IOP Conf. Series: Earth and Environmental Science **190** (2018) 012035 doi:10.1088/1755-1315/190/1/012035

Self-organization of the geosystems of the southern Cisbaikalia

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Abstract. The southern Cisbaikalia is located within the Baikal rift zone and the Altai-Sayan folded region. Self-organization of the geosystems in the research area is formed under a specific impact of geodynamically active regions. The main factors of self-organization of geosystems, especially the real-energy exchange, development, internal and external relationships, resonance, stability, are influenced by increased inflow of endogenous heat, Neogene-Quaternary volcanism and high tectonic activity of the territory. Formation and development of the neotectonic structure of the research area determine three energy-carrying elements of the Earth's deep structure - a powerful asthenolite, light blocks of the earth's crust and a vertical channel of the mantle. They in turn affect the formation of components of geosystems and their interrelationships. The paper presents the results of studying the factors of self-organization of geosystems of the southern Cisbaikalia, carried out using the methodology of self-organization process research, field expedition work, and interpretation of space images. The influence of energy-bearing elements on the formation, development and current state of geosystems is shown. It has been observed that within the regions, where elevated values of endogenous heat are recorded, geosystems containing both ancient (relic) and endemic components are concentrated.

1. Introduction

The study of spatio-temporal self-organization of geosystems is one of the most important tasks of landscape studies. The concept of self-organization was developed in the 50-60s of the 20th century with the emergence of a new scientific trend - synergetics, which studied self-organizing systems and considered general patterns of different systems development. G. Haken [1] gave a definition of the concepts of organization and self-organization, and carried out a number of works on this topic. Based on the ideas of self-organization, A.D. Armand [2] developed a theory of geographic processes, formulated general principles for the development of geographic systems. The doctrine of geosystems is associated with the name of V.B. Sochava [3], who laid the foundations, contributed subsequently in understanding the factors of self-organization of geosystems. The works of T.I. Konovalova [4] are devoted to complex studies of the self-organization of geosystems in the south of Central Siberia, as well as of V.I. Bulatov and D.V. Chernykh [5] on the organization of the Altai mountains.
Modern directions of geographical research complicate this task in connection with the need to study geosystems developing under climatic and geodynamic changes.

The study of the self-organization of geosystems acquires a special urgency due to the location of the southern Cisbaikalia within the Baikal rift zone (BRZ) and the Sayan-Baikal orogenous region. High tectonic activity, Neogene-Quaternary (basaltic) volcanism, increased values of endogenous heat

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flow affect the factors of self-organization of geosystems, which in turn affects the formation of new boundaries, preservation of relict and the development of new components of geosystems. The southern Cisbaikalia is characterized by a great variety and contrast of landscapes on closely located sites, which makes the area of research a unique site for solving problems of identifying factors of self-organization of geosystems.

2. Objects, Data and Methods

The study aims to identify the features of the geosystem self-organization of the southern Cisbaikalia.

The object of the study is the territory of the southern Cisbaikalia, which consists of Tunkinskaya depression, northern and northeastern macroslopes of the Khamar-Daban Ridge and the south-eastern part of East Sayan.

Currently, there are many definitions of the concept "self-organization", however, all its definitions boil down to the notion that this process that translates an open disequilibrium system that has reached a critical state in its development into a new, stable state with a higher level of orderliness of components and interrelations of the system.

In domestic geographical publications, self-organization is understood as:

- "internal orderliness, coherence, interaction of more or less differentiated and autonomous elements of the whole, conditioned by its structure" [6];
- "the emergence of new structures, evolutionarily more advanced than the previous ones" [2];
- "the formation of qualitatively new structures on a macroscopic scale, when the regularities of the emergence of order from chaos are established by the methods of thermodynamics of nonequilibrium processes" [7];
- "complex forming, preservation and orderly transformation of integrity through internal mechanisms" [4].

In this study, the author adheres to the notion that self-organization is a complex forming, preservation and orderly transformation of integrity through material-energy exchange, internal interrelations, resonance of processes, interrelation with the environment, development, coherence of ongoing processes. The real-energy exchange between geosystems and their components determines their internal unity.

Studies of the self-organization of geosystems of the southern Cisbaikalia were carried out using methods of complex physical-geographical studies, field-based observation and interpretation of space images, cartographic, comparative-geographical methods and GIS. Furthermore, we analyzed literature sources on the landscape structure of the region, works on self-organization, mapping, dynamics and functioning of geosystems, geobotany, tectonic and geological structure, as well as a number of integrated and sectoral maps.

In this work, when analyzing the effect of thermal endogenous fluxes on the geosystems of a district, we used published information on the results of measuring the temperatures in wells and determining the values of geothermal gradients. Geothermal studies in wells were carried out by the Institute of Earth Physics of the Russian Academy of Sciences, the Institute of Petroleum Geology and Geophysics, and the Institute of the Earth's Crust of the SB RAS. Temperature measurements were carried out both in support wells having a depth of more than 2-3 km and located in the basins of the Baikal type and in the Irkutsk amphitheater and in exploration wells with a depth of 300-600 m, drilled in sections of mountain lintels or in thermal water deposits [8].

3. Results and Discussion

Factors of self-organization of geosystems of the southern Cisbaikalia change depending on specific impacts of the Baikal rift zone: increased influx of endogenous heat, Neogene-Quaternary volcanism and high tectonic activity of the territory.

According to the published data [9], the formation and development of the neotectonic structure of the research area determine three energy-carrying elements of the Earth's deep structure. They in turn affect the formation of geosystem component and their interrelationships.

1. Powerful asthenolite is a magmatic body, which arose due to the heating of the lithosphere and its thermal expansion, which caused its isostatic movement. This determined the formation of the Mongol-Siberian revived orogenic belt and the maximum elevation within its boundaries of the East Sayan megaanticlinorium. The northern macroslope of the Eastern Sayan coincides with the margin of the asthenolith, as a result of which the mountains stop abruptly toward Baikal.

2. Light blocks of the earth's crust, saturated with granitoid intrusions, which experience prolonged uplifting in the form of arched uplifts. One of these blocks is confined to the Okinskoe plateau, located at an altitude of more than 2000 m and surrounded by high-mountain massifs. From the Miocene time (20-2.5 Ma ago), volcanic activity was intensive here, which ended only in the early Holocene (10 ka). That was illustrated by covers of basalts, cones of volcanoes and lava domes. A specific combination of structural and geodynamic factors defines the plateau as a unique geographical object in the newest structure of the mountainous regions of Eurasia.

3. The vertical channel of the mantle, which is a special element of the newest tectonic structure of Inner Asia. Under its influence in the southern Cisbaikalia, the largest thermal anomaly is recorded among the known thermal maxima outside the regions of active volcanism. In the southern Baikal Cisbaikalia, the heat flux (HF) is 4 times higher than in the neighboring areas of the Siberian platform [9]. The average value of HF is (10.5-11.3) • 10-6 J / (cm^2/ s), while for the Siberian platform it is equal to 4.4 • 10-6 J / (cm^2/ s). In the Tunka depression, the heat flux averages 5.4-7.5 10-6 J / (cm^2/s). Besides, on the general high thermal background in the zones of large young faults within the rift basins, anomalous areas are observed, which are associated with additional removal of deep heat. The greatest values of the heat flux within the territory under study are recorded in the Tunka depression (Arshan, Tunka, Irkut and Irkut), along the Predsayanskii Fault, along straight sections of large river valleys and in the foothills of the Khamar-Daban Ridge (the rivers Snezhnaya, Khara-Murin, Utulik and Zun-Murin). All these areas are associated, first of all, with regional faults and the largest deposits of hot mineral waters.

The impact of energy-bearing elements of the Earth's deep structure led to the formation of diverse and contrasting forms of relief in the region. This glacial erosion mountains with vertical dismemberment from 600 to 1200 m, which are characterized by a steeply slope alpinotypic relief with heights of up to 3284 m (Tunka goletz); gently middle-mountainous north-western spurs of the western part of the Khamar-Daban Ridge, flattened surfaces of Neogene-Quaternary basaltic covers (Khamar-Daban); the depression territory (the system of the Tunka depressions).

The combination of mountain and depressions affects the lithologic-geomorphological conditions and differentiation of climatic parameters. The mean annual air temperature ranges from -0.4 to -7.7 ° C, its highest values are recorded in the coastal part of the territory (from -0.4 to -1° C). The warmest point within the Tunka depression of the basins is Arshan, with a mean annual air temperature of -1.5 ° C, which is two and more times higher than in Mondy (-3 °C), Tunka (-3.5 °C), Kyren (- 3.8°C) [10]. Distribution of precipitation is extremely uneven. The smallest number is recorded in the Tunka depression: from 360 mm in the central part (Mondy) to 550 mm at the foot of the Tunka goletz (Arshan); the largest - on the windward slopes of the Khamar-Daban Ridge - from 520 (Kultuk, Slyudyanka) to 1.450 mm (Snezhnaya, Khamar-Daban) per year [11].

As is known, all processes in the geographic environment occur under the influence of solar energy and inland (endogenous) sources of energy. Into the geographical envelope, most of the internal energy comes in the form of a heat flux [12]. The southern Cisbaikalia is located in the mobile region of the Earth, where the largest thermal anomaly is observed among the known thermal maxima outside the areas of active volcanism. The total solar radiation in this area is on average 4100 mJ /cm^2 per year, or 105.3 • 10-6 J / cm^2/ s [13], while the values of the heat flux vary from 4.3 to 10.5 • 10-6 J / cm^2/ s [8]. In the southern Cisbaikalia, as a percentage, the share of inland energy sources relative to total solar radiation is 4-9%. A comparison of these data shows that solar energy is several times greater than the endogenous energy. However, the value of each type of energy cannot be estimated only quantitatively, since the efficiency of the energy flow depends not only on the power, but also on the form of the intake (concentrated or scattered, to the lower or upper boundary of the geosphere, etc.) [12]. Thus, quantitatively small fluxes of endogenous origin are no less a factor differentiating nature than solar energy [14].

The results of field studies and the study of literature data on the nature of the endogenous flow served as the basis for extrapolating materials to the area of study using space information. For the study, a space image was taken from the Landsat-7 satellite with RGB 4.6,7 channels (0.775-0.9, 10.4-12.5, 2.09-2.35 μm). Comparison of interpretation results, literary data, with topographic link to the territory of representative regions, field studies using a GPS receiver have shown high data comparability.

The effect of endogenous heat is especially evident in the self-organization of geosystems of the Khamar-Daban Ridge and the Tunka depression. Thus, for the depression, within the areas with higher values of heat flow, development of primordial steppe and endemic communities is indicative, such as cryophyte steppe with Festuca kryloviana and sandy with Bromopsis korotkiji. In the Mondy depression within such areas there are cryoxerophilic petrophytic-herbaceous steppes, unique for the Baikal region. Eritrichium sajanense, the Eastern Sayan endemic cryophytic steppe species can be found here, also periglacial relics - Gentiana decumbens, Pulsatilla ambigua, and Eremogone formosa [15].

During the field landscape studies we found that on the same habitats of terraced plots of the Irkut river with a uniform petrological composition, areas of the north-Asian meadow steppes and sub-taiga pine forests are distributed on the left and right bank in regions with smaller values of endogenous heat. Comparison with the literature data and the interpretation results of space images showed that wherever a larger inflow of endogenous heat is recorded, Central Asian dry-step geosystems are represented.

To river valleys of the Khamar- Daban Ridge, which tend to have higher values of heat flux (rivers Utulik, Snezhnaya, Khara-Murin, Zun-Murin), poplar forests are confined, having in its composition tertiary relics such as Oreopteris limbosperma, Fritillaria dagana, Arsenjevia baicalensis, Waldsteinia ternata, Gallium triflorum, Poa ircutica, Polystichum lonchitis, Dryopteris filix-mas, and others.

There are still traces of volcanic activity in the study area. At present, they have a residual character and are noted in the Elovskii spur of the Tunka depression, near the Irkut tributaries (Zamaraiha and B.Taiturka), on the Okinskoe plateau (East Sayan), in the basin of the Zun-Murin river and in the upper reaches of the Utulik, Khara-Murin, Snezhnaya rivers (Khamar-Daban).

At Okinskoe plateau, mainly on Miocene basalts spruce landscapes (with birch and larch), sometimes bushes (Lonicera altaica, Berberis sibirica, Ribes spicatum, Caragana arborescens) with powerful moss lichen cover on thin fragmentary soils of facies group. The overlapping of different age lavas, differences in their chemical composition, peculiarities of the microrelief and microclimatic conditions cause the presence of different-age plant groups here, which provides a variety of landscapes of the basaltic field [16]. On open sections of the basalt flow, steppe geosystems are represented; however, in most of the territory the most common are areas with Aulacomnium palustre, Rhytidium rugosum and Thymus serpyllum. There are also common shrubs and bushes (Lonicera altaica, Berberis sibirica, Empetrum sibiricum), and herbaceous plants (Saxifraga oppositifolia, Bergenia crassifolia, Festuca sphagnicola), as well as larch-spruce undergrowth.

In other areas, where an increased influx of endogenous heat is not recorded, the geosystems, most typical for the zonal background, are represented: Siberian pine within the Khamar-Daban Ridge, steppes (of North Asian type) and larch forests in the Tunka depression.

While analyzing the geosystem self-organization in the region, taking into account natural conditions and the impact of neotectonic processes, it was identified that in regions with an increased inflow of endogenous heat, the relic components of geosystems are still remained; in the areas of development of alpinotype relief forms, young goletz types of geosystems are formed.

4. Conclusion

A distinctive feature of the geosystem self-organization in the research area is that the cross-cutting criteria for all hierarchical levels are as follows: the real-energy exchange and development can

IOP Conf. Series: Earth and Environmental Science **190** (2018) 012035 doi:10.1088/1755-1315/190/1/012035

change as a result of the specific impact of rift factors: high tectonic activity, Neogene-Quaternary volcanism, and increased endogenous heat flux.

The formation and development of the neotectonic structure of the southern Cisbaikalia is determined by three energy-bearing elements of the Earth's deep structure: a powerful asthenolite; light blocks of the earth's crust, saturated with granitoid intrusions; vertical channel of the Earth's mantle. Energy-bearing elements in turn influence the formation of components of geosystems and their interrelations.

The impact of energy-bearing elements of the Earth's deep structure led to the formation of various contrasting forms of relief in the region. These are glacial erosion mountains with vertical dismemberment from 600 to 1200 m, which are characterized by a steeply slope alpinotypic relief with heights of up to 3284 m (Tunka goletz); gently middle-mountainous north-western spurs of the western part of the Khamar-Daban Ridge, flattened surfaces of Neogene-Quaternary basaltic covers (Khamar-Daban) and the depression area (the system of the Tunka depression).

The combination of mountain and depression areas affects the lithologic-geomorphological conditions and differentiation of climatic parameters. Differentiation of the geosystems of the region reflects the features of the formation of their components, occurring under the conditions of a specific impact of endogenous energy sources.

The effect of endogenous heat is especially pronounced in the self-organization of the geosystems of the Tunkinskaya depression and the river valleys of the northern macroslope of the Khamar-Daban ridge where the highest values of heat flow are recorded. Here the dry-step geosystems of the Central Asian type, foothill subtaiga, and steppe geosystems are confined to areas of increased endogenous heat. On the foothills of Khamar-Daban wide-spread fir-forests are common, referring to relicts of the non-moral complex and the connection between fir forests and broad-leaved-coniferous forests of the Pliocene is traced. In fir forests there are still relicts of deciduous forests.

Acknowledgments
This work was supported by a grant from RFBR 16-05-00902

References
[1] Haken G 1980 *Information and Self-Organization* (Moscow: World Pub) p 224
[2] Armand A D 1988 *Self-Organization and Self-Regulation of Geographic Systems* (Moscow: Science Pub) p 54
Armand A D 1992 *Mechanisms of Geosystem Stability* (Moscow: Science Pub) p 206
[3] Sochava V B 1978 *Introduction to the Theory of Geosystems* (Novosibirsk: Science Pub) p 319
[4] Konovalova T I 2012 *Self-Organization of Geosystems in the South of Central Siberia* (Novosibirsk: Academic Publishing House "GEO") p 148
[5] Chernykh D V and Bulatov V.I. 2002 *Mountain Landscapes: Spatial Organization and Ecological Specificity* (Novosibirsk: GPNTB, IVEP SB RAS Pub) p 83
[6] Preobrazhensky V S 1986 *Organization, Organization Ratio of Landscapes* (Moscow: Institute of Geography Pub) p 33
[7] Reteyum A Y 1988 *Earth Worlds* (Moscow: Thought Pub) p 95
[8] Vilor N V 2002 Satellite monitoring of infrared radiation of geological and structural elements of the Sayan-Baikal-Patom mountainous region and the Baikal rift zone *Research of the Earth from Space* **4** 55-61
Golubev V A 1982 *Geothermy of Lake Baikal* (Novosibirsk: Science Pub) p 150
Golubev V A 2007 *Conducted and Convective Heat Transfer in the Baikal Rift Zone* (Novosibirsk: Academic Publishing House "GEO") p 222
Kiselev A I, Medvedev M E and Golovko G A 1979 *Volcanism of the Baikal Rift Zone and Problems of Deep Magma Formation* (Novosibirsk: Science Pub) p 198
Lysak S V and Zorin Y A 1976 *Geothermal Field of the Baikal Rift Zone* (Moscow: Science Pub) p 91

IOP Conf. Series: Earth and Environmental Science **190** (2018) 012035 doi:10.1088/1755-1315/190/1/012035

Lyubimova E A 1968 *Thermal Anomaly in the Region of the Baikal Rift* (Moscow: Science Pub) p 160
[9] Bugaevskii G N 1978 *Seismological Studies of Heterogeneities in the Earth's Mantle* (Kiev: Scientific thought Pub) p 184
Ufimtsev G F 1992 *Morphotectonics of the Baikal Rift Zone* (Novosibirsk: Science Pub) p 216
Shchetnikov A A and Ufimtsev G F 2004 *The Relief Structure and the Latest Tectonics of the Tunkinskii Rift (South-Western Baikal Region)* (Moscow: Scientific world Pub) p 160
Doglioni C and Carminati E 2003 Rift assimetry and continental uplift *Tectonics* **1024**(22**)** 8-11
[10] *Manuals for Hydrometeorological Stations and Posts* 1966 vol **22**(2) (Leningrad: Hydrometeo Pub) p 360
[11] *Manuals for Hydrometeorological Stations and Posts* 1968 vol **22**(4) (Leningrad: Hydrometeo Pub) p 280
[12] Gerenchuk K I, Bokov V A and Chervanets I G 1984 *General Geoscience* (Moscow: Higher school Pub) p 255
[13] *Baikal Atlas* 1993 (Moscow: Federal Service of Geodesy and Cartography of Russia) p 159
[14] Grigoriev A A 1966 *Regularities in the Structure and Development of the Geographical Environment* (Moscow: Thought Pub) p 382
[15] Namzalov B B and Holboeva S A 1996 The main features of the vegetation cover of the Tunkinskii National Park *Proc. of the Republican Meeting State and Problems of Specially Protected Natural Territories of the Baikal Region* 81-94
Namzalov B B, Holboeva S A and Grishkina T. M. 1998 *The Steppes. General Outline and Description of Steppe Phytocenoses* (Ulan-Ude: Publishing house of BSU) 109-42
[16] Vyrkin V B 2012 The current state of the landscapes of the Oka depression (East Sayan) *Geography and Natural Resources* **4** 98-107