Patterns of development and distribution of soil cover in Southern Predbaikalia

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Abstract. The territory of Southern Predbaikalia includes the Irkutsk-Cheremkhovo plain and the southern part of the Predbaikalsky basin, both of which are the marginal basins of the Siberian platform, and the Priolikhonsky plateau, a tectonic block squeezed between the Baikal Mountains and the Baikal basin. The main factors of soil formation, climate and relief, determine the unique mechanisms of the local circulation of air, heat and moisture, and affect the diversity of soil types and their distribution on the macro- and meso-levels of the soil cover organization. The combination of the basin effect and aridic-shadow form of vertical zonation in Southern Predbaikalia led to the development of dramatically contrasting landscapes and soils within a limited area: from subtaiga to dry steppes. Paleocryogenic phenomena in the form of polygons and cracks or hillocks and hollows contributed to the differentiation of the soil formation processes, mottling of the soil cover on the micro-level of its organization in the form of contrasting soil microcombinations. The research resulted in the creation of the Southern Predbaikalia soil cover map built using Quantum-GIS and landscape indication methods, morphometrical parameters and relief forms, space imaging and schemes showing key sites of determined soil profiles.

1. Introduction
It is a known fact that any territory (or region) is characterized by a certain complex of present-day environmental conditions, relict phenomena, and economic activity, which all affect its soil cover [1]. A soil cover is a combination of various soil types, which resulted from the interaction of the soil formation factors and the changes that occur in them over time. Soil cover is a prerequisite for the existence of life, as it provides the optimal conditions for the continuous functioning of biocoenoses [2]. Soil diversity is the foundation or basis of biological diversity as well as an essential factor for the preservation and sustainability of geo- and ecosystems. At the same time, mottling of the soil cover generally leads to natural growth and its simplification to a sharp decline in biodiversity [3, 4]. The development of soils belonging to different types is associated with the presence of certain profile-forming processes, each occurring at its own pace and revealing itself clearly in various models of pedogenesis [5].

Being part of the subcontinent of Northern Asia, Southern Predbaikalia represents the region that, according to soil zonation, makes part of a subboreal belt, which, in turn, is part of a boreal belt. Here,
at the intersection of various sharply contrasting landscapes with the alternation of climate warming and cooling, the changes within the borders of subtaiga, steppe and forest steppe occurred repeatedly [6, 7]. That affected significantly the features of the texture and composition of the local soils, including those complexified by paleocryorelief. Various forms of paleocryogenic microrelief (polygonal-crack or hillocks-hollow, etc.) are widespread in the middle latitudes of Russia, including Southern Predbaikalia [8, 9]. It has a significant impact on the redistribution of moisture, lithodynamic flows and heat availability, which leads to a sharp contrast between the soils of polygons or hillocks and cryogenic clinoform structures (cracks-hollows) in terms of their profile form, qualities and fertility. It creates a cryogenic polygonal structure of the soil cover. The development of soils in these conditions corresponds to various models of pedogenesis: in polygons and hillocks, it is a denudation model, in cryogenic clinoform structures (cracks-hollows) – accumulative-sedimentary [5].

It is a relevant scientific issue to determine the specifics of the formation and diversity of soils, patterns of their distribution in different landscapes under the influence of various factors of soil formation whose combination is specific for each region.

2. Objects and methods of research
The research was carried out using a comparative ecological-genetic approach [2] and a substantive – genetic approach [10]. Soil and geographical testings in the territory of Southern Predbaikalia were conducted from 2005 to 2018 in subtaiga, forest steppe, steppe, and dry steppe of Southern Predbaikalia with more than 100 soil profiles taken in the course of the research. They were diagnosed on the basis of morphological descriptions and qualities of soils, after which their classification properties were determined according to the principles of Classification-2004 [11]. The map of Southern Predbaikalia was generated using Quantum-GIS. The transition from soil key sites to soil sites on the map was carried out through the interpolation of soil sampling points using the methods of landscape indication. Morphometrical parameters of the relief determining the redistribution of heat and moisture were used as indication characteristics. The topographical map allowed us to take into account such parameters as surface shape (watersheds, slopes of various exposure, the height of a base level, etc.); satellite imaging, scheme with key sites and field description of the main soil profiles were also used in the study. The resulting spatial model of the factors of soil formation was compared to the field descriptions of the soil profiles.

Radiocarbon dating of the present-day and buried humus horizons of the hollow soils was conducted in the laboratory for radiocarbon dating in Institute of Geography of the Russian Academy of Sciences (Moscow) by determining humic acid carbon [12].

3. Research results and discussion
The distinctive combination of the soil formation factors, notably combined manifestation of the basin effect and vertical foothill (aridic-shadow) zonation led to the development of sharply contrasting landscapes, from dry steppes to subtaiga. Slight differences in heat availability and between genetically alienated soils precondition their territorial proximity. The low energy level of soil formation is another distinctive regional feature. The patterns of soil distribution in the territory of Southern Predbaikalia are predetermined by the changes in bioclimatic conditions from west to east and increasing height above sea level [13].

Based on the conducted soil and geographical research, the soil sequences with eluvial-illuvial and undifferentiated soil profiles were formed within mountain taiga in the southwestern and northeastern part of Predbaikalia (figure 1, 2).

The soils of taiga submontane landscapes occupy medium and low locations with sedimentary rocks of medium thickness. Podzolic and sod-podzolic soils are widespread in the upper part of the taiga belt with fine-grained soil. The combinations of (peat-) podzols (gleyic), (peat-) podbours prevail in the uppermost part of the belt (above 1200 meters). The combinations of sod-podzolic and podzolic soils dominate in the acid silicate deposits. In the subtaiga conditions, watershed heads are occupied by sod-podzolic soils, podzolized burozem and residual carbonate soils. The lower and medium parts
of the slopes are occupied by typical forest-steppe and metamorphic soils as well as by gleic-illuvial chernozem. Dispersive-carbonate and chestnut soils are formed in the river terraces under steppe and dry steppe conditions.

Figure 1. Landscape map of Southern Predbaikalia. Map symbols: 1 – medium- and low-mountain taiga, subtaiga and south-taiga softwood, locally hardwood forests; 2 – south-taiga and subtaiga forest steppes, locally steppificated forest outlier; 3 – foothill-submontane and slightly sloping steppe; dry steppe with sparse larch forest; 4 – valley plainlike and hilly steppe, meadow-steppe landscape with meadows, bogs, birch woods and shrubs.

The comparison of the landscape and soil maps has shown a distinctive shift in soil contours under the conditions of homogenous forest and steppe vegetation in the northeast direction. It is explained by the shift in the composition of soil formation rocks from the Jurassic noncarbonate or low-carbonate rocks to the Cambrian high-carbonate rocks. In general, forest-steppe soils occupy a larger area of Southern Predbaikalia and are 61% of the total area, with subtaiga soils occupying 21%, steppe and dry stepp – 3% and river valleys – 15%.

At the meso-level, slope exposure affects significantly the spatial distribution of soils. Windward northwestern slopes that receive more precipitation are occupied with sod-podzolic, sod-brown-podzolic, typical grey soils and gleic-illuvial chernozems. Podzolized burozem, grey metamorphic soils, dispersive-carbonate chernozems and chestnut soils prevail in the windward south-eastern slopes with less precipitation.

The diversity of soils, peculiarities of their formation and qualities, patterns of spatial distribution largely depend on the heterogeneity of the microrelief, notably in the form cryogenic clinoform structures (polygonal-crack and hillock-hollow). They were formed at the end of the Pleistocene (the Sartan Age) under conditions of a significant aridization of climate and its severe cooling. Periglacial conditions contributed to the primary division of the surface into polygons and cracks filled with lode ice that melted completely during the Holocene. The resulting cracks and hollows were gradually filled with low-humusized material from the collapsed walls of the cracks in the forest area as well as with humusized material of the upper horizons of the high-humus soils of polygons and hillocks in the
steppe area. Polygons and hillocks are the blocks of an undisturbed structure up to 3.5 meters high and up to 10-20 meters in diameter. In the absence of moisture, polygons developed an even surface, whereas the surplus and freezing of the moisture led to the bulging of soil. Thus, the hillocks with a rounded surface were formed. Due to the degradation of permafrost, the cracks became free of ice and were filled with soil material that broke off the walls of the cracks. The cracks then expanded in width and transformed into hollows.

![Soil map of Southern Predbaikalia](image)

**Figure 2.** Soil map of Southern Predbaikalia. Map symbols: Subtaiga soils: 1 – sod-podzolic soils, including residual carbonate and sod-(peat-) podzols; 2 – peat-podzolic, including residual carbonate and gleyic, peat-podzolic, peat-podbour soils; 3 – sod-podzolic, sod-podbour, sod-podzolic and residual carbonate soils; 4 – podzolic and raw humus, sod-podzolic, burozem-residual carbonate soils; 5 – peat-podbour, sod-podzolic soils; 6 – raw-humus burozem soils, podzolized burozem soils. Forest steppe soils: 7 – grey, sod-podzolic-burozem soils, sod-podzolic soils; 8 – grey metamorphic, dark grey, dark humus, residual carbonate soils; 9 – dark grey metamorphic, dark humus, dark humus residual carbonate soils; 10 – dark humus, clay illuvial chernozem (hydrometamorphized); 11 – dark grey, grey, dark humus residual carbonate soils; Steppe, dry steppe and floodplain soils: 12 – grey humus, chestnut, chestnut-like soils; 13 – alluvial, peat-mineral, peat-gleyic, alluvial and muck-gleyic, dark humus (gleyic) soils; 14 – fibrous-alluvial and humus, alluvial peat-gleyic and mock-gleyic soils; 15 – alluvial humus, dark humus metamorphized, mock and dark humus, dispersive-carbonate chernozem soils.

The hollow soils are significantly different from those of polygons and hillocks in terms of their genesis, evolution and qualities. They have the buried humus horizon in their profile. Bedding of a lighter horizon between the present-day and buried horizons is observed in the soils of forest landscapes, and a gradual transition of the present-day horizon to the buried one with increasing color intensity is observed in the steppe soils. The morphological structure of their profile corresponds to the accumulative-sedimentary model of pedogenesis. According to Classification-2004 [11], hollow soils refer to the synlithogenic soils, type of grey- and dark-humus stratozems on buried soil. Radiocarbon
dating indicates the formation of the upper humus horizons in the present-day soil formation phase, referring to the Late Holocene, whereas the buried horizon was formed in the Atlantic period (the Holocene Climatic Optimum) that is characterized by the development of tallgrass mesophilic vegetation and high-humus soils (table 1) [14].

Table 1. Results of the radiocarbon dating of humic acids of the present-day and buried humus horizons of soils of the cryogenic clinoform structures (hollows) – stratozems.

| Soil type                        | No.  | Institute of Geography of the RAS | Horizon, depth, cm | Radiocarbon age of the horizon (years ago) | Range of the calibration age 1σ: Cal BP-years ago: [beginning: end] probability |
|----------------------------------|------|----------------------------------|-------------------|--------------------------------------------|--------------------------------------------------------------------------------|
| Grey-humus stratozem on buried soil | 3214 | RY 0-37                          | A 0-37            | 1960 ± 50                                  | [1867 BP:1952 BP] 0.845366                                                      |
|                                  |      |                                  |                   |                                            | [1959 BP:1972 BP] 0.095339                                                      |
|                                  |      |                                  |                   |                                            | [1977 BP:1986 BP] 0.059295                                                      |
|                                  |      |                                  |                   |                                            | [4650 BP:4671 BP] 0.080919                                                      |
|                                  | 3215 | [A] 37-70                        | [A] 37-70         | 4260 ± 60                                  | [4701 BP:4759 BP] 0.307260                                                      |
|                                  |      |                                  |                   |                                            | [4944 BP:4948 BP] 0.012235                                                      |
| Dark-humus stratozem             | 3219 | AU 0-30                          | Ad 0-13           | 2510 ± 40                                  | [2497 BP:2597 BP] 0.627898                                                      |
|                                  |      |                                  |                   |                                            | [2612 BP:2638 BP] 0.171945                                                      |
|                                  | 3217 | A 13-30                          |                   | 2720 ± 50                                  | [2687 BP:2720 BP] 0.201056                                                      |
|                                  |      |                                  |                   |                                            | [2768 BP:2854 BP] 1                                                            |
|                                  | 3220 | RU 30-68                         | [A] 30-68         | 6030 ± 70                                  | [6759 BP:2597 BP] 0.003546                                                      |
|                                  |      |                                  |                   |                                            | [6784 BP:6966 BP] 0.996454                                                      |

The differentiation of soil processes contributed to the complexity of soil cover on a micro-level in the form of polychronic regular cyclic complexes and mottlings [15], whose components are the soils of polygons-hillocks and cracks-hollows. Polygonal-hillock soils are automorphic and autonomous and represent different ‘zonal’ types, depending on the landscape. The soils of cracks and hollows were formed as a result of the transfer of finely dispersed humus material from the soil surface of polygons and hillocks into the cracks and hollows due to erosion and deflation, which corresponds to the denudation model of pedogenesis. Semihydromorphic and heteronomous soils formed in the conditions of cracks or hollows are located in the close proximity of the soils of polygons and hillocks at a distance of 10-40 meters and are in the genetic and geochemical conjugation with them.

4. Conclusion
The combined impact of the hollow influence and the aridic-shadow form of the vertical zonation contributed to the development of sharply contrasting landscapes and soils in Southern Predbaikalia. Low moisture and heat availability precondition territorial proximity of soils that vary in structure and qualities. At the meso-level, a decisive role in the spatial distribution of soils belongs to the direction and angle of the inclination (exposure) of slopes; at the micro-level – to the phenomenon of paleocryogenesis in the form polygonal-crack and hillock-hollow forms of the micro-relief.

In general, the specifics of the soil formation in the investigated territory are high inertia of the changes in soil qualities occurring under changing bioclimatic conditions, which is explained by the age diversity of the profile horizons characterized by a different rate and intensity of soil formation and weathering processes. Soil cover formation follows a specific genetic code instilled in it during the evolution of the environment. Paleogeographic conditions are the foundation (matrix) that determines the diversity of soils and their spatial distribution.
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