open, hierarchically organized dynamic systems. This defines the nonlinearity and coherence of their relationships. Coherence is the consistency of behavior, which contributes to enhancing transformation. Nonlinearity determines various reactions of the geosystem to external influences, which depend on its structure. Structure is the spatio-temporal organization of the geosystem. It is represented by components, interrelationships and temporal geosystem state transition. The openness of geosystems means the exchange of matter, energy and information between them. The trajectory of information transmission is related to the direction from top to bottom, from the planetary level of the hierarchy to the topological one [4, 5]. The transformation of geosystems occurs under the influence of the transformative dynamics and evolution of geosystems.

3. Methodology for mapping the geosystem transformation
The mapping of geosystem transformation consists of delineation of integral geographic objects that are variable in their characteristics and trends of their spatial and temporal transformations. While mapping geosystems we also used the idea of a factorial-dynamic classification of topogeosystems according to their modification degree under the influence of various factors [6]. To reflect the transition from higher taxonomic levels to lower ones, all new assessment factors are introduced into the map legend. The initial factor of mapping is the nature of the relationships – material, energy and information. Therefore, the general criteria for heating (zonal features) and humidification (sectorial) are taken as a principle for identifying large taxonomic subdivisions of geosystems. Transformation of the zonal-sectoral features of each geosystem and the influence of neighboring geosystems are taken into account in classification at the next taxonomic stage. At this level, we distinguished northern, middle and southern subzones in the class of plain geosystems and in the class of mountainous geosystems – geosystems of reduced, limited and optimal development – mountain analogs of the above-mentioned subzones. At a lower level of the hierarchy, there is a modification of the plain type of geosystems (low/elevated), barrier-submontane variants. At the landscape level, relief forms, petrographic composition of rocks, an inflow of endogenous heat, and land cover features are displayed. Landscapes unite classes of facies of different factor series – of nodal trends of intra-systemic changes in natural conditions under the influence of waterlogging, salinity development, etc. The map legends also include the categories “pseudo-root extra-oblast unstable” (geosystems that are outside their main range); “serial factorial least stable” (i.e., hydromorphic, cryomorphic, lithomorphic, etc.), “conditionally long-term derived” (stable over time and do not return to their initial state after any impact).

4. Results and discussion
Analysis of geosystem transformation during the Late Cenozoic witnessed that the transformation was largely caused by tectonic processes, which determined changes in the composition of rocks and sedimentary rocks, relief, climate, atmospheric circulation pattern and the prevailing sedimentary environment.
In the Mesozoic era the early stage of rifting was for instance accompanied by endogenous heat warming. This entailed formation of one of the largest granite provinces on Earth, which is represented by the Angara-Vitim batholith - an intrusive massif with an area of about 200,000 km². The batholith is bounded from the west by Lake Baikal, from the east and south by the valleys of the Vitim and Khilok rivers, respectively. We revealed that dark coniferous-taiga geosystems are confined to felsic granites, in contrast to larch geosystems dominating in the region. On the Barguzinskii Range in the area of the outcropping of ancient felsic granites, dark coniferous taiga is distributed from the golets belt to the level of Lake Baikal. On the opposite side of Lake Baikal, outside the area of such granite distribution mountain forest-steppe is developed. For the same reason a special feature of the vertical zonation of the Barguzinskii and Khamar-Daban Ranges is the upper border of the forest formed by fir stand. These are the most ancient forests that appeared on the territory after the Pacific monsoon.

Fast ecosystem transformation began at the border of the Miocene and Pliocene epochs about 5-6 million years ago during the active stage of the Baikal rift zone development. The prevailing sedimentation environment is replaced from acidic to alkaline. In the Pliocene, the elevation of ridges and highlands in the east resulted in the formation of Siberian anticyclone, increase in the western transport of air masses, and the cessation of the monsoon influence [7]. Active orogenesis also manifested itself within the Siberian Platform. Its basement was broken into blocks, which experienced high-amplitude vertical movements, significantly influencing the formation of zones of accumulation or denudation. In the south of the area, the platform basement protrusion was elevated high and formed the northeastern part of the Eastern Sayan [8]. The transformations contributed to the reduction of surface runoff, the development of forest-steppe ecosystems, and the widespread occurrence of steppes on the mountain slopes.

Another powerful tectonic uplift of the earth's crust blocks occurred at the turn of the Neogene and Quaternary periods, which was accompanied again by climate cooling and aridization. This caused the development of mountain-valley glaciation. The endogenous heat in fault zones and residual volcanic activity contributed to the preservation of Miocene-Pliocene relics, which contributed to the transformation of the landscape structure of the region. This era made the final transformation of the taiga. This stage is associated with the areal extent of Larix dahurica and steppification of coniferous forests inherited from their contact with the periglacial steppes. On the periphery of glaciers in the north of the area, a dark coniferous-taiga complex with Siberian stone pine, dwarf Siberian pine, mountain-tundra subshrub was formed.

Further transformation of geosystems in the Holocene is associated with the most significant activation of tectonic processes in comparison with past eras. The climate became warmer and aridization intensified. We note that the main role in the transformation of the territory belongs to the southern shelf rock of the Siberian platform. The mountains obducted onto the platform. Herewith, a subsidence zones were formed [9]. One of them was the Pre-Sayan depression. The northern slopes of the Eastern Sayan uplifted above the Pre-Sayan depression with a steep scarp up to 800 m high. In the rivers flowing into the depression, internal deltas were formed. Swamy plain several tens of kilometers wide formed along the piedmont. The depression experienced constant subsidence and stretching. Destructive processes were developing: waterlogging, destruction of carbonate and loess-like sediments, soil salinization and geosystem transformation.

The middle trough bottom of the lake is one of the most mobile young continental zones on Earth. A powerful seismically active system of Cherskii faults is hidden here, under the waters of Lake Baikal. Tectonic movements accelerate the transformation of geosystems, creating high contrast in a small area. It is exemplified by the Selenga delta region. The branches of powerful faults are visible in the satellite image. They are separated by rectilinear sections of the Selenga anabranches and deltaic bog geosystems. Geosystems here are distinguished by significant contrasts, despite their close location (figure 1).
A – Faults and subsidence of microblocks of the earth's crust near the Selenga River. Satellite Terra (MODIS) as of 07/08/2013; B – Landscape scheme of the Selenga delta (eastern shore of Lake Baikal). 1 – delta bog and meadow-bog; 2 – valley meadow-bog and moistened; 3 – piedmont – valley dry steppe; 4 – piedmont – valley meadow-steppe; 5 – light coniferous high sandy ridges of lacustrine-river accumulation; 6 – light coniferous high terraces and piedmont plumes; 7 – piedmont-valley meadow-bog hydro-accumulative and saline ancient lake mires; 8 – larch-taiga grass; 9 – piedmont-taiga light-coniferous.

Significant changes in relief and landscapes are typical for areas of pre-rift zones. Deep rift processes are distributed in a weakened form from the boundary of the Baikal rift zone and contribute to the development of the mountainous relief of the Lena-Angara plateau of the Siberian platform, the Ikat Range and part of the Vitim plateau. The amplitude of swell reached 1000 m within this zone on the platform, uplifts and subsidence form linear shift fault; the heat flux differs from the platform one by 2 times. This contributes to the development of mountainous dark coniferous taiga and subalpine woodlands in the north of the Lena-Angara plateau [10] (figure 2).

Figure 1. Relief (A) and inflow of endogenous heat (B) in the zone of influence of the BRZ on the space image. Satellite NOAA-20 (VIIRS radiometer; thermal spectral channel i4).
The geosystems of the eastern part of the Irkutsk amphitheater of the platform differ significantly from those located on the left bank of the Angara. The dissected "semi-mountainous" relief, a mountainous regime of rivers, elements of altitudinal zonation, tectonic and morphostructural features of the plateau formed the basis for attributing the eastern part of the Irkutsk amphitheater to this structure.

5. Conclusion
Nowadays, several contradictions have arisen in the area under study concerning the impact of climatic and tectonic factors on geosystems. Climate change, on the one hand, caused the further development of the regional expansion of light coniferous forests and meadow steppes that had been established in the Holocene. On the other hand, the geosystem transformations associated with the further uplift of mountains resulted in the functioning of mountain dark coniferous taiga, development of subalpine woodlands and mountain tundra.

Acknowledgements
The work was done at the expense of the state assignment (No. of state registration AAAA-A17-117041910167-0) and with the financial support of the Russian Foundation for Basic Research within the framework of the scientific project No. 20-05-00253

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