Soils of mountain floodplains in the zone of tectonic joints of Mongol-Okhotsk Orogenic Belt (Mongolia)

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Abstract. New data on the soils of mountain floodplains in the tectonic joints zone of the Mongol-Okhotsk Orogenic Belt on the example of the Upper Kerulen Basin are presented. Soil diversity is mostly determined by sedimentation conditions and drainage of the parent rocks. There are alluvial–humus (Fluvisol (Humic)), mucky–humus (Folic Fluvisol), dark–humus (Fluvisol (Mollic)), dark–humus gley (Gleyic Fluvisol) and dark–humus saline soils (Sodic Gleyic Fluvisol (Mollic)) were diagnosed. Tectonic movements of the earth’s crust lead to the appearance of shaftlike linear dams, blocking river flow through the valley. So, the Kerulen river changed the direction of the channel and go beyond the depression, embedding into its mountain frame. Current seismicity impact on soils appears locally at tectonically active positions of epigenetic areas, close to outputs of saline underground deep waters, in the form of surface soil salinity and hydrometamorphism.

1. Introduction
Rivers flow in various geological and geomorphological areas, in different natural zones around the world; they play significant role in human activity as a source of water for subsistence and economic activities. River floodplains, as a rule, are landscapes with highly fertile soils, valuable for agricultural use. Riverside soils have dynamic conditions of genesis associated with regular floodplain processes, such as sedimentation and washout of alluvial material, cyclic renewal of the soil profile, which significantly complicates their study and classification [1].

The most dynamic soil formation conditions are characteristic of mountainous areas with narrow, highly sloping floodplains, high river flow rates, powerful and rapid floods. Currently, the temporary or permanent prevalence of sedimentation over soil formation is the reason that the soils are generally young and have a simplified, underdeveloped profile.

According to previous studies of floodplain soils in large mountain valleys of the Baikal Rift [2, 3], the local endogenous processes sometimes dominate over other soil-forming processes in tectonically active areas. Underground deep gas fluids and groundwater erupting through the earth’s crust fault form unique soil-like bodies with the features of turbations by ascending diapirs, impregnation with oil bitumen, salts saturation – even in unsuitable climatic conditions.

Rivers of the Kerulen Basin flow within the Mongol-Okhotsk Orogenic Belt of the Khentei-Daurian folded area [4]. River valleys are confined to zones of tectonic faults of various orders. The Khentei Ridge forms a tectonic pair with the Baikal Rift zone and is characterized by high tectonic activity. Seismic processes of the Baikal Rift are compensated by hogging and accompanying phenomena such as earthquakes, landslides, gas emissions, and water uploading in the peripheral areas [5].
Currently, endogenous impact on the soil formation in the periphery of the Baikal Rift zone has not been studied. This work aimed to investigate the soil-forming conditions, morphogenetic features of soils, and soil diversity within the mountain floodplains of the circumference of the Baikal Rift on the example of the Upper Kerulen Basin and to assess the influence of endogenous factors.

2. Objects and methods
The objects of research are the floodplain soils of the Upper Kerulen Depression (figure 1).

![Figure 1. Relief of the Upper Kerulen Basin and its mountainous framing (a), territories with intra-depression bridges, and lines of hypsometric profiles (b, c).](image)

The basin is located in the area of the active tectonic joint at the junction between the terrane of the Paleoasian Ocean and the continental one – the Siberian Craton. The depression is about 100 km long, and its width varies from 2 to 12-15 km. Altitude increases from 1,306 to 1,493 m (drop is 187 m) from north to south. The development of this territory is associated with continuous Late Mesozoic-Cenozoic endogenous activity [4-6]. A feature of the study area is the heterogeneity of the geomorphologic, tectonic, geological, and hydro-geological structures of the northern, central and southern parts [7-11]. Paleozoic and Mesozoic intrusions are widespread within the east of the basin, Hercynian rocks prevail in the south, and sedimentary and intrusive Carboniferous rocks in the northeast [6]. Cenozoic sediments are thin.
The basin has several morphologically and dynamically heterogeneous segments (figure 1). The northern segment is characterized by a relatively wide valley with a developed river network. In the central and southern parts, the basin contracts and has a narrow elongated floodplain. Seismic activity occurs in the central segment. Tectonic gaps are noticeable in the Kerulen River tributaries, temporary streams, and swampy areas of floodplains [6]. Depressions overlap (figure 1a, b, c), and the epigenetic area can be clearly traced when interpreting the satellite images.

The territory under the study belongs to the Khangai soil-bioclimatic region with altitudinal (northern part) and latitudinal (central and southern parts) zoning structures [7, 8]. The average annual air temperature is below zero, the frost-free period is 77 days. The annual precipitation varies from 300 to 500 mm [11].

In the course of the field studies, 23 soil profiles and 30 soil cuts were performed (table 1). Soil physical and chemical properties were determined according to [12]. Soil classification was carried out following [13, 14].

### Table 1. Location and structure of main soil profiles within floodplains in the northern, central, and southern parts of the Upper Kerulen Basin.

| Profile No. | Location              | Altitude, m a.s.l. | Soil horizons       | Soil type (WRB, 2014)          |
|-------------|-----------------------|--------------------|---------------------|--------------------------------|
| 528         | 48.419381° N 108.780833° E | 1,452              | AY – AYC™™ – C™™   | Fluvisol (Humic)               |
| 529         | 48.42125848° N 108.799885° E | 1,456              | AH – AC™™          | Folix Fluvisol                 |
| 527         | 48.413188° N 108.825689° E | 1,454              | Ahs – AHg – AC™™   | Sodic Folix Gleyic Fluvisol    |
| 533         | 48.1650863° N 108.5664414° E | 1,400              | AUs – Aug – ACg™™ – C™™ | Gleyic Fluvisol (Molllic)     |
| 535         | 48.191779° N 108.493077° E | 1,423              | AU – AUs,sn,g – ACca™™ – CG™™ | Sodic Gleyic Fluvisol (Molllic) |
| 525         | 47.915140° N 108.480625° E | 1,335              | AUca,g – AUCg™™ – C™™ | Sodic Gleyic Fluvisol (Molllic) |

### 3. Results and Discussion

In the northern part of the depression within the forest-steppe, the mainstream flows close to the axial part of the valley. There are numerous left- and right-sided tributaries flowing down from the surrounding mountains (figure 1). The origin of the expanded segment in the northern part of the valley is associated with the mountain-valley glaciers melting and a periglacial lake subsequently formed [15]. A rather dense river network has occurred in this area. The flow-insular type of floodplain structure predominates. Alluvial gravel is the main material composing the alluvial sediments. Slightly acidic sand fills the gravel-pebble-boulder deposits (table 2).

Soils under the study had a thin profile (~40 cm) and a simple morphological structure: AH – C™™ and AY – C. Weakly developed layering or its absence is one of the morphological features of the floodplains. In turn, layering occurs deeper than 50 cm, below the contemporary soil profile and manifests in the form of alternation of medium and large rubble proluvial, alluvial layers, and buried humus horizons. The buried soils are located at depths of 0.8 and 1.2 m and, according to radiocarbon dating, are 3,160 ± 110 and 7,890 ± 180 years old, respectively [16]. Peat formation and gleying are not registered in soil morphology, despite the high soil water content. It is associated with good drainage of the parent and underlying rocks and good aeration and heating of the profile with a periodic decrease in the groundwater level.
Table 2. Some physical and chemical properties of the fine fraction of alluvial deposits (C˜˜).

| Plot, altitude, m | Natural zone | pH      | Corg, % | Salts, % | Exchange bases, cmol/kg | Particle size >0,01 mm, % |
|------------------|--------------|---------|---------|----------|-------------------------|--------------------------|
| Northern, 1,395-1,500 | Forest       | 6.3 ± 0.2 | 1.75 ± 0.32 | 0.033 ± 0.009 | 8.2 ± 0.3               | 83 ± 8                   |
| Central, 1,357-1,394 | Forest-steppe | 6.9 ± 0.1  | 4.32 ± 0.53 | 0.044 ± 0.002 | 4.5 ± 0.2               | 86 ± 5                   |
| Southern, 1,306-1,357 | Steppe       | 8.1 ± 0.1  | 2.99 ± 0.41 | 0.056 ± 0.007 | 1.6 ± 0.1               | 96 ± 1                   |

Soil type diagnostics were performed by humus horizons, among which gray-humus and mucky-humus horizons were distinguished. The grey-humus horizons were slightly acidic with a light texture, low content of organic carbon, and readily soluble, including toxic, salts (table 3). The mucky-humus horizons were enriched with organic carbon and exchange bases. According to WRB [14], they were classified as Folic Fluvisol and Fluvisol (Humic).

A few water discharges near tectonic faults in the northern segment of the basin manifested the presence of endogenous processes. The existence of a dense river network, significantly inclined slopes, and, accordingly, high flow rates as well as good drainage of soils, prevent the permanent accumulation of salts inputted endogenously into the soil profile. Slightly saline surface soils (<5 cm depth) of chloride–magnesium–calcium type, which is identical to underground mineral waters, are formed quite seldom in the zones of local influence of springs and weakened flood capacity, i.e. on the elevated sites within floodplains or above floodplains [5]. There are also signs of gleying at the depth of 6-25 cm. Soil morphology is reflected by the following formula: Ahs (0-5 cm) – AHg (6-24) – AC˜˜ (25-33). Soil type is Folix Gleyic Fluvisol [14].

Table 3. Some physical and chemical properties of humus horizons of alluvial soils in the Upper Kerulen Basin.

| Horizon | pH      | C, %     | Salts, % | Exchange bases, cmol (Equiv.) / kg | Particle size >0,01 mm, % |
|---------|---------|----------|----------|-----------------------------------|--------------------------|
| AY      | 6.3 ± 0.1 | 2.08 ± 0.2 | 0.038 ± 0.005 | 14.2 ± 0.3                        | 87 ± 3                   |
| AH      | 6.4 ± 0.2 | 8.94 ± 1.12 | 0.157 ± 0.063 | 21.8 ± 0.7                        | 84 ± 6                   |
| AU      | 7.3 ± 0.4 | 4.59 ± 0.84 | 0.256 ± 0.032 | 22.3 ± 0.8                        | 63 ± 4                   |

There is a sharp narrowing of the Kerulen River valley in the central (forest-steppe zone) and southern (steppe zone) parts of the Upper Kerulen Basin (figure 1b, 1c). That is associated with the peculiarities of the mountain framing of the depression, the latest rupture deformations, vertical displacements of rock blocks in the form of faults, reverse faults, and thrusts [6]. This results in a sharp change in the direction of the mainstream and its incision into the bedrock sidewall of the depression. The epigenetic site is formed to the south from the confluence of the right-sided tributary – Dzun-Burkhiin-Gol River into the Kerulen. Here the river cuts through the dense rocks of the Norovsatalynuru Ridge and flows 11 km in a narrow canyon-like gorge. In front of the entrance to the gorge, on the washout of the relief (figure 1b) and the hypsometric profile 1 (figure 2), a positive linear structure in the form of a bulkhead, acting as a dam, is deciphered. Such swells are characteristics of many intermountain Meso-Cenozoic depressions in the region [17] and are associated with Cenozoic upthrust faults [4]. They are indicators of lithosphere extension in transform geodynamic settings and are common in the Alps, New Zealand, Vietnam, Mongolia, and Transbaikalia of Russia.
Figure 2. Hypsometric profiles of the Upper Kerulen Depression sites with dams. (The geographical location of the profiles is shown in figure 1).

Additional consequences of neotectonic processes currently affecting soil formation are numerous outflows of underground deep waters recorded on satellite images as surface soil salinity in the direction of runoff, or along the periphery of closed or low-flow lake depressions.

In the central part of the Upper Kerulen Depression, the floodplain of the Kerulen River is strongly narrowed, so the main floodplain and floodplain-lake territories belong to the small rivers: the Dzun-Burkhiin-Gol and the Barun-Burkhiin-Gol. The volumes and rates of runoff here are much low, the rivers meander strongly and often change their channel, the water runoff is limited by a dam and a spur of the ridge. Such conditions contribute to sedimentation of the thinnest fractions, and, accordingly, forming more developed soil profiles with carbonate accumulation, gleying, weak salinity, and alkalinity. Dark humus horizons prevail spatially among others.

Soil morphological structure is performed by the following system of genetic horizons:

- AU0 (0-9) – AUg (10-42) – ACg – AU (0-5) – AUca, sn, g (6-35) – ACca (36-70) – CG (71-120). The AU horizons are neutral, slightly saline, have a high content of organic carbon (table 2). Salinity chemistry is chloride and sulphate-chloride, according to the ratio of anions; considering the ratio of cations, it is of calcium-magnesium and magnesium-sodium type.

There is also a tectonic rampart in the form of a solid dam at the depression closure (figure 1c, point B), which blocking the Kerulen River runoff and forcing it to bypass through the gorge in the ridge spurs. There is a group of several small salt lakes within the dam area, which can feed by outputs of low-mineralized waters and salinization of the surrounding landscapes. Soils possessing highly saline topsoils of sulphate-magnesium type are formed in a narrow coastal strip along the lakeside depressions.

4. Conclusion

The study of soils within the floodplain of the upper reaches of the Kerulen River and its tributaries (within the Upper Kerulen depression) revealed a complicated hydrogeological structure and heterogeneous conditions of sedimentation of alluvial deposits, which are the parent and underlying rocks.

According to the data [4, 6, 17], geomorphological analysis, interpretation of the space images and the land surface survey, current neotectonic processes are expressed in 1) asymmetric structure of valleys; 2) development of the epigenetic areas with damming the river runoff, leading to a change in the flooding of the floodplains and the incision of the Kerulen River mainstream into the bedrocks of the depression’s sidewall with subsequent forming the gorges in the surrounding mountains; and 3) multiple outputs of underground deep waters.

In the northern part of the basin within the forest belt, floodplain-alluvial processes are weak; therefore, the layering in the soil profile occurs deeper than 50 cm. Small profile thickness, humus accumulation of the mucky-humus type, as well as well-drained gravel-pebble-boulder deposits with sandy filler are the features of the soil morphology. Gleying processes and peat accumulation are not developed even at high water cut, due to the specific structure of soils, parent and underlying alluvial rocks of mountain floodplains, their high water permeability, and good aeration.
Typical differences between soils are expressed only in humus horizons (AY, AH). There is a typical for the forest zone salinization of alluvial soils associated with active faults which induce the discharge of underground deep low-mineralized waters.

Alluvial dark-humus soils widespread in the central and southern parts of the basin formed within forest-steppe and steppe zones are featured with carbonate accumulation, gleying, salinization, and alkalinization. Endogenous processes are performed in soils only in salinity.

Zonal factor impacts the change in pH values from slightly acidic to slightly alkaline in the direction from the north to the south. The influence of seismically driven endogenous processes on soils was noted in the form of salinization by open and subsoil outputs of deep waters.

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