Manifestation of "flower structures" in geophysical models of the Central Tien Shan

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Abstract. Based on the analysis of deep geophysical (geoelectric and seismic) models of the Central Tien Shan, structures with the morphology resembling the crown of palm trees or the shape of a flower were identified. Geoelectric models are considered along a series of regional profiles (75º, 76º, 76º 30'). The length of the profiles intersecting all the main tectonic structures of the Tien Shan ranges from 75 to 250 km. Particular attention was paid to those zones of concentrated deformation, where the tectonic regime combines the conditions of shear and lateral compression (transpression zones). The structure of the collisional - accretionary wedge of the Atbashi zone in the distribution of electrical and velocity characteristics of the geological section is considered. Geoelectric models plotted along a series of regional profiles identify areas of increased electrical conductivity and show “flower structures”. The integral picture of the distribution and morphology of zones of increased electrical conductivity in the segments of the Earth's crust of the Central Tien Shan may reflect a discretely localized manifestation of palm tree structures due to the evolution of transpressive suture zones during the Hercynian and Alpine tectogenesis.

1. Introduction

The Tien Shan (Figure 1) is characterized by the presence of extended zones, which are accompanied by fault structures with feathering wings, expressed both on the surface and at depth [1-4]. In this case, the morphology of structures often resembles the crown of palm trees or the shape of a flower; therefore, these zones are called “palm-tree structures” or “flower structures” [5,6]. With the development of geophysical methods that make it possible to study the deep structure of the upper parts of the Earth's crust (Figure 1), more and more such structures began to be found. Often oil and gas deposits are associated with these structures, which determine the importance of investigation of them. First of all, flower structures were described (and then reproduced experimentally) in the zones of transpression.

Transpression is a tectonic regime that combines the conditions of shear and compression. The indicators of the transpression zones are uplift-strike-slip faults and the so-called flower structures (palm tree structures) (Figure 2), which are packets of tectonic plates squeezed out of the shear zone [5,6]. Transpression zones are formed when the shear zone experiences additional lateral compression. Here they represent a system of uplifts or thrusts with uplift of central blocks (“positive flower structures”) (Figure 2). Later, the system of faults with the lowering of the central blocks in the transtension zones was called "negative flowering structures". Zones of concentrated deformations are...
characterized by considerable length, the presence of fault structures of various ranks and intense internal structural and material processing of rocks and the presence of shear deformation [2,4]. The aim of this work is to analyze deep geophysical (geoelectric and seismic) models of the Central Tien Shan for the manifestation of “flower structures” in them.

Figure 1. Scheme of geophysical profiles intersecting the Atbashi accretionary - collisional zone and the Issyk-Kul microcontinent: TF - Talas-Fergana, LN - Nikolaev Line, CT - Central Terskey; AI - Atbashi-Inylchek, GK - Gissar-Kokshaal; ChI – Chu-Ily. The shaded areas show the ancient microcontinents: Issyk-Kul and Atbashi

2. Data and method
Geoelectric models are built on the basis of data obtained by the method of magnetotelluric sounding (MTS), one of the deepest electromagnetic methods based on the study of the natural alternating electromagnetic field of the Earth. One of the advantages of the method is the detection of hidden fault structures that do not appear in the sedimentary cover, but are zones of increased fracturing and fluid permeability of the basement and are manifested by anomalies in geophysical fields. Field observations by the MT sounding method were carried out using MTU instruments from Phoenix Geophysics Ltd (Canada) [7-8] in the range of periods from 0.001 to 1600 s. The measurements of the three components of the magnetic field were carried out using standard MTC-50 induction sensors oriented to the north, east and vertically. The components of the electric field were measured by dipoles 50 m long, grounded by non-polarizable electrodes with manganese-carbon chips, developed and patented by the Research station of Russian Academy of Sciences. Data processing was performed only in one-point mode. Mathematical processing of the obtained data of field sounding along the profiles was carried out using the standard software package SSMT-2000 (Phoenix). As a result of processing, the frequency dependences of the components of the impedance tensor and the Wiese-
Parkinson matrix were obtained in the range of periods from 0.001 to 1600 s. Based on the results of MT data processing, estimates of the impedance tensor, tippers (Wiese vectors) and the horizontal magnetic tensor were obtained in the MT-Corrector program (developed by the Russian company North-West) according to the standard research scheme for mountainous region. 2D smoothing inversion of MT data was performed using Rodi-Mackie software. The program implements the nonlinear conjugate gradient method, which tries to minimize the objective function, which is the sum of the normalized data residuals and model smoothness [9].

3. Result
Models built on the basis of MTS data indicate that the above-described structures take place in geoelectric sections. This is due to the fact that the MTS method has proven itself very well in the study of the structure of fault zones of thrust and underthrust types in orogenic areas, as evidenced by numerous publications [2, 4, 10, etc.]. Upon closer examination of regional geoelectric models, the systems of tectonic faults in large shear zones also have a complex shape in vertical sections, resembling a flower (Figures 2-5).

Figure 2. Comparison of geophysical models (top panel) with a schematic section of the accretion-collisional zone according to [11]. The geoelectric structure of the Earth's crust along the MT-profile of 76°E, grad. through the Tien Shan [12] is shown in color. The seismic model is represented by Vp velocity isolines for the considered area. 1 – faults, 2 – seismic velocity isolines, 3 – main fault, 4 – MTS points. Fault structures are plotted in accordance with [13].

In Figure 2, attention is drawn to the alternation of zones of contrasting values of electrical resistivity from a few to the first thousand Ohm*m and their confinement to deep faults. This distribution of geoelectric inhomogeneities in the section emphasizes the overall triangular shape of the wedge and demonstrates nested "wedges". Comparison of the behavior of the Vp velocity isolines for the considered area also indicates the presence of structures parallel to the wedge boundaries, which confirms the general orientation and shape of the structures observed in the geoelectric section. In this case, the nature of the distribution of geoelectric and velocity inhomogeneities is different: if the behavior of electrical conductivity has the character of alternating conductors and insulators, then the velocity characteristics (Vp) of the geological section change gradiently with depth from 5 to 6.5 km/s.
Thus, the distribution of electrical and velocity characteristics of the geological section reflects the structure of the collisional - accretionary wedge of the Atbashi suture zone, which has a good correlation with the model of exhumation of eclogites in northwestern China [11]. The model proposed by Gao and Klemd is similar to the structure of the Tarim-Tien Shan junction zone in both geoelectric and seismic models [10]. The relationships between anomalies in electrical conductivity, velocity characteristics, and seismicity of the lithosphere in the Central Tien Shan are described in detail in [14, 15].

Figure 3. Deep geoelectric model along the Son-Kul profile (75º) [17]. 1 – major faults, 2 – faults, 3 – flower structure, 4 – ridges, 5 – isolators, 6 – conductors

In the geoelectric models shown in Figures 3 and 4, the key heterogeneities of the section are numbered for ease of interpretation, and in the text the numbers are indicated by numbers in brackets. In general, the model is characterized by a contrasting distribution of objects with different resistivity. For the upper part of the section, there is a good correlation between the high-resistivity blocks of the model and mountain ranges - Moldo-Too (4), Dzhumgal-Too and Kyrgyz (8) (Fig. 4), with the exception of the Son-Kul-Too ridge. The most contrasting subvertical geoelectric structure is the Nikolaev Line zone (1) (Fig. 3), which is characterized by abnormally low resistivity (2-10 Ohm ∙ m) with a depth of 45-50 km and is the border between the Northern and Central Tien Shan.

The main elements of the geoelectric structure of the Central Tien Shan (Fig. 2-5) are inclined and sub-vertical conducting bodies (for example, Fig. 4, objects 1-4), often flattening at depth, and high-resistivity objects (for example, Fig. 4, objects 6-9). The upper part of the sections is also characterized by a lenticular form of conducting structures, consisting of tectonically isolated blocks of various sizes and electrical conductivity. At the same time, the morphology of these structures often resembles the crown of palm trees or the shape of a flower and can be traced down to depths of 15-20 km. Anomalies of electrical conductivity presented in geoelectric models in the form of sub-vertical conducting objects can be caused by zones of dynamic influence of faults and cataclasis of granites. In Figures 4 and 5, in the conductive structures of the constructed geoelectric sections, evidence of the reflection of the boundaries of the Issyk-Kul (object 3 - Karabuk model) and Atbashi microcontinent.
Fault zones are clearly identified in the presented sections in the form of subvertical conductive inhomogeneities with different slopes of their lateral boundaries.

**Figure 4.** Deep geoelectric model along the "Karabuk" (75º) profile [16]. 1 – major faults, 2 – faults, 3 – ridges, 4 – conductors, 5 – isolators, 6 – flower structure

**Figure 5.** Deep geoelectric model along the "Maly Naryn" (76º30’) [7]. 1 – major faults, 2 – faults, 3 – flower structure, 4 – ridges, 5 – isolators, 6 – conductors
Taking into account the existing geophysical models of the deep structure and the wide development of fold-thrust structural ensembles of the Central Tien Shan, it is obvious that the compression or transpression mode prevailed in the late tectonic evolution of the earth's crust (Fig. 3-5).

4. Conclusion

The data presented in the research on the deep geoelectric structure along a series of regional profiles (75º, 76º, 76º 30') indicate a fundamental similarity in the structure of geoelectric sections for different regions of the Central Tien Shan. The presence of structures in the geophysical sections, the morphology of which resembles the crown of palm trees or the shape of a flower, reflects the geodynamic setting of the Late Alpine stage of tectogenesis. It is noteworthy that the flower structures in geoelectric models have significant differences for the upper part of the section (inside the Cenozoic cover and in the Paleozoic basement) and the depths of the middle-lower crust, which can be explained by the peculiarities of the rheology of rocks. The distribution of electrical and velocity characteristics of the geological section reflects the structure of the collisional - accretionary wedge of the Atbash zone and the Issyk-Kul microcontinent.

In general, the integral picture of the distribution and morphology of zones of increased electrical conductivity in the segments of the earth's crust of the Central Tien Shan may reflect, in our opinion, a discretely localized manifestation of "palm tree" associated with development Cenozoic tectogenesis of regional fault zones [17].

5. References

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