Structural and geological studies in the Naryn and Atbashi depressions (Tien Shan) and geological interpretation of magnetotelluric data

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Abstract. The article presents the results of complex geological and geophysical studies in the Naryn depression and Atbashi depression in the Middle Tien Shan. They included the geological interpretation of new magnetotelluric data along the detailed profile crossing the key segment of the Tien Shan, and the study of the morphology and spatial position of the sedimentary cover and basement structures. The compilation of the results of structural-geological and geophysical studies makes it possible to create a 2D model of the upper-crust geological structure, consistent with the structure of the electrical conductivity to depths of about 10 km and to analyze the structural features of deeper horizons. Two types of structural patterns of the electric conductivity, corresponding to the sedimentary complexes of the cover and the folded-metamorphic complexes of the basement, have been identified. Sedimentary rock complexes in depressions have a high electrical conductivity and subhorizontal structure. The upper crust above the K2 density layer is characterized by an alternation of rocks volumes with contrasting conductivity, elongated vertically. The recorded structure of the field confirms the presence of steep zones of fluid permeability and fragmentation, noted earlier in seismic profiles and probably corresponding to the Paleozoic structures of fragmentation of the Earth's crust, activated during Alpine orogeny. Comprehensive research allow to characterize the deformations of the Cenozoic sedimentary complex and the surface of the Paleozoic basement associated with the Alpine activation of the key segment of the Tien Shan.

1. Introduction
The study of the structure and geological evolution of the inner-mountain depressions of the Tien Shan is the most important tool for determining the features of the geodynamic regime of the entire region at the stage of Alpine Orogeny. A very significant object is the tectonic ensemble "Naryn Depression – Baibichetoo Uplift – Atbashi Depression" (NBA) of the Middle Tien Shan, which was formed during...
the entire Cenozoic as a system of sedimentary depressions separated by uplifts (Fig. 1, 2). At the final stages of the India/Eurasia plate collision, all upper-crust complexes, including a multi-kilometer sedimentary cover, were intensively deformed.

The lithological and stratigraphic features of the cover deposits of the Naryn and the Atbashi depressions allow us to conclude that during the Oligocene, Miocene and at the beginning of the Pliocene, both depressions were a single terrestrial sedimentary depression [1]. Variations in the thickness of the Kyrgyz and lower part of the Naryn suite indicate the origin of local consedimentary uplifts, one of which was the Baibichetoo uplift. The uplifts were expressed in the relief of the Paleozoic basement, but the Paleozoic rocks were not exposed on the surface and were not eroded. It was only in the Pleistocene that a dissected high-mountain relief appeared and the river network was rebuilt [2], the central uplift has undergone a relative rise and denudation.

Figure 1. The position of the Naryn depression (1) and the Atbashi depression (2) in the structure of the Tien Shan and their relief. Fault boundaries of the Middle Tien Shan: the Talas-Ferghana fault (TFF), the Nikolaev Line fault (NL) and the Atbashi-Inylchek fault (AI).

Figure 2. General morpho-structural scheme of the Naryn and Atbashi depressions.
1 – Paleozoic basement; 2 – Cenozoic cover (lighter shade corresponds to more thickness); 3 – isohypses of the bottom; 4 – pickets of the MT profile "Karabuk".

Despite the good geological and geophysical level of study of the area, the deep structure of the depressions is still interpreted ambiguously. First of all, this concerns the peripheral parts of the depressions, where the Paleozoic basement is pushed over the sedimentary cover, and there are certain problems in the interpretation of geophysical data obtained during oil-search work in the 60-70s. Probably, an equally important reason for the ambiguity of the interpretation of the deep structure of the depressions is the complexity of fold-thrust deformations inside the sedimentary cover, which do not have a direct correlation with the morphology of the basement roof. The compilation of the results of the conducted studies with the materials of the previous geological and geophysical studies made it possible to create a 2D model of the geological structure consistent with the structure of the electrical conductivity to a depth of about 10 km and to determine the main phases of the tectonic development.

2. Methods

Comprehensive studies included the analysis of the electrical characteristics of the Earth’s crust and structural and geological studies within a wide band along the MT profile (Fig. 2) and the compilation of the obtained data and materials of the previous geological and geophysical study.

1. Analysis of geophysical data.

Based on the software processing of MT-sounding data along the profile "Karabuk" [3] with a length of about 70 km (30 pickets with a step of about 2 km), a 2D model of deep electrical conductivity was constructed. The components of the electromagnetic field were measured using the Phoenix Geophysics MTU-5 wide-range measuring stations according to the methodology adapted at the RAS Scientific Station for the mountain conditions of the Tien Shan [3]. The degree of two-dimensionality of the geoelectric structure and the correctness of calculations were estimated using additional parameters. The interpretation of the resulting model of deep electrical conductivity was carried out taking into account other geophysical materials, in particular, the data of the seismic survey (reflection and refractions wave methods) [4, 5].

2. Structural and geological studies.

The studies included detailing the geological map in the coordinates 75.0 - 75.4°E and 41.1 - 41.6°N, tracing the key horizons, fixing the changes in the thickness of layers and formations, constructing detailed structural and geological sections and lithological columns along the valleys transverse to the strike of structures. In order to correctly construct the deep parts of the sections, the deformation structures of the sedimentary cover of the depressions and the morphology of the peneplenized surface of the Paleozoic basement were analyzed. The structures of Cenozoic disintegration in Paleozoic rocks (faults, fracture systems, cataclase zones) were traced on satellite images and studied in outcrops, their syngenetic nature to the structures in the sedimentary cover has been verified.

The whole complex of the obtained data served as the basis for the construction of a general geological section that crosses the geodynamic system NBA from north to south and reflects the structures of the sedimentary cover and the basement surface.

3. Results

The geoelectric model of the Karabuk profile revealed the peculiarities of the electrical conductivity of the Earth's crust layer to depths of more than 40 km. Due to the small step of the location of the pickets, the structure of the upper crust is determined in the most detail to a depth of 10 -15 km. At this level, there are differences in the conductivity of intermountain depressions and uplifts, where the Paleozoic rocks come to the surface. Within the depressions, especially the Naryn one, within the near-surface layer which has a relatively low conductivity (10 – 50 ohm/m), gentle wave-like conduction zones (5-15 ohm/m) are common, corresponding to the bedding in the Cenozoic cover. The deeper horizons of the crust and the Baibichetoo uplift are characterized by a high contrast of the conductivity structure with large high-resistance massifs (more than 600 ohm/m), stretched vertically.
with a lateral deviation in one direction or another. In the near-surface layer, high-resistance blocks are sometimes framed by arc-shaped conductive zones (less than 10 ohm/m), possibly reflecting structural and rock inhomogeneities arising during the Hercynian Orogeny. The electrical structure of the middle and lower crust is characterized by a steep or inclined orientation of elongated arc-shaped arrays contrasting in conductivity, where high-resistance arrays (presumably the least fragmented) are bordered by conductors (filtration or mineralization zones).

The structure of electrical conductivity clearly reflects the regional boundaries of the layers of the Earth's crust with different density characteristics, which were independently determined by seismic sounding methods (Fig. 3, left). The upper crust under the Cenozoic cover above the density section K1 (which approximately corresponds to the earthquake hypocenter layer) is characterized by an alternation of objects elongated in the vertical plane with contrasting conductivity (Fig. 3, right). It can be assumed that such a conductivity structure reflects the macroblock fragmentation of the crust by the Hercynian faults, which were activated from the very beginning of the Alpine continental collision. Comparability of the results of sounding the earth's crust under study by independent geophysical methods is an important criterion for the objectivity of structural information.

Figure 3. Comparison of geophysical data of the Earth's crust sounding of the NBA system. On the left is a fragment of the MANAS seismic profile MOV-OGT according to [4], on the right is the "Karabuk" MTS geoelectric profile [3]. The scale and binding of the sections are the same. The wave velocity (density) boundaries (K1, K2, M) from the MANAS profile were removed to the geoelectric section.

The main results of structural studies are displayed on the map and the resulting profile. It can be noted that the folded deformations and faults within the depressions are localized within the extended linear zones, which are usually expressed by elevation of the relief (Fig. 4). Some of these zones (with significant block displacements) are identified with active faults of regional rank, many of which inherit Paleozoic tectonic sections within the Paleozoic basement. We determined the kinematic characteristics of the zones by analyzing structural parageneses.

Within the Naryn depression, the axis of the principal compressive stress σ1 (perpendicular to the axial surfaces of the folds) is flat and is oriented to the NW, obliquely to the largest sub-wide deformation zones with fold-thrust paragenesis. Such a geometry of the structure in plan indicates a transgressive kinematics of deformations with a dextral (clockwise) displacement component along the main faults. For the Atbashi depression, where the extension of the thrust zones and folds practically coincides, we can assume the condition of general horizontal NNW compression, and for some zones - sinistral transpression.

Tectonic structures corresponding to the previous stage of the development of depressions are obscured by later intense deformations. The early deformations can be judged by the change in the total thickness of the sedimentary cover or individual formations, the location of the structures of the depression's bottom. The backstage positions of uplifts, as well as local troughs in the Naryn and Atbashi
Figure 4. Structural geological map of the Karabuk transect (the geological basis is the State Geological Map 1:200000, detailed by the authors).

1 – Quaternary deposits, excluding sharpyldakskiy retinue (Q2-4); 2 – sharpyldakskiy entourage (Q1); 3 – the upper Naryn Suite (N2nr3); 4 – the average of the Naryn Suite (N2nr2); 5 – the lower nurinskoy Suite (N2nr1); 6 – top of the Kirghiz Suite (P3–N1kr2); 7 – the lower the Kyrgyz Suite (P3–N1kr1); 8 – Paleozoic basement; 9 – main faults: a – shifts and discharges, b – thrusts; 10 – the axis of the folds: a – anticlinal, b – sinklinali; 11 – tectonic zones; 12 – attitude of layers; 13 – detailed structural and geological profiles; 14 – position of the principal geological profile and pickets of the MT-profile "Karabuk".
depressions (according to geophysical data) indicate the left-shift component of the displacements at the stage of subsidence and sedimentation [5, 6], which is confirmed by kinematic indicators in the deformation zones of the Naryn River valley [7].

However, we emphasize once again that the most intense deformations of the basement surface and Paleogene-Neogene deposits occurred at a late stage of development, which began at the boundary of the Neogene and the Quarter. At this stage, the central uplift, blocked up to this point by a thin cover of sediments, turned into a chain of ridges, where Paleozoic rocks appeared on the surface. At this time, fold-thrust parageneses began to form inside the depressions in linear zones of intensive strain. These are typical ensembles of structures that arise during the deformation of sediments inside sedimentary depression under condition of compression or transpression.

The data on the near-surface structure of the depressions were generalized on the main geological section crossing the NBA ensemble from north to south approximately along the meridian of 75.2°E, along the line of the MT profile (Fig. 5). The section was constructed taking into account the style of deformations and data from measurements of thickness of sedimentary cover in different parts of the depressions. The available data on the depth of the Paleozoic basement surface based on the materials of previous geophysical study and drilling [5, 6] and new MTS data were used in the deep parts of the depressions.

The fundamental differences noted above in the structure of the electrical conductivity of the basement and the cover made it possible to detail the morphology of the bed of the depressions. The geoelectric section on the roof of the Paleozoic complex in the Naryn depression is in good agreement with the data on the near-surface structure and with the data of seismic exploration [5]. The depression has an asymmetric structure - its bed is deeper in the northern part, where the thickness of the cover probably reaches 5 km. The steep northern slope of depression is complicated by thrusts, which are elements of a typical tectonic ensemble for the orogenic depressions of the Tien Shan [8-11]. Along a steep reverse fault (thrust) or as an overturned prontrusive fold, Paleozoic rocks push over the sedimentary strata, which are deformed in the front of the main reverse fault and forms the fault-related folds ensembles.

Figure 5. Compilation of structural and geophysical data (B) and the general geological section of the Naryn-Baybiche-Atbashi system along the "Karabuk" profile (C). Relief profile with an enlarged vertical scale (A) is at the top (dotted line – channel of the Karabuk river). 1 – Paleogene-Neogene sediments; 2 – Paleozoic basement; 3 – faults; 4–5 – position of the basement roof according to geophysics seismic data: 4 – according to S A Chekina [5], 8 – according to [6].
The deep structure of the Atbash depression is not interpreted so unambiguously. The MT profile crosses it in the southwestern part, where the cover is intensively deformed and the numerous thrusts and the tectonic slides take place. This complicates the interpretation of the seismic profiling data and explains the ambiguity of determining the depth of the depression by different researchers. A high-resistance object was identified on the MT profile in the central part of the depression. It elongated vertically and inclined under the Atbashi ridge; it can be interpreted as the roof of the basement, similar to the Baybichetoo uplift. Not far from a high-resistance object, 10 km to the south from the profile, Paleozoic rocks come to the surface, but directly on the section line they are covered by tectonic slides of the Neogen sediments (the Naryn suite) of considerable thickness. Low electrical conductivity of the near-surface layer in the region of the Kumbel Ridge is caused by the predominance of coarse-grained rocks here, which are no different from the base rocks in conductivity.

4. Conclusions
* For the first time, a complex of coordinated structural-geological and magnetotelluric studies was conducted on the geotransect covering most of the central segment of the Middle Tien Shan. The characteristic of the surface structure and deep structure studied for the key object of the Tien Shan - the geodynamic triad "Naryn Depression–Baibichetoo Ridge–Atbashi Depression".
* Two types of structural patterns of the electric conductivity have been identified, corresponding to the sedimentary complexes of the cover and the folded-metamorphic complexes of the basement. Sedimentary rock complexes in depressions have a high electrical conductivity and subhorizontal structure. The upper crust above the K2 density layer is characterized by an alternation of rocks volumes with contrasting conductivity, elongated vertically. The recorded structure of the field confirms the presence of steep zones of fluid permeability and fragmentation, noted earlier in seismic profiles [4], and probably corresponding to the Paleozoic structures of fragmentation of the Earth's crust, activated during Alpine orogeny.
* Based on the joint analysis of geological and geophysical information, a two-dimensional structural and geological model was created. The model reflects the position and shape of the surface of the Paleozoic basement (pre-depression alignment surface) and the infrastructure of the sedimentary cover of the depressions.
* It is shown that the features of Cenozoic structural ensembles are consistent with the kinematic model [7], which assumes a two-stage development of the system: the long-term deflection and sedimentation phases under conditions of left-hand transtension (1) and the phases of relatively short-term deformation and relief formation under conditions of meridional compression or right-hand transpression (2).

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