Transformation and ecological stability of soils of phosphoritic landscape-geochemical systems of depression of Lake Khuvsgul of the Baikal rift zone

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Abstract. Sustainable development of the Baikal-Khuvsgul basin is not only of national, but also of great international importance. This status gives priority to preserving biodiversity and the natural-historical biosphere in general, and to the development of strategies for the rational utilization of natural resources and sustainable development of territories within the basin of the unique ecosystems of Lakes Baikal (Russia) and Khuvsgul (Mongolia). We carried out a comprehensive study of the morphogenetic and ecological features, ecological stability of soils and landscapes of the Khuvsgul phosphorite basin of the mountainous Khuvsgul region of the southwestern branch of the Baikal rift zone (BRZ). This analysis upgraded the existing knowledge of possible trends in the transformational growth and ecological balance of the soil cover of this territory both under the conditions of the natural development of geosystems and under the destabilizing anthropogenic and technogenic impact. Possible negative side effects of the development of phosphorite deposits on the unique in natural and cultural terms ecosystems of Lake Khuvsgul were predicted.

1. Introduction
The singularity of natural conditions, soils, biocenoses and landscapes formed near Baikal as a World Heritage site and the Baikal-Khuvsgul basin of the BRZ that are subject to protection predetermine the relevance of this study. High recreational activity of the local population causes the assessment and accounting of natural resources and their sustainability. A dense network of various types of protected areas, reserves, and national parks of federal significance has been created around Lake Baikal and Khuvsgul (figure 1, [1]), where soil cover is characterized by great diversity. It is associated with mountainous relief, altitudinal zoning and bedrock exposure.

Thereby, environmental monitoring of the lake is especially relevant. Assessment of the ecological balance and sustainability of soils, biocenoses and landscapes, identification of the background characteristics of development areas are necessary to predict the possible consequences of anthropogenic and technogenic load and prevent their pollution. The unique natural ecosystems of Lakes Khuvsgul and Baikal are interconnected by the Selenga River flowing into Baikal and its tributary Egiin-gol, which originates from Lake Khuvsgul.

The population carrying capacity of a natural ecosystem as an ability to perform its socio-economic functions is determined through the natural system stability. Stability assessment presupposes an integral multicriteria hierarchical analysis of the heterogeneous factor contribution, with due regard to their qualitative and quantitative characteristics [2-4]. The natural ecosystem adapts to adverse
changes through the restructuring of its internal structure. Accordingly, the number of combinations that the system generates in response to external disturbances can serve as a quantitative measure of its adaptive stability. Stability can be defined as the bioorganic potential of a given natural system to maintain a mode of functioning, as the ability to be in a state of quasi-equilibrium, which makes it necessary to assess the ratio of its three components: 1) normal natural functioning, 2) ability to resist external influences and irreversible transformations 3) relaxation and recovery capability after load removal of load [5-7]. All dynamic changes occurring within one invariant (i.e., a qualitatively unchanged state) serve as indicators of soil stability, since they reflect its ability to return to its original state.

2. Objects and methods
The objects of study were various soils of the Khuvsgul National Park ("Khovsgol") of Mongolia, formed at the outcrops of phosphorite rocks of the Khubsugul phosphorite basin. Soil-morphological, pedolithological, geological-geomorphological, botanical, comparative-geographical research methods were used for field soil investigations of the landscapes under study. In laboratory studies of the physicochemical properties of soils we used standard methods of potentiometry, titration,
The integral stability of soils and landscapes was assessed through an expert point system for each component of the ecosystem. This enables enough informative and fast, comparative, variable and correlative measurements and successful use in practical application. The ecological stability of the soils depends on the position in the landscape, humus content, steepness of the slope, mineralogical, chemical and granulometric composition of soils and parent rocks. We quantified the ecological stability of soils using the following indicators [11, 12]: acidity (\(\text{pH}_{10}\)); cation-exchange capacity (CEC) for the 0-20 cm layer; capacity/reserves of the humus accumulative horizon (A + AB); type of soil water regime; position of the biogeocenosis at the catena; and slope steepness. The proposed set of indicators reflects both types of soil stability. The first two indicators reflect adaptive stability: CEC to chemical pollution, and the humus accumulative horizon capacity to mechanical disturbance. Other indicators characterize the soil resilience (manifestation of regenerative stability). In addition, we have introduced indicators of parent rocks and grain size distribution of soils to assess the ecological stability of soils. Stability can also be assessed using indicators of soil buffering capacity, because after the depletion of natural resources and proton neutralization, the activation of the neighboring, more acidic, buffer zone occurs. This is actively reflected in the composition and properties of the liquid and solid phases of the soil as a whole [13].

Each indicator of stability was evaluated according to a 5-point system. The soils were divided into the following categories of stability: very high stable (36-40 points); highly stable (31-35 points); medium stable (26-30 points); relatively stable (21-25); weakly stable (16-20 points); not stable (11-15); not stable degrading - (1-10 points).

3. Results and discussion

The northern regions of Mongolia are similar in their natural conditions and are closely related to Eastern Siberia and Transbaikalia. The basin of Lake Khuvsgul [14], which is one of the stable main feeding sources of the Selenga River, and, consequently, Lake Baikal, is practically not yet impacted by human and can serve to recreate and decipher the master pattern of nature. These unique ecosystems and habitats are characterized by a high degree of diversity and a large number of endemic or endangered species. They are of great social, economic, cultural and scientific importance.

The Lake Khuvsgul basin belongs to the territories, the sustainable development of which is of both national and international importance. The Baikal-Khuvsgul natural territory is a very peculiar complex geographic system, where the main features of the boreal-taiga and boreal-steppe planetary types of the Asian environment manifested themselves [1]. The study area is part of the Khuvsgul province of the Altai-Sayan-Mongolian mountainous country and belongs to the southwestern end of the Baikal rift zone, formed at the Neogene-Anthropogen border [15]. The region has a complex development history.

The Khuvsgul phosphorite basin (KPB) belongs to the vast Central Asian phosphorite belt, stretching from west to east from South Kazakhstan through the Altai-Sayan region (Prekhuvsugul and Prekosogol’) and Transbaikalia to the shores of the Sea of Okhotsk [16]. The CPB was formed on the territory of the ancient paleogeosynclinal basin of the Ural-Mongolian belt of Asia with the subsequent consolidation of the Paleozoic (Riphean-Cambrian) folded structures of southern Siberia and northern Mongolia. As a result, the Tuva-Mongolian massif of the synclinor type was formed, covering Eastern Tuva, the southeastern part of the Eastern Sayan, Khamar-Daban Range and Prekhuvsugul area. On this territory more than 30 deposits of chemogenic (aphanite and granular) phosphorites of the bed type have been formed, combined into the Khuvsgul phosphorite-bearing submeridionally oriented basin about 300 km long with a maximum width of 120 km with a total area of 30,000 km² and with reserves – more than 1 billion tons [17].

We investigated the territory of the largest CPB deposit in Mongolia - Ongolignur, which stretches along the western shore of Lake Khuvsgul in a continuous strip of 50 km with a width of 30 km. The phosphorus content in phosphorite layers, represented by the mineral fluorapatite (francolite), varies widely, reaching 32% \(\text{P}_{2}\text{O}_{5}\) [17, 18]. The immediate objects under study are the soils of the mountain geosystems of the Khuvsgul area, formed at original outcrops of phosphorites of the Ongolignur
deposit. The outcrops of phosphorite rocks provide a unique opportunity to study “phosphate” soils, their properties and characteristics of genesis, effect of the phosphorite matrix on the processes of soil formation and ecology of the surrounding landscapes. These soils, including the southwestern and eastern areas of the Lake Khuvsgul basin, belong to the Darkhat-Khuvsgul depression of high-mountainous and hollow-valley soils in the southwestern part of the Baikal rift zone.

Weakly and relatively stable gray-humus petrozem, cryozems, coarse humus cryo-lithozems, dark humus lithozems, podburs, sod-(peat) - gleyed subburs, dry peat and their combinations are formed on high watersheds and slopes of the Khuvsgul depression. In weakly filtered and waterlogged areas dark humus and humus-hydrometamorphic soils, peat-gley, cryometamorphic gley, and locally peat eutrophic soils are formed. On phosphate-carbonate rocks in the tundra zone, humus, dark-humus cryometamorphosed and quasi-gleyic carbolithozems are formed. In the taiga-forest belt of the deposit gray and dark gray metamorphic eluvated residual calcareous soils and dark humus eluvated burozems develop; and gleyic residual carbonate [19, 20]. The southern and southwestern mountain slopes of this territory are locally represented by steppe cenoses with chernozems and dark chestnut soils. Chernozems, chernozem-like and dark humus soils are formed on landscapes of terraces and high floodplains. In the coastal zone of Lake Khuvsgul, in intermontane depressions, as well as along river valleys, soil complexes of boggy meadows and lacustrine-marshlands are widespread.

Alluvial dark humus soils are formed on elevated deltas, on alluvial fans of temporary streams in river floodplains. Various types of alluvial soils (mainly of medium thickness, sandy loam and loamy, slightly acidic, neutral, slightly alkaline and alkaline, moderately and slightly moist, cold, permafrost soils) provide a sufficiently high productivity of vegetation. In the conditions of low river floodplains with a long-term surface and subsurface moisturing and along the edges of overgrown wetlands, alluvial peat-gley (peat-mineral) soils are formed. In river valleys and coastal depressions of the deposit territory, dark humus quasi-gley soils were formed. Seasonal freezing for a long time leads to the formation of silty humus-hydrometamorphic cryogenic soils in the central parts of floodplains and around the lake depressions.

The soil is a complex, multiphase, thermodynamically open heterogeneous system, which is characterized by phase transitions of 1st and 2nd orders. The stability of soil systems is based on the principles of linear thermodynamics [21-24] and fractal geometry [25, 26, 27] and includes: the formation of a system of humus nitrogen-organic and other compounds with nonlinear feedback; a decrease in entropy with an increase in free energy due to the accumulation of clay-humus compounds; establishment of the dynamic ordering of an equilibrium system.

Degradation occurs when the buffer capacity of landscapes and soils, the permissible level of the degree of openness of the ‘soil-plant’ system, the permissible threshold of mechanical action, the limits of humus mineralization, migration of elements, accumulation of toxins and others are exceeded. Soil degradation is also noted with an unbalanced effect on the soil, caused by matter, energy and information, which must be balanced at higher hierarchical levels of organization of a field, landscape or basin. In the process of soil system degradation, the violation of the adequate mechanisms of soil responses to external impacts occurs in stages with simplification of their natural structural relationships and matrix function, energy and information loss, change in the material composition, biota diversity decrease, degradation of soil, decrease in their bioproductivity and fertility. All this ultimately leads to an imbalance in the processes of self-regulation and self-development encoded in the memory of soils and plants.

Assessment of soil sustainability as a natural system includes an assessment of its autoregulation [28], its ability to preserve its spatiotemporal structure, features and modes of functioning, parameters of resistance and restoration of disturbed properties under external influences within the limits of natural soil variability within the boundaries of their classification [29-31]. The maximum adaptive stability is characterized by “average” natural systems, balanced both in qualitative and quantitative characteristics (biodiversity, saturation with elements of one species, etc.). The adaptive diversity of soil systems that determine the stability of landscapes has a combinatorial nature (determined by the
number of possible combinations of their various elements). This enables the quantitative assessment of the information component of sustainability in addition to their energy-material components.

We used the indicators presented in Table 1 for a rating point evaluation of the ecological sustainability of natural soils of “phosphorite” soils.

**Table 1. Indicators for rating score assessment of soil environmental sustainability.**

| Indicators                                | Rating point                          |
|-------------------------------------------|---------------------------------------|
| Soil-forming rocks                        |                                       |
| Alluvial stratified deposits of peat,     |                                     |
| morainic and fluvio-glacial deposits      |                                     |
| of sands and sandy loams                  |                                     |
| Eluvial deposits, light loam and subjacent |                                     |
| heavy loam moraine (binomial)             |                                     |
| Deluvial deposits, moraine loams and      |                                     |
| clays,                                   |                                     |
| Cover loams and clays, carbonate deposits |                                     |
| (clays and loams)                         |                                     |
| Loess and loess-like loams                |                                     |
| Acidity (pH<sub>20</sub>)                 |                                       |
| 4.5 and less or 8.6 and more              |                                       |
| Acidic (4.5-5.0) or alkaline (7.6-8.5)    |                                       |
| (5.1-5.5) or (7.0-7.5)                    |                                       |
| 5.6-6.0 or neutral (6.1-7.0)              |                                       |
| Granulometric composition                 |                                       |
| sand                                      |                                       |
| sandy loam                                |                                       |
| light loam                                |                                       |
| medium loam                               |                                       |
| heavy loam, clay                          |                                       |
| Cation exchange capacity (mg- equiv/100g) |                                       |
| < 10                                      |                                       |
| 10 – 20                                   |                                       |
| 21 – 30                                   |                                       |
| 31 – 40                                   |                                       |
| > 40                                      |                                       |
| Humus reserves of 20 cm (t / ha)          |                                       |
| 10-20                                     |                                       |
| 20-40                                     |                                       |
| 40-60                                     |                                       |
| 60-80                                     |                                       |
| more 80                                   |                                       |
| Water regime                              |                                       |
| effusion                                  |                                       |
| non-flushing                              |                                       |
| periodically flushing                     |                                       |
| flushing                                  |                                       |
| permafrost                                |                                       |
| Position at landscape                     |                                       |
| accumulative                              |                                       |
| trans-accumulative                        |                                       |
| transit                                   |                                       |
| transeluvial                              |                                       |
| eluvial                                   |                                       |
| Steepness of slopes                       |                                       |
| Strongly undulating territory             |                                       |
| territory with slopes of 8.1-10°          |                                       |
| Average undulating territory              |                                       |
| with slopes of 5.1-8                      |                                       |
| undulating territory with slopes of 3.1-5°|                                       |
| slightly undulating and leveled territory |                                       |
| with slopes of <1.1-3°                    |                                       |
| leveled territory with slopes of 1° or less|                                       |

The stability of soils and landscapes as natural territorial systems is most influenced by climatic factors that determine the energy of radial geomatic processes (radiation balance, degree of moisture and wind regime) and tectonic factors that determine lateral geomatic processes (intensity and direction of seismicity movements). In their sustainable (quasi-equilibrium) condition, the energy-material fluxes of the formed natural system function according to the principles of a closed cycle. They form this state through “natural selection” of 3 groups of factors: 1) energy-material factors, which determine the free energy reserve and the “extensive” component of stability; 2) producing, characterizing the efficiency of processing matter and energy ("intensive" component of stability); 3) informational, characterizing the variety of options for structural restructuring while maintaining the development invariant (information component of sustainability).
We assessed the sustainability of natural systems using following indicators: 1) inertia (gross mass or power characteristics); 2) efficiency; 3) structural balance (indicators of the combinative diversity of structural elements). The soil and landscape stability (defined as the potential for conservation of functioning regime for natural system) is formed with a due regard to the ability to resist to external impact through buffering neutralizing capability (internal factor) and due to ability to remove the load onto other ecosystems thanks to its position in the catena and climate features (external factor).

On phosphate-bearing rocks there are tundra cenoses, larch forests, and steppes, differing in structure and composition with an exceptionally rich herbaceous layer of gramineous and leguminous. Weathering and soil formation on phosphate-bearing soil-forming rocks of the southwestern Prekhuvsugul area leads to the formation of alkaline high-humus soils, a significant accumulation of silty silicate and fine-grained alevrite material in the soil profile as the phosphate-carbonate component is decomposing and removing, as well as to the residual accumulation of clay minerals and silty organic matter. The structure and functioning of the studied ecosystems is determined by the processes of accumulation of organic matter and low-mobile humus of fulvate-humate and humate composition (with a high content of 2nd and 3rd fractions of humic acids) [32]. The high content of humic acids is due to the mineral francolite (tricalcium phosphate). It contributes to the “consolidation” of humus substances, conservation and “aging” of humus, as the dehydration processes of mobile humus acids in a sharply continental climate. An excess of phosphorus and carbonates contributes to the formation of strong carbonate-phosphorus-humus coagulated complexes and increases the natural fertility and ecological stability of soils [33].

Our studies determined the classification inhering (according to the Russian and international classifications of soils [34-37]), assessed and compiled a rating of the stability of mountain-valley soils in the southwestern part of the Khuvsgul National Park of Mongolia, confined to the outcrops of phosphorite rocks of the deposit (table 2).

The ecological stability of the soils under study is mainly characterized as medium and high. This is due to the wide distribution of carbonate and basic rocks here, high enrichment of rocks with carbon, cations of alkali and alkaline-earth metals, high humus content of the upper horizons. The lowest ecological and geochemical stability is characteristic of the soils of ecosystems of subalpine larch, larch-pine and pine woodlands. Burozems and soddy-podzolic soils of the Baikal region and the Khubsugul region are characterized, as a rule, by a medium level of ecological stability. The highest values of the soil-ecological potential are characteristic of humus-carbonate soils.

In the mountainous territories of the BRZ, there is a vertical-belt change of soils characterized by different degrees of stability, from the highest (usually) at the bottom to the lowest at the top [38, 39, 40]. Such patterns are not observed at the territories composed by phosphate-carbonate rocks. At areas of the lack of carbonate rocks, soil stability, as well as the values of critical recreational loads on landscapes, is determined by the productivity of biogeocenoses and the intensity of biogeochemical processes (i.e., the number of annual return with decay of physiologically active cations), as well as by the rate of weathering, variety of soils, weak weathered minerals and favorable hydrothermal regime.

The unique natural environment requires regular monitoring the ecological state of landscapes of phosphorite-bearing deposit [41] and programs for sustainable development [42] to preserve this area. In mountainous areas, under a wide range of natural conditions and migration conditions of soil elements of different landscapes, directed substance flow is formed, contrastingly differentiated in time and space. The most information is provided by the ratio of the content of mobile fractions of pollutants in the soils of eluvial landscape (stable invariant component) to their content in the soils of accumulative landscape (indicator component). Instabilization of physical and physico-chemical properties of phosphorite-bearing landscapes as a result of their erosion, degradation processes, possible industrial disintegration and inputs of secondary products into waters of Lake Khuvsgul should be considered from the standpoint of determining of geochemical barriers and directions of substance flows, mobility of soil phosphates and of material composition of the lake waters in the system of conjugated landscapes.
Increased incidence of urolithiasis ("urovskaya disease") is observed in the phosphorite-bearing landscapes with phospho-manganese specialization. In addition to a large amount of phosphorus, they are characterized by local anomalies of mercury (element of 1st hazard class), large sizes of fluorine areas (2nd hazard classes), a radioactive uranium component, an increased content of vanadium and nickel (transformer elements that contribute to genetic disorders in biota). All this makes it possible to classify the location of phosphophytes as ecologically highly hazardous.

A possible reason for the limitation of the pollutant mobility in the Khuvsgul area can be clay accumulation, presence of carbonates, and a regenerating gleyed medium. Areas of pollutant mobility:

Table 2. Rating points of ecological soil stability of high-altitude zones of the territory of the Khuvsgul phosphorite deposit in Mongolia.

| Zone                | Rating point | Soil type according to classification RU [35, 36], WRB [37]                                                                 | The index of soil cut |
|---------------------|--------------|---------------------------------------------------------------------------------------------------------------------------|----------------------|
| Tundra zone         | 32           | Humus clay-illuviimine Carbolitozem. WRB: Rendzic-Cambic Leptosol (Molic, Eutric, Humic)                                      | 5-OG                 |
|                     | 32           | Humus clay-illuviimine Carbolitozem. WRB: Rendzic-Cambic Leptosol (Molic, Eutric, Humic)                                      | 6-OG                 |
|                     | 31           | Dark humus cryo-metamorphic elluviimine Carbolitozem. WRB: Rendzic-Cambic Leptosol (Molic, Eutric, Humic, Cryic)             | 3-MB                 |
|                     | 31           | Dark-humus carbo-lithozem (rendzina). WRB: Rendzic-Cambic Leptosols (Gleic, Molic, Eutric, Humic, Infraleptic)               | BBM-5                |
|                     | 30           | Dark-humus gleic carbo-lithozem (rendzina). WRB: Rendzic-Cambic Leptosols (Gleic, Molic, Eutric, Humic, Infraleptic)         | 4-MB                 |
|                     | 33           | Dark grey residual carbonate. WRB: Cambic Mollic Phaeozem (Epi-Calcaric)                                                     | 1-OG                 |
|                     | 32           | Dark grey residual carbonate. WRB: Cambic Mollic Phaeozem (Epi-Calcaric)                                                     | 4-OG                 |
| Forest zone         | 31           | Burozems (residual carbonate). WRB: Mollic-Dystric Cambisols (Epi-Calcaric)                                                | 2-MB                 |
|                     | 31           | Burozems (residual carbonate). WRB: Mollic-Dystric Cambisols (Epi-Calcaric)                                                | 5-MB                 |
|                     | 30           | Gray metamorphic residual carbonate). WRB: Cambic-Mollis Umbrisols (Epi-Calcaric)                                            | 6-MB                 |
|                     | 33           | Clay-illuvial chernozems. WRB: Gelic Chernozems                                                                          | 2-OG                 |
|                     | 32           | Clay-illuvial chernozems. WRB: Haplic Chernozems                                                                          | BBM-10               |
|                     | 31           | Chernozems texture-carbonate. WRB: Gelic Chernozems (Molic, Epi-Calcaric)                                                | BBM-8                |
| Steppe zone         | 31           | Cryoarid pale-metamorphic eluvial. WRB: Gelic Umbrisols                                                                 | 1-MB                 |
|                     | 30           | Clai-illuvial chernozem. WRB: Greyi-Luvic Phaeozem                                                                       | BBM-7                |
|                     | 29           | Clai-illuvial chernozem. WRB: Greyi-Luvic Phaeozem                                                                       | 11-OG                |
| Meadow-marsh        | 32           | Dark humus crypto-gleic. WRB: Humi-Mollic Gleysoys (Calcaric)                                                             | 3-OG                 |
|                     | 30           | Dark humus crypto-gleic silt-humus-peat cryoturbated. WRB: Molli-Histic Gleysoys (Eutric, Calcaric)                         | 8-MB                 |

Increased incidence of urolithiasis ("urovskaya disease") is observed in the phosphorite-bearing landscapes with phospho-manganese specialization. In addition to a large amount of phosphorus, they are characterized by local anomalies of mercury (element of 1st hazard class), large sizes of fluorine areas (2nd hazard classes), a radioactive uranium component, an increased content of vanadium and nickel (transformer elements that contribute to genetic disorders in biota). All this makes it possible to classify the location of phosphophytes as ecologically highly hazardous.

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|                     | 30           | Dark-humus gleic carbo-lithozem (rendzina). WRB: Rendzic-Cambic Leptosols (Gleic, Molic, Eutric, Humic, Infraleptic)         | 4-MB                 |
|                     | 33           | Dark grey residual carbonate. WRB: Cambic Mollic Phaeozem (Epi-Calcaric)                                                     | 1-OG                 |
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| Steppe zone         | 31           | Cryoarid pale-metamorphic eluvial. WRB: Gelic Umbrisols                                                                 | 1-MB                 |
|                     | 30           | Clai-illuvial chernozem. WRB: Greyi-Luvic Phaeozem                                                                       | BBM-7                |
|                     | 29           | Clai-illuvial chernozem. WRB: Greyi-Luvic Phaeozem                                                                       | 11-OG                |
| Meadow-marsh        | 32           | Dark humus crypto-gleic. WRB: Humi-Mollic Gleysoys (Calcaric)                                                             | 3-OG                 |
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accumulation in the soil can be associated with new formations, especially ferruginous, carbonate and gypsum. Retention mechanisms can be co-precipitation, adsorption, and the formation of organo-mineral complexes after the destruction of organic components by microflora. Most of the pollutants come from the atmosphere to the soil cover of the background areas in a water-soluble form. In the dust fraction, they are mainly represented by metal oxides.

Currently, the natural complexes of the deposit area are in a balanced state. The development of the deposit will entail the eutrophication of part or all of the water area of Lake Khuvsgul, the death of the least stable components of the soil microbiota and individual endemics of the fauna and flora of Lake Khuvsgul. Hydrogen sulfide contamination will require several “geological” periods to restore the current state of the lake ultraoligotrophy.

4. Conclusion
The diversity of bioclimatic conditions determines the formation of a soil type range, the maximum diversity of which is observed in more humidified areas.

In the Khuvsgul National Park, the most stable are the soils of the southwestern part of Lake Khuvsgul of the BRZ, where phosphate-carbonate rocks are developed. These are dark gray metamorphic eluvated residual carbonate; carbolithozems dark humus clay-illuviated residual (phosphate) -carbonate; dark humus-gley; sod-humus soils; cryogenic-micellar chernozems.

The soils under study are characterized by a large amount of total and mobile phosphorus, which determines the peculiar properties of soils and the biological diversity of the territory. The weathering of phosphorites leads to a significant accumulation of the silicon component and the destruction and removal of the carbonate component, as well as to the residual accumulation of clay minerals and silty organic matter. The weathering of phosphate-carbonate rocks and migration processes contribute to the alkalinization and decrease in soil acidity in the landscapes underneath the slope. Anthropogenic and recreational activities, high pasture load have a negative impact on the natural stability of soils in the southwestern Khuvsgul region.

The high degree of ecological stability of the natural soils of the phosphorite deposit is due to the influence of phosphate-carbonate rocks, saturation of the soil absorbed complex with cations of alkaline-earth metals and the high content of organic matter of humate composition. The phosphate and carbonate content of rocks contributes to the accumulation of humus and the maturation of humic acids, and also inhibits the transformation of the organic-mineral matrix. The transformational changes are “obscured” by the influence of carbonates. The simplification of the information and energy structure of the mineral matrix of phosphorite soils leads to a significant convergence of a number of basic properties, characterized by the duration of the interaction of the parent rock with biotic and abiotic components of the ecosystem.

Soils formed on pure carbonate rocks which do not change the chemistry of soil formation are distinguished by lower reflex ability. A higher degree of sensory and reflex ability is inherent to soils developed on siliceous-carbonate rocks.

Generally, the spatial distribution of the critical values of recreational loads corresponds to the general laws of the soil cover formation under the vertical zonality. It is complicated, on the one hand, by the spatial variability of the values of subsurface weathering (which, in turn, depends on the peculiarities of the geological structure of the territory), and by the capacity of the biological cycle, on the other.

The integrated program of land use policy of the Baikal-Khuvsgul natural territory does not recommend the development of the phosphorite deposit within the Khuvsgul basin to preserve the lake water area, unique cenoses, soils and landscapes of the Khuvsgul National Park. In the case of industrial development of phosphorite deposits, and there are many of them in the Khubsugul region, there is an ecological hazard of the emergence of a natural geochemical field. This can lead to significant changes in the elemental composition of the components of the natural environment of the areas within the zone of influence of overburden rocks, which have undergone the processes of water and wind erosion. Thus, the issue of monitoring and protection of these unique (caused by the high
phosphate content of the parent rocks) soils and landscapes that have no analogues in Southeast Asia is highly relevant.

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