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The structure of the lithosphere in the junction zone of the Southern Tien Shan and Tarim according to magnetotelluric sounding data

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Introduction

Multi-disciplinary geological-geophysical investigations of modern orogeny areas substantially extend the understanding of the fundamental geodynamic processes. During several decades the Central Tien Shan region serves as an ideal polygon for such studies including the network seismological monitoring, regional seismic experiments and extensive array of electromagnetic soundings [1]. Passive and active seismic profiling on the MANAS transect [2, 3] has made a significant contribution to the studies of the South Tien Shan and Tarim plate junction zone - an area subjected to intense Late Paleozoic tectonic movements, activated in the Cenozoic in response to the Eocene India-Eurasian collision and is still prone to serious seismic hazard (fig.1a). Broad-band and long-period magnetotelluric sounding data collected at the southern part of the MANAS transect (fig. 1b, [4]) have complemented seismic ones as a source of unique information on the deep structural and material properties of the crust and upper mantle as well as on their thermal and fluid regimes. 2D inversion of the broad-band MT data ensemble has been performed in [4] with the smoothing code [5] and generally confirmed the idea of Tarim plate subduction under South Tien Shan, which was suggested in [3]. The current research is an attempt to increase resolution of MT inversion with a help of alternative approaches [6-8] and to get integrated ideas on stably resolves features of the geoelectric section which can be used as specific constraints on the tectonic pattern of the junction zone under study and geodynamic hypotheses of its evolution [2, 3 and others].

Data, methods and results

The geophysical transect MANAS extends from south of Kashgar, China, to the south of Bishkek, Kyrgyzstan, crossing the whole Tien Shan orogenic belt in transverse direction to the main strike of the ranges. In 2008 at its southern 140 km long segment 40 broad-band MT soundings (with remote base and average step along the profile about 3 km) were performed to complement seismic studies. MTU-5 (produced by «Phoenix Geophysics Ltd», Canada) and MT-24 (produced by EMI Center, Russia) equipment were used. Additional 5 long-period LIMS soundings were available at the profile from previous field campaigns [1, 4]. The observations were processed by Phoenix tools and transfer functions were estimated in “local” and “remote reference" regimes.

Complex geological structure of orogenic areas, Tien Shan in particular, introduces rigorous requirements to the geophysical methods applied including not only detailed observation grids and precise processing but also effective analysis of the data to define the dimensionality of the interpretational model and finally - application of high resolution and stable inversion tools.

The main efforts of our current round of Aksai-Artush sounding data analyses are directed to the increase of the MT inversions’ resolution with preserving their robustness. At the first stage we tried another then in [4] 2D MT inversion approach, following basic methodical principles, which were elaborated in RS RAS and IPE RAS [1, 6] to overcome general problems of high mountain MT data caused by irregular observation grids, topography effect, strong near surface heterogeneity of conductivity distribution, multi-level anomalous geoelectric structure of crust and upper mantle of orogens.

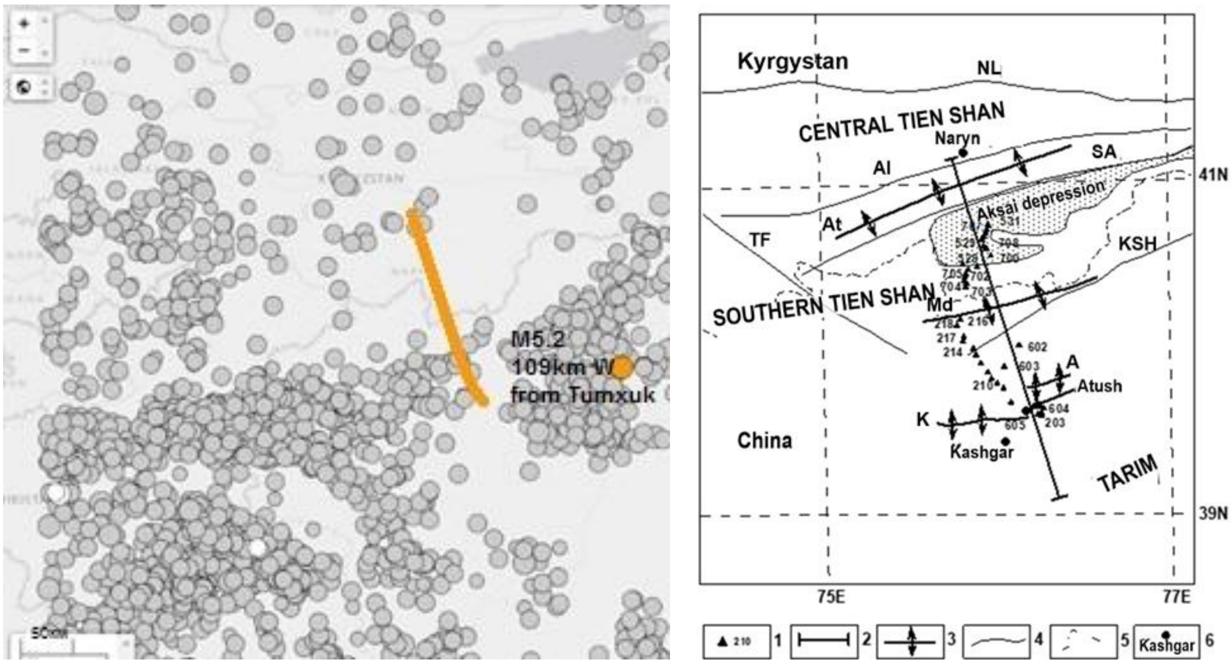

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Fig. 1. *(a) - the seismicity map for the South Tien Shan and Tarim plate junction zone (M>2.5, for the time period from 2000y to the end of 2023, from USGS WEB site) with the most recent M5.2 EQ (November, 2023), China-Kyrgyzstan border, Issyk-Kul lake and schematic line of Aksay-Atrush profile; (b) - a map of the magnetotelluric measurements' area: 1 - MT points; 2 - MT profile inversion line; 3 – axes of anticlines; 4 – main faults; 5 - border of Kyrgyzstan with China; 6 – large cities. Anticlines: A - Artush, At - Atbashi, K - Kashgar, Md - Maydantag. Faults: AI - Atbashi-Inylchek, KSH - Kokshaal, NL - Nikolaev Line, TF - Talas-Fergana, SA - South Atbashy*

We applied adaptive 2D inversion code [7] which is based on detailed piece-wise continuous model parameterization and permits to reconstruct both smooth and sharp conductivity boundaries as well as precise accounting for the topography. The specific weighting strategy considering different sensitivity to targets and "immunity" to 3D distortions of the different data components helptd to emphasize the influence of generally 2D and less galvanically distorted data subset (construction of quasi-2D ensemble of data for profile inversion by penalty application for local 3D effects). The scheme of successive partial and multi-component profile inversions was implemented in the course of MT inversions.

The preferred model obtained by applying the above-mentioned approach is presented in fig. 2b. The following features of the lithosphere of the collision belt under study are identified:

- presence of a low resistivity inclined zone that can be associated with a steep underthrusting (delamination as proposed in [2]?) of Tarim tectonic sheets under Tien Shan;

- presence of the conductive mid-crustal zones/layers and local conductive lenses (saline fluids/partial melt from 1-2% to 7%), corresponding to lower velocity ones in seismic images [3] and thus testifying the fluid nature of both kind anomalies (in [8] seismic velocity anomalies are believed to demonstrate rheological layering and chambers of partial melt);

- correlation of the crustal seismicity distribution with the areas of the resistive (consolidated) blocks in the vicinity of conductive structures (not shown now in fig.2, while well seen in fig. 3).

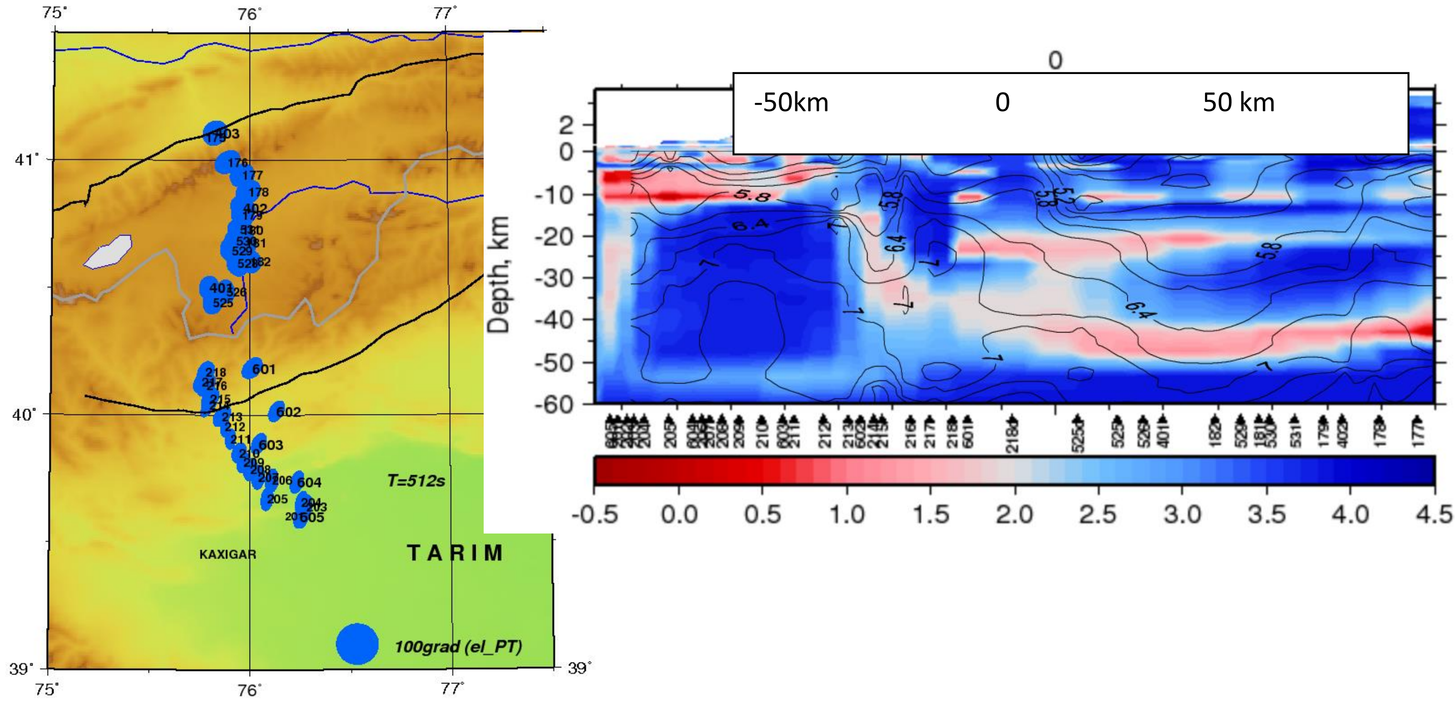

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Fig. 2. *The results of the first approach of Aksay –Artush MT data analyses: (a) - the Phase Tensor ellipses at T=512s in the sounding sites of the Southern segment of MANAS transect with major fault lines reflecting quasy-2D behavior of the long-period MT data (blue arrow – direction of the Tarim plate subduction proposed in [3]; grey curve – Kyrgyzstan-China border line); (b) – the results of bi-modal weighted inversion of MT data ensemble (Ro_Hp, Arg_Z_Hp, Ep; RMS=1.87) at Southern segment of MANAS transect (fig.1, left) in detailed piece-wise continuous model approximation (the color scale in lg Om·m) and overlapped by isolines of Vp values (in km\s) from [3]. The correspondences of the features of geoelectric and seismic cross-sections testify to the fluid nature of these anomalies.*

The second attempt to gain stability with adequate resolution of the deep geoeletric structure of the studied area consisted in application of 3D approach to the inversion of available quasi-profile MT data ensemble. We have carried out 3D focused inversion with well known ModEM tools based on the recently invented divergence-free algorithm of forward problem solution [9]. The preliminary inversion model (fig. 3, RMS= 1.89, with 2.5% error floor) is well agreed with results [4] and in general structural elements - with the model in fig. 2.

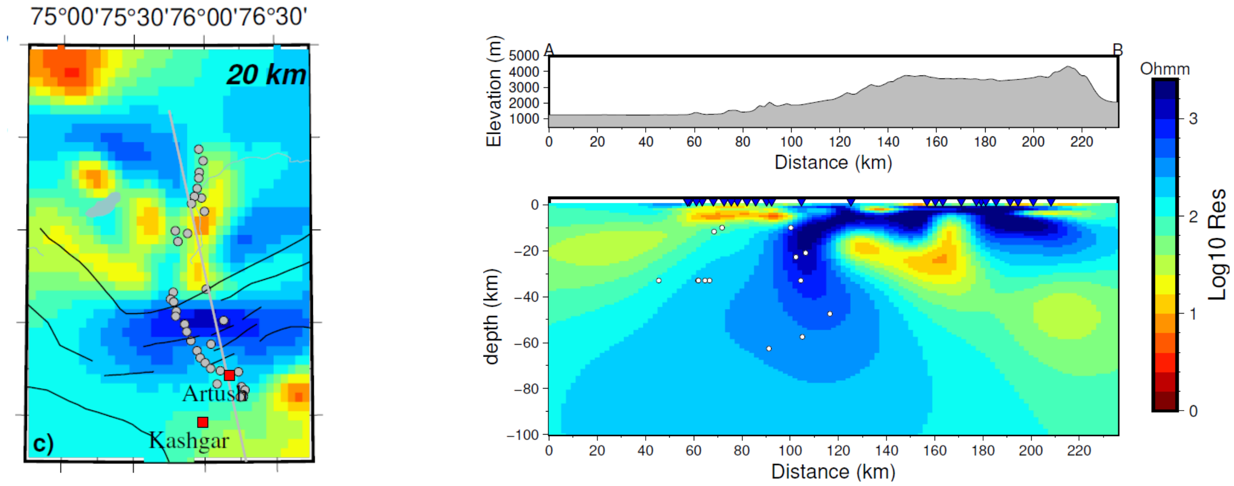

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Fig. 3. *The inversion result obtained in the frames of the second approach: (a) - 20 km depth slice of the preliminary volume resistivity model, obtained in the course of 3D focused inversion of Aksay-Artush profile MT data (RMS= 1.89) with grey circles as MT sites used; (b) - the cross-section of the volume model along the profile line with EQs hypocenters (see fig. 1a).*

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The underthrusting/dragging a thinning layer of conductive sediments under the resistive Tien Shan crust implies the possibility of imposing anisotropy on the conductivity structure, in a similar way as it happens with the elastic properties of a moving rock layer sandwiched between two rigid constraints - the case when seismic anisotropy occurs [10]. To verify this option we are testing the third approach which seemed to be promising for resolution increase - anisotropic MT inversion based on the algorithms and program codes [9, 11].

Some results of the resolution studies for the models obtained in the frames of new inversion approaches are discussed and the stably resolved features of all available conductivity ross-section are integrated.

The results of our study may be helpful in verification of the geotectonic/dynamic ideas regarding the Tarim-Tien Shan junction zone structure as well as in constraining the corresponding seismotectonic patterns.

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