The results of magnetotelluric studies on the profile of the Kuray depression – lake Teletskoye

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Annotation. The results of magnetotelluric studies (MTS) conducted in the western part of the Mountainous Altai region on the profile of the Kurai depression – lake Teletskoye are presented. The profile intersects two large tectonic units – the Mountainous Altai and Teletskaya, bounded by regional tectonic sutures of the Teletsko-Bashkausskiy, Northern Sayans, Shapshalskiy and other faults. The obtained data indicate a fairly fractional recent block divisibility of the Earth's crust of the Mountainous Altai territory. It is shown that according to the characteristics of the electrical resistivity distribution within the studied profile, large blocks are distinguished that differ sharply in the features of the composition and structure of the Earth's crust, as well as the manifestation intensity of deep processes. The sections constructed from magnetotelluric data allow us to trace the behavior of the main neotectonic disturbances, which are marked by subvertical zones with abnormally low resistivity values (1-5 Ohm·m).

1. Introduction
The study of the fault-block tectonics of the Mountainous Altai territory is of great importance both for fundamental geology and for its applied aspects related to the mineralogy of the Earth's crust and the forecast of natural catastrophic phenomena. At the same time, the study of the interrelations between the processes occurring in the zones of earthquake manifestation and the features of the deep electrical conductivity distribution becomes particularly relevant. The MTS method, as one of the most in-depth methods, has shown high efficiency in studying the deep Earth’s horizons in many tectonic provinces of the world. An important component of these studies is the identification and study of active fault zones, the development of which is associated with deformations of the Earth's crust and is accompanied by seismicity. Active faults form conducting channels that, crossing the high-resistance lithosphere, provide a vertical redistribution of excess currents and are fixed in the magnetotelluric field (MT-field) in the form of conducting geoelectric inhomogeneities with vertical and inclined lateral boundaries.

The Mountainous Altai region belongs to the western part of the Altai-Sayan folded region, formed during the Paleozoic accretion-collision tectonic stage. Manifestations of accretion-collision events and multiple episodes of shear tectonic deformations caused the formation of the modern mosaic structure of the Mountainous Altai, in which geoblocks of various nature and age are separated by zones of long-lived deep faults [1, 2].

The main distinguishing feature of the tectonic structure of the Altai-Sayan folded region is the multidirectional and side junction of individual structural elements, due to the large-amplitude displacement of structures along faults of a shear nature, the multidirectional and inhomogeneous...
processes of accretion and collision. The result of the collision is the Late Devonian Charysh-Terekta-Ulagan-Sayan suture-shear zone and the Kurai and Teletsko-Bashkaus Late Devonian-Early Carboniferous shear zones deforming it (figure 1).

Figure 1. Structural diagram of the Mountainous Altai eastern part
[Buslov et al., 2003]:

1 – Altai-Mongolian terrane of the Gondwana group; 2-4 – tectonic units of the Siberian continent margin; 2 – Mountainous Altai, 3 – Teletskaya, 4 – Western Sayans; 5 – Permian continental molasse; 6 – Early-Middle Jurassic continental molasse; 7 – Devonian volcanogenic sedimentary rocks; 8 – Ulagan segment of the Charysh-Terekta-Ulagan-Sayan suture-shear zone; 9 – Middle Paleozoic granitoids; 10 – Late Silurian-Early Devonian metamorphic complexes; 11 – Late Devonian-Early Carboniferous granite-gneiss domes; 12 – Early Triassic granitoids; 13 – Late Devonian-Early Carboniferous granites; 14 – Late Devonian-Early Carboniferous shear zones; 15 – Late Devonian-Early Carboniferous thrusts; 16 – Permian-Triassic shifts; 17 – Late Carboniferous-Permian thrusts and shear thrusts; 18 – MTS points.

The Kurai zone of shifts and thrusts is located at the base of the cover represented by the Altai-Mongolian terrane and separates it from the Mountainous Altai terrane (figure 1). The Teletsko-Bashkausskaya shear zone was formed as a result of left-sided shear displacements and is one of the regional fault zones of the Altai-Sayan region. In the northern part of the Teletsko-Bashkausskaya zone, three large tectonic units are distinguished in the area of lake Teletskoye: Mountainous Altai, Western Sayans and Teletskaya, separated by fault zones [1, 2]. The Mountainous Altai tectonic unit is located to the North of the sublatitudinal part of the lake and is represented by Vendian-Early Cambrian ophiolites and siliceous-terrigenous rocks. The Teletskaya tectonic unit is located on the western shore of lake Teletskoye and is composed of the Late Silurian Altyntausskiy massif of double-mica granitoids and Early Paleozoic green shales. The Sayan tectonic unit is exposed on the eastern shore of the lake. Tectonic units are limited by the regional tectonic seams of the Northern Sayans, Teletsko-Bashkausskii, Shapshalskiy and other faults (figure 1).

2. Methods of work
The MTS studies were carried out along the profile crossing the Mountainous Altai and Teletskaya tectonic units from South to North (figure 1). Their purpose was to study the features of the distribution of deep electrical conductivity and their connection with young Alpine processes.
The work was carried out by the equipment of the Canadian company “Phoenix Geophysics Ltd” in the range of periods $3 \times 10^{-3} - 10^4$ s. Two MTU-5 measuring modules were used. Four components of the magnetotelluric field were recorded: $E_x$, $E_y$, $H_x$, $H_y$. The average observation step was 4-5 km, the recording duration was 19-22 hours. A cruciform installation with a length of electric lines of 100 m was used, oriented according to the scale of magnetologists: the $X$ – axis is North, the $Y$ – axis is East. Field data were processed in the program “SSMT-2000”, 1D- and 2D-inversion – in the software package “WinGLink”.

3. Research results

As a result of studies conducted on the profile of the Kurai depression – lake Teletskoye, large blocks of the Earth's crust were identified, separated by zones of deep faults (figure 2, 3).

![Graph](image)

**Figure 2.** Deep geoelectric section along the profile of the Kurai depression – lake Teletskoye: 1 – MTS points; 2 – electrical resistivity isolines; 3 – graph of the module of the anomalous magnetic field vector $\Delta T_a$, nT.

**Figure 3.** Deep geoelectric section along the profile of the Kurai depression – lake Teletskoye, showing the blocks of the Earth's crust.

**BLOCK I** (points pr 13-1 – pr 15-9) fully belongs to the Mountainous Altai tectonic unit and includes the western side of the Kurai depression and its mountain frame – the Northern Chuya and Kurai ranges (figure 3). The southern part of the block (points pr 13-1 – pr 13-7) characterizes the slope of the Northern Chuya ridge, composed of metamorphosed rocks of the Cambrian and Ordovician, in the southern part (points pr 13-1 – 13-3) overlain by modern sediments. In the interval of the section of 5-20 km, low resistivity values are observed, due to the strong fragmentation of the Earth's crust. Disturbed, highly permeable areas of the Earth's crust ensure its saturation with fluids, which in turn leads to the formation of an area with high electrical conductivity. Within the latter, the subvertical zones with minimum resistivity values (5 Ohm·m) are isolated, marking the newest faults and the nodes of their intersection with the faults of the Paleozoic stage of laying. In the Mountainous Altai, the latest faults use Paleozoic fault zones only in certain areas and usually cut them at different angles [3]. These nodes are expressed in the MT-field by a combination of conducting zones with vertical and inclined
lateral boundaries, which are well traced on the electric section (figure 3). This can be interpreted as a combination of upsurge and shear movements along separate zones of the newest faults [4].

The central part of the first block (points pr 13-9 – pr 15-6) characterizes the features of the composition and tectonic structure of the north-western part of the Kurai depression (figure 3). The Kurai depression is a large intermountain depression with upslope and upslope-shear tectonic boundaries. From the South and North-East, it is bounded by the North Chuya and Kurai ranges. From the North-West, it is closed by the Aigulak and Kubadrinskiy mountain ranges. In the western part of the Kurai depression, the foundation, represented by Paleozoic and Late Proterozoic volcanogenic and sedimentary rocks, comes to the surface. The eastern part is a basin of Cenozoic sedimentation on the Paleozoic and Late Proterozoic basis. According to the MTS data [4], the modern sediments of the Kurai depression are divided into three geoelectric horizons: $\rho_1 < \rho_2 > \rho_3$ (figure 4). The first one is represented by fluvioglacial deposits of the Middle-Late Pleistocene. The horizon is maintained according to the resistivity values, which are 15-20 Ohm·m and varies significantly in width: from 150 m to complete wedging in the North-East direction. The second horizon with a capacity of 250-300 m and resistivity of 50-70 Ohm·m is represented by undifferentiated Early-Middle Pleistocene deposits and deposits of the Tueryk formation of the Middle Miocene. The third – most conducting horizon is confined to the Lower Miocene deposits of the Koshagach formation and the deposits of the Karachum formation of the Lower Oligocene. The width and resistivity of the horizon are 350 m and 10-20 Ohm·m, respectively.

![Figure 3. A – the newest faults position [Novikov, 2017]; B – a deep geoelectric section along the profile of the Severo-Chuyskiy ridge – Kurayskiy ridge (the symbols are shown in figure 2).](image)

In the north-western part of the Kurai depression, a large massif composed of crystalline rocks resistant to denudation is mapped (figure 2, 3). From the West, it is bounded by the newest deep faults with a large displacement amplitude, forming the natural western boundary of the depression. The massif is an outlet to the surface of the Kurai depression foundation, which is peculiarly curved and separated from the ridges from the North and South by small deflections. The basement rocks are represented by deposits of the Upper Riphean, Vendian and Cambrian [3, 4].

In the geoelectric section, the array is expressed by formations with sufficiently high resistivity values reaching 1500 Ohm·m. The depression is separated from its nearest mountain frame – the Northern Chuya and Kurai ridges – by zones of deep faults that spatially coincide with the areas of abnormally low resistivity values.
The northern part of the profile (points pr 15-6 – pr 15-10) crosses the slope of the Kurai ridge (figure 2), the formation of which occurred as a result of the Late Cenozoic activation of tectonic movements. It is established that the intensive growth of the Kurai ridge dates back to the end of the Pliocene. At the same time, it was moving towards the sediments of the Chuya depression with the accumulation of coarse-grained sediments with increased resistivity values [5]. The axial part of the ridge is represented by zonal - metamorphic rocks of the epidote-amphibolite facies of regional metamorphism: granitogneisses, migmatites, gneisses and amphibolites of various composition. A significant part of its northern slope is occupied by deeply metamorphosed rocks of the Kurai complex: amphibolites, biotite-amphibolite shales, gneiss and granitogneiss. These rocks are characterized by high resistivity values, which within the studied profile vary down the section from 1000 to 500 Ohm·m.

BLOCK II is located within the Teletskiy tectonic unit. The upper part of the Earth's crust section, represented by Paleozoic green shales, to depths of 5-7 km, is characterized by relatively elevated resistivity values (from 200 to 1000 Ohm·m). At a depth of 7 km, a subvertical conducting zone with a resistivity of 7-15 Ohm·m is allocated, confined to the active fault zone (figure 2).

Figure 4. Geoelectric section of the sedimentary cover of the Kurai depression (sedimentary cover complexes according to [Buslov et al., 2013]):

1 – MTS points; 2 – electrical resistivity values in Ohm·m; 3 – tectonic disturbances established by MTS after a sharp change of electrical resistivity; Cenozoic deposits: 4 – fluvio-glacial, 5 – alluvial-lacustrine, 6 – glacial, 7 – alluvial-proluvial, 8 – clays, marls, loams, sandy loams, brown coals; 9 – early-Middle Devonian volcanogenic-sedimentary rocks of the active margin; 10 – Vendian volcanites; 11 – Cambrian carbonate rocks; 12 – tectonic disturbances recorded on the MTS profile by subvertical conducting zones.

BLOCK III (pr15-14 – pr16-6) occupies almost the entire central part of the studied profile and completely belongs to the Mountainous Altai tectonic unit (figure 2). A special feature of the block under consideration is the two-layer structure of the Earth's crust section. The upper part to depths of about 6 km has the highest resistivity values, which are distributed in descending order from the central part of the block to the marginal ones from 2500 Ohm·m to 500 Ohm·m. Starting from depths of 6-7 km, there is a gradual decrease in the resistivity values to 10 Ohm·m. The sharp decrease in the resistivity values in this section interval is due to the high fluidization of the crust. From the South-East and North-
West, the central block is bounded by conducting zones with an expressed slope of the lateral borders (points pr 15-16 – pr 15-17; pr 16-8 – pr 16-9).

BLOCK IV (points pr 16-6 – pr 16-14) is located within the Teletskiy tectonic unit and is a complex geoelectric heterogeneity with low resistivity values. They vary from 50 Ohm·m in the upper part of the section to 5-7 Ohm·m in the lower part. In the south-eastern part of the block, at a depth of about 5 km, an inclined conducting zone is allocated, sinking under block III. Here, the resistivity values vary from 30 to 10 Ohm·m.

4. Conclusion
The features of the electrical resistivity distribution in the Earth's crust of the studied territory are due to the intensity of deep processes. High tectonic activity is expressed in the formation of new faults and the fluidization of the consolidated crust, which in turn leads to the formation of areas with abnormally low resistance values. Neotectonic disturbances can be traced to depths of more than 20 km and are distinguished on the geoelectric section by subvertical zones with minimal resistivity values (less than 5 Ohm·m). It is established that vertical falls of displacers are characteristic for discharges and shifts, and inclined ones are characteristic for surges and thrusts, which generally confirms the kinematic characteristics of faults determined from morphotectonic and geological data.

5. References
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