Influence of mineral sources on formation of soils in the foothills of Eastern Sayan Mountains (Buryatia)

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Abstract. The results of studying unique soils’ genesis and properties in the zone of underground mineral water influence as well as geological conditions are presented on mineral springs sites in the foothills of the Eastern Sayan Mountains. The spatial regularities of soil changes and their dependence on landscape conditions and the composition of mineral water are revealed. It has been established that soils near springs and at a distance of 5 and 20 m are more susceptible to mineral water than distal one at 50 and 200 m. Soil types and its properties change from calcisols that are hydromorphic, thin, gravelly and are formed on travertines, calcites and marbles, to brown soils formed on acidic and ferruginous rocks under the influence of forest vegetation. The salt composition of soils correlates with the mineral water composition and includes ready soluble salts - chlorides, sulfates and bicarbonates of calcium, magnesium and sodium in concentrations from 0.5 to 0.26%, pH changes from acidic to alkaline. The concentration of organic substances varies from 0.5 to 15.0%.

1. Introduction and Background

Issues of the geological activity of groundwater are studied in various aspects of Earth sciences and often relate to interaction in the system “water - rock - gas-organic matter” [1, 2, 3, 4, 5]. Along with the formation of the chemical and gas composition of mineral waters in a geological environment, including not only rocks, but also the geological, structural and thermodynamic conditions of the subsoil the study of the groundwater influence on the formation of soil mantle has a great practical interest.

Soils in the zone under the mineral springs influence on the Eastern Sayan mountains have not been studied until recently, although Arshan springs have been known since the 17th century. The first official information about it was published in 1894. Later these sources were studied by many authors, mainly geologists and geographers [1, 2, 3, 6, 7 etc.]. In 1965 V.P. Martynov published the results of detailed investigations of mountain soils in the Eastern Sayan Mountains but there is no information on soils forming near sources [8].

Since groundwater as well as mineral one being part of the geochemical landscape plays the role of a landscape-forming factor, data on soils under the influence of mineral sources are of particular interest.

The aim of the work is to study and analyze the factors of soil formation and the processes of migration of water-soluble substances in soils on the sites of mineral waters discharge in the foothills of the Eastern Sayan Mountains.
2. Objects and Methods
The studied area is located in the southern part of the Baikal rift zone on the border of the Tunka rift valley and framing the East Sayan mountain ridge from the north with absolute height of 2,000-3,200 m.

The upper part of the geological section of the basin is composed of a thick (hundreds of meters) layer of Cenozoic sediments lying on the block basement of the Lower Proterozoic rocks (crystalline schists of the Ilchir Formation and carbonate rocks of the Irkut Formation). The leading role in the geological and structural plan and hydrogeological features formation belongs to tectonic faults of different ages.

Hydrogeological conditions are determined by the presence of three types of hydrogeological structures - hydrogeological massifs, hydrogeological basins and water-bearing faults [9]. While groundwater (their resources, regime and composition) of the first two types (areal) of hydrogeological structures are directly dependent on landscape and climatic factors, fractured-vein fault waters have only an indirect relationship with external factors.

Discharge of fractured-vein fault waters including mineral ones is localized as a rule in zones of tectonic faulting [3, 5, 9, 10, 11], moreover, young ruptures cutting older structure-forming fault zones are more often water-bearing or permeable [9, 11].

The studied mineral springs Arshan, Suburga, Papiy Arshan, Caltsievaya Gora (source at the foot of a high terrace composed of calcites) are located on the border of the East Sayan massif and the Tunka valley in the planes of crosscutting submeridional faults.

The object of the study is soil formed under influence of the natural mineral waters discharge. On the base of field and chemical and analytical investigations of soils and groundwater their spatial relationship was studied with consideration to landscape conditions.

Soil sections were organized and tested in depth - till the parent rock and in plan - at a distance of 0-0.5, 20, 50 and 200 m from the spring.

Chemical and analytical studies of soils were carried out on methods described by E.V. Arinushkina [12]. The chemical analysis of water was performed according to the methods of Reznikov and Mulikovskaya [13].

3. Results and Discussion
The East Sayan mountain system is distinguished by a sharply dissected alpinotype relief, parent rocks are carbonates (calcite, marble), crystalline schists, in some cases ferruginous.

Soils in the zone of mineral springs influence are seasonal freezing to a depth of 0.2 m and only around the spring remain in a thawed state.

In different geochemical landscapes where mineral waters discharge on the surface, similar or different conditions for soil formation appear. In the process of soil formation chemicals either accumulate in the soil profile or migrate and then accumulate in the lower parts of the relief [14]. With slope runoff and groundwater discharge, substances migrate in related geochemical landscapes. The composition of the rocks determines the formation and distribution of various types of groundwater [4, 5], and they affect the formation of soils in the discharge area [15, 16].

The water of the studied sources is highly gas-saturated sulfate- or chloride-bicarbonate sodium-calcium-magnesium or calcium-magnesium with a salinity of 0.3 to 2.4 g/dm³ (table 1). The composition of the water extract from the soil is identical to the chemical composition of water from the corresponding spring.

Arshan Resort. Soils mainly belong to calcisols, have a short soil profile A-C, and can also be called primitive soils, soils with an underdeveloped soil profile or parasols [5]. Near the spring (0 m) calcites and other rocks are observed; at a distance of 5, 20, 50, 200 m - the soils become calcisols and have O-Mca profile. The litter-peat horizon on carbonate rocks is distinguished in the profile [14].

As moving away from the source, the organic matter content is initially high, then sharply decreases and then increases again (Figure 1). This is due to the different rate of accumulation and decomposition of organic matter in the soil. Near the source, the amount of moisture is sufficient to form a peat horizon. At some distance from the spring (5, 20 m), the soil surface is devoid of
vegetation and trampled. The humus content here decreases to 0.87% however it again increases with distance from the discharge zone to 1.30%. This is due to a change in vegetation, an increase in its diversity, and the inclusion of various sedges and cereals in its composition.

Table 1. The results of hydrochemical analysis of mineral springs.

| Mineral spring                  | Chemical composition of water (salinity, g/dm³) |
|---------------------------------|-----------------------------------------------|
| Suburga                         |  $M0.4 \frac{HCO_3}{Ca48Mg42}SO_4_{27}Cl19$, $pH8.3$ |
| Papiy Arshan (water in karst pothole) |  $M0.3 \frac{HCO_3}{Mg55Ca40}SO_4_{13}$, $pH8.2$ |
| Papiy Arshan (water in stream)  |  $M1.8 \frac{HCO_3}{Ca88},SO_4_{91}$, $pH8.4$ |
| Arshan                          |  $M2.4 \frac{HCO_3}{Ca55Na24},SO_4_{25}$, $pH7.0$ |
| Spring Caltsievaya Gora         |  $M0.5 \frac{HCO_3}{Mg61Ca38},SO_4_{16}$, $pH8.4$ |

All soil horizons are well drained. The pH reaches 8.8, it’s likely inherited from carbonate rocks since soils are formed on calcites and marbles. The uneven change of pH may be caused by the underlying rocks composition (sands, travertines, fine grained soil), a thin soil profile (up to 20 cm) and the influence of the source.

Analysis of the aqueous extract showed the anionic and cationic salts composition is heterogeneous: bicarbonate-sulfate calcium-magnesium. The highest salt concentrations were noted near the spring (0 m) - 0.26%. All soils including those near the source are not saline. However a certain trend in the amount of salts is noted depending on the distance from the spring (maximum 0.26% near the spring and minimum 0.04% at a distance of 50 and 200 m), which is associated with a weakening of the source’s influence. The origin of sulfates is apparently associated with groundwater rising through the sulfur-containing volcanic deposits. Calcium and magnesium bicarbonates are part of parent rocks located at the surface. Sodium and potassium are most likely come from groundwater as a result of accumulation during weathering of rocks.

Suburga Source (Old Arshan, Second Arshan). The spring is located 5 km west of the Arshan Resort along the Tunkinsky ridge at the base of the slope. The discharge of slightly mineralized chloride-sulfate-carbonate sodium-calcium karst waters is noted. On an area of 100 - 110 m², three different in size and yield sources are found. The eastern spring discharges with yield of 0.8 - 0.9 m³/s, the flow rate in the channel is 2 m/s. The largest second spring is medium with a flow rate of 2-4 l/s and the third one is insignificant [2]. Water is chloride-sulfate-bicarbonate magnesium-calcium [11]. Water temperature is 5-8°C. The source water has a pH of 8.3, mineralization is 0.4 g/dm³.

In the geochemical landscape a change in soil types is observed. At the water-soil boundary (0 m) there are travertine outcrops; at a distance of 5 m - calcisols with O-Mca profile on travertines; at 20 m - gluey brown soil with AY-BMg-Cg profile; 50 m - brown soil with AY-BM-C profile; at 200 m - podzolized brown soil with AYe-BM-C profile.

Water from three spring heads run into a single stream, which forms a small lake in travertines, gradually turning into a swamp. Water filtration is prevented by dense travertine deposits. The upper soil horizons are humus with rough humus. They lie on travertines, with a thickness of 10 - 50 cm, of different density and degree of disturbance. In the soil profile, travertine layers are located almost horizontally in the form of light yellow horizons. At a distance of 5 m, an alternation of humus horizons and travertines is clearly visible in the soil profile. Such layering is characteristic of
mountainous areas and often associated with slope processes. Travertine fragments are noted at a considerable distance from the source (along the Bugata River, fragments are transported to a distance of 3 km).

An analysis of the humus content in soils showed that in the 0–10 cm layer it varies from 5 to 15%. Near the spring, the upper soil horizon is humus, and the humus content is up to 15%. At 5 m from the spring its content decreases to 5%, and at a distance of 20 m it is 7%.

Figure 1. Graphs of matter distribution in soils near mineral springs at a distance of 0 to 200 m: 1 – Arshan, 2 – Suburga, 3 – Papiy Arshan, 4 – Spring Caltsievaya Gora.
The presence of a humus horizon and a high percentage of humus at a distance of 20 m from the spring are connected with the accumulation of organic matter from abundant forbs. At a distance of 50 and 200 m, the humus content decreases. The pH near the source is 8.2, as moving away from the spring, pH decreases to 5.2 and corresponds to zonal soils.

The soils near the spring are non-saline. The cationic and anionic composition contains bicarbonates and calcium and magnesium chlorides, less often sulfates.

Near the head of spring (0 m) and at a short distance away (5, 20 m) the salt concentration is higher (up to 0.13%) than at a distance of 50 and 200 m - 0.06 and 0.04% respectively. Near the source the soils are easily washed by water, and already at a distance of 5 m the salts are converted into dense, often waterproof travertines that impede the water movement. At a distance of 200 m salts accumulate in very low concentrations (0.04%).

Papiy Arshan source is located 12 km from the Arshan Resort at the base of the southern slope of the East Sayan Ridge. It is formed at the bottom of a carbonate karst pothole (small karst lake), from which the water runs with the Small Bugatay stream. At a distance of about 2 km the water stream is lost among the boulders. The spring yield is 0.05 m3/s. Deposits of a dark blue color are found at the bottom of the lake and along the shores, due to the presence of the mineral vivianite (Fe3 [PO4]2 • 8H2O). Water temperature is 5° C.

The geochemical type of the Papiy Arshan water is similar to the Suburga source. Mineralization of water is 0.27 - 1.80 g/l, pH 8.5. The composition of the water is bicarbonate-chloride calcium-magnesium (table 1).

The soils near the spring are of the calcisols O-Mca type; at a distance of 5 m - calcisols of humic with W-Mca profile; at 20 m - gleyous brown soils with AY-BMg-Cg profile; at 50 and 200 m - roughly humus-covered brown soils AYao-BM-C profile.

A humus horizon forms on carbonate rocks along the edge of the karst pothole near the water line. Therefore, the content of organic matter in the upper horizons is very high, however as moving away from the spring it decreases and the humus content decreases to 8% (figure 1). The pH value changes from 4.8 till 6.3.

The composition of the aqueous extract is dominated by bicarbonates and chlorides of sodium, calcium and magnesium. The maximum salt content is observed in the immediate vicinity of the spring head (0.15%). At the distance from the spring the salt content and pH decrease under the influence of plant litter of conifers and parent rocks which is typical for forest soils. The soils are not saline.

Spring Caltsievaya gora is located at the foot of a high terrace composed of calcites. The source water in terms of chemical composition is chloride-bicarbonate calcium-magnesium, pH 8.4, mineralization 0.3 g/dm³.

The soils on discharge site represented by calcite deposits, at a distance of 5, 20, 50, 200 m they are typical calcisols O-Mca profile [15].

Changes in the concentration of organic matter (from 1 to 13%) are due to the heterogeneous composition of the vegetation (the presence of mosses, algae and other plant residues in the soil). Around the source anthropogenic load is noted, the soil surface is trampled, therefore the humus values are low (2%), pH 7.8 - 8.4 (figure 1).

Near the source the soil is slightly saline and not saline at a distance of 200 m. The amount of salts in the soil near the source is 0.15%, at a distance of 5 m and further from 0.08 to 0.17%. The salts contain chlorides and bicarbonates of magnesium and calcium.

Comparison of the chemical composition of the water from the studied mineral sources showed a close pH value (8.2–8.4) but difference in mineralization (0.2–1.8 g/dm³). The composition of mineral waters is presented in table 1.

It is known, official resort areas are more subjected to anthropogenic impact than the so-called “wild” resorts. At anthropogenic degradation with a thin soil and vegetation cover the soils characterized by low thickness profile, graveliness and disturbance.
Soils at a distance from the springs in the forest zone have lower pH values (5.5–6.0) than on open spaces (7.0–8.0). All studied soils contain an unequal amount of readily soluble salts and are non-saline and slightly saline. The largest travertine deposits (up to 0.5 m) are noted at the Suburga source in the form of a strip 5-10 m wide extending downstream for 3 km.

The different cationic and anionic composition of the soils near the source is connected rather with the chemical composition of water than parent rocks, since groundwater rises from different depths. A special case is the Arshan spring. Here, water comes from carbonate rocks through a captured well.

The Suburga and Papiy Arshan sources are located nearby, therefore soils formed under the influence of these sources have the similar genetic properties. It is the same applies to Arshan and Caltsievaya Gora springs.

In all soils near the springs the humus content is high, then decreases, and with distance from it, increases again.

Hydrochemical properties of mineral sources determine the relationship between the chemical composition of rock, water and soil, as well as the general condition of the ecosystem. With distance from the water discharge zone the properties of water, vegetation, soil and air temperature, water, and chemical regimes of the soil change.

4. Summary and Conclusion

In the foothills of the Eastern Sayans in the zone of mineral springs influence peculiar soils are formed, the features of which change on the distance from the source and depend on the landscape conditions of the mineral water discharge site and hydrochemical parameters.

Soils near springs and at a distance of 0, 5 and 20 m are more susceptible to the influence of mineral water than at 50 and 200 m. In the first case they are usually hydromorphic, thin, gravelly and form on travertines with a thickness of up to 1.5–2 m, and can be classified as calcisols. In the process of the calcisols formation the main role is played by carbonate parent rocks - calcites and marbles. On acidic and ferruginous rocks (distances of 50 and 200 m) brown soils are formed under forest vegetation effect.

The composition of the water extract from the soils near the spring is more appropriate to the hydrochemical composition of water than to parent rocks. On pH value the soils vary from slightly acidic to alkaline. The upper horizons of calcisols near the springs (at distance 0 - 5 m) are humus, at a distance of 20 m - less humus than in brown soils at a distance of 50 and more meters.

The salt content varies from 0.04 to 0.26%. Despite the increased salinity of the water sources (up to 2.4 g/dm^3) the soils around the sources are not saline due to their good drainage and large amount of precipitation (up to 500-600 mm).

The established features of soil formation in the areas of mineral springs influence are of scientific interest to researchers in various areas of geological science and are of practical importance for solving a number of issues in balneology and ecology.

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