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Deep Geoelectric Structure of the Earth's Crust and the Upper Mantle of the Pamir–Alai Zone

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Abstract—Results of profile magnetotelluric (MT) and magnetovariational (MV) soundings of the Pamir–Alai zone are presented. The problems of construction of a 2D geoelectric model of the lithosphere of the Pamir–Alai zone and its characteristics are considered. The results of the MT sounding inversion indicate the existence of a zone of lateral plastic flow in the Earth's crust beneath the Alai depression, which manifested itself as a conductive lower-crust structure traced for at least 200 km in the E–W direction along the strike of the Alai depression. Analysis of the relationship between the parameters of the geoelectric structure and the seismicity distribution in the study region has revealed a spatial correlation between the location of the hypocenters of $K > 11$ earthquakes that occurred in the Pamir–Alai territory and the geoelectric structure of the Earth's crust in this region. New data on the tectonic stratification of the Earth's crust have been obtained, which permits us to supplement and refine the existing geological and geophysical data on the deep structure of the Pamir–Tien Shan junction zone. Conclusions about the nature of anomalous crustal conductivity in the Alai basin have been drawn.

Keywords: magnetotelluric sounding, geoelectric model, electrical conductivity, seismicity, lithosphere, Pamir, Tien Shan

INTRODUCTION

The research station of the RAS (RS RAS) has been studying the deep structure of the Earth's crust and the upper mantle of the Tien Shan intracontinental orogen and the adjacent regions for over 35 years; a number of publications are much in evidence (Batalev et al., 1989, 1993, 2011; Trapeznikov et al., 1997; Rybin et al., 2001, 2005; Makarov et al., 2010; Rybin, 2011; and others). MT/MV sounding plays an important role in the investigation of the Tien Shan deep structure by providing information about the geoelectric nonhomogeneities distribution as far as the depths of the lower crust and the upper mantle (Trapeznikov et al., 1997; Bielinski et al., 2003; Park et al., 2003; Berdichevsky et al., 2010). The study is confined to the reliable definition of deep faults behavior in the Earth's crust (Bataleva, 2005; Bataleva et al., 2005, 2006a,b; Rybin et al., 2008; Batalev et al., 2013) and to the conclusions concerning the nature of electrical conductivity (Trapeznikov et al., 1997; Rybin, 2011; Batalev, 2013). The geoelectric depth model of the Central Tien Shan lithosphere has been constructed on the basis of the results obtained; moreover, the modeling results have been generalized with the data of geological-geophysical exploration (Trapeznikov et al., 1997; Bataleva et al., 2004; Buslov et al., 2004, 2007; Rybin et al., 2005, 2011; Makarov et al., 2010; Batalev et al., 2011; Rybin, 2011; and others).

The study of the characteristics peculiar to the geodynamic interaction system of the two largest orogens, such as the Pamir and the Tien Shan, is recognized to be the issue of central importance and interest. The convergence area of the Pamir and Tien Shan will be conventionally called the Pamir–Alai zone. The zone is comprised of the Trans-Alai Range, the high-mountain Alai depression and the adjacent Tien Shan ranges propagating to the north from the Fergana valley (Fig. 1). It should be noted that geoelectrical investigations were conducted in several stages in the territory of the Alai depression zone. Firstly, in the second half of the XX century, the area was the subject of intensive prospecting by various electrical exploration techniques with the objective to study the neotectonic structure (Belousov, 1997). The exploration was carried out by the party of the Alai Kirgiz geophysical expedition with the application of sounding at depth of 3–8 km, and it allowed the prospectors to define the main characteristics of the geological structure of the upper part of the profile. The prospecting data were partially used for constructing regional geological profiles. The next exploration stage was related to the 90s of last century and marked by the introduction of deep electromagnetic prospecting by MT sounding technique with the use of MT-PIK systems developed by the RS RAS. 19 sounding cycles were performed on two sections, but the work had to be delayed. A new exploration stage is connected with the TIPAGE project implementation. The project implied the fulfillment

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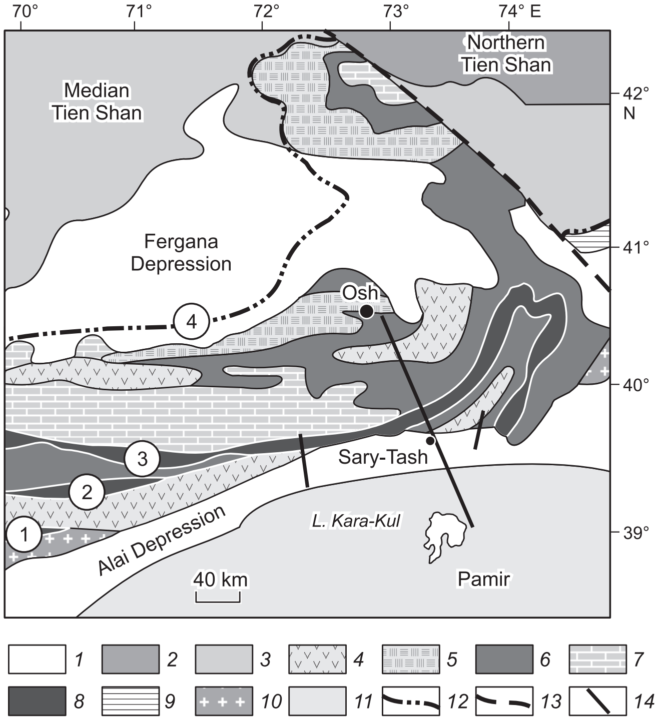

Fig. 1. Tectonic structural elements of the Pamir–Alai zone (according to (Leonov, 2012)). *1*, Mesozoic–Cenozoic sedimentary cover of the Tien Shan orogen; *2*, Northern Tien Shan; *3*, Central Tien Shan; *4–9*, Southern Tien Shan; *4*, exposure of intrabasin volcanic ridges rocks (parautochthonous), *5*, exposure of intrabasin volcanic ridges rocks in allochthonous bedding, *6*, rocks exposure in relation to: deepwater depressions, the slopes of volcanic uplifts and shallow water areas, *7*, rocks exposure from the microcontinents sedimentary cover, *8*, concentrated deformation zones, *9*, undivided structures of the Southern Tien Shan; *10*, Sulterek and Southern Hissar blocks; *11*, Pamir structures; *12*, suture of the paleo-Turkestan Ocean; *13*, Talass–Fergana thrust; *14*, available profiles of MT/MV sounding. Circled figures: the zones of concentrated deformation: 1, Karakul–Ziddinsk, 2, Zeravshan, 3, Nupatau–Kurgan, 4, Southern Fergana ophiolitic suture.

of multidiscipline deep geophysical studies including electromagnetic sounding. The key exploration feature appears to be the use of the Phoenix MTU-5 high-precision digital wide-band measuring equipment, which caused a real revolution in geoelectric prospecting techniques with the application of alternating magnetic fields and its remarkable precision, low power consumption, high productivity, noise immunity and automation level.

MAIN CHARACTERISTICS OF THE GEOLOGICAL STRUCTURE OF THE PAMIR–ALAI ZONE

The region under investigation lies in the suture zone of two-fold belts: Central Asian (Caledonian–Hercynian) and Alpine–Himalayan (Cimmerian–Alpine) and appears to be a subject of unfailing scientists' interest owing to the complexity of the tectonic structure and evolution. It is standard practice to identify two evolution stages of the Tien Shan post-Paleozoic period, i.e., the platform stage (Jurassic–Paleogenic) and the orogen stage (Neogene–Quaternary). The present-day tectonic regional structure turns out to be a result of the successive lateral growth and continental lithosphere consolidation, and permanent activation of the earlier suture structures, and superimposed deformations of rheologically inhomogeneous blocks of subsurface rocks under changing dynamic conditions. On the whole, the basement consolidation the Pamir–Hissar–Alai region corresponds to the Hercynian era. However, the dominating sublatitudinal strikes of the main structural elements are a result of overlap by front of the Cimmerian–Alpine arched intraplate collisional structure of the Pamir syntaxis onto the mega-folds and strike-slips system of the same Hercynian Tien Shan strike (Burtman, 2012). The structures of late activation mostly manifest themselves along the Trans Alai and in the Alai depression, which tends to converge with the wider Tadzhik depression along the arch of the Northern Pamir thrust. The main structural elements of the basin are the Central graben, the Northern and Southern flanks. It was the Neogene–Quaternary period, which had the greatest effect on the formation of the basin structure due to its characteristic large amplitudes and a high gradient of vertical and horizontal movements. The difference in structural geometry of the Pamir and the Tien Shan, and, particularly, in the Tadzhik basin presupposes rheological weakness of the Earth's crust, which tends to be at the same level in the modern orogen period (Leonov, 2008). The base current representation of geological-geophysical structure of the Pamir-Tien Shan suture zone is obtained according to the findings of structural-geological, paleomagnetic, seismic and seismological prospecting, and also in accord with the study of present Earth's crust movements by terrestrial and space geodesy techniques (Bazhenov and Burtman, 1986; Chedinya, 1986; Sadybakasov, 1990; Coutand et al., 2002; and others). The findings of the studies provide reliably determined characteristics of subsurface structures. Nevertheless, the scope of the detailed recent studies of the Pamir–Hissar–Alai zone depth structures is severely limited. It should be noted that the constituents of the lithosphere depth structure of the Pamir–Alai territory are considered to be the fault zones which usually tend to be shown in geoelectrical profiles obtained in the time of geoelectrical exploration. Under such conditions, valuable information can be provided by detailed MT sounding technique, which findings lay the foundation of the present study.

MAGNETOTELLURIC INVESTIGATION OF THE PAMIR–ALAI ZONE

MT sounding lets prospectors determine electrical Earth's resistivity, which is known to be a physical parameter being rather sensitive to low resistance phases, such as fluids, partial melts and metal compounds. It is a well-known fact that medium electrical conductivity characterizes not only its material composition and rheological properties, but is able, at some extent, to reveal the processes taking place in different 3D scales, as follows: destruction of the upper Earth's crust, rocks hydration and dehydration, geothermal circulation, heat and mass transfer, partial melting, etc. Consequently, being based on MT data, the obtained geoelectrical profiles of the explored region lithosphere will enable researchers to trace the development of fault zones in depth, to determine characteristics of areas with higher porosity, fluid saturation and partial melting, and they also provide additional information for geodynamic constructions (Rybin, 2011).

The main methods applied in metallotelluric prospecting are the following: numerical model study and inversion of electromagnetic fields in 2D/3D inhomogeneous media. Solutions of the inverse problem of electromagnetic sounding are based on the methods of residual functional minimization in unified space of inverted data and optimized model parameters with the use of Tichonov topology concepts, robust statistics of residual functional, Gaussian–Newton nonlinear minimization or conjugative gradients. Mackie's program of two-dimensional inversion was used to implement such an approach to numeric interpretation of MT/MV sounding data (Rodi and Mackie, 2001). The basic inversion elements of MT data set prove to be: (1) tracking the effect of the observation surface relief on electromagnetic responses, (2) increase of input errors used by inversion in proportion to quantitative measures of 3D-distortion and (3) robust averaging of the set of acceptable inversion problems solutions when constructing a final model (Rybin, 2011; Varentsov, 2011).

When applied in the Pamir–Alai suture zone, the MT-prospecting technique implies the involvement both of MT-sounding based on simultaneous measurements of time variations in electrical and magnetic Earth's fields, and MV-sounding, where time variations only in magnetic field are used including the processing of experimental data at the observation station. The key feature of the described prospecting technique was the use of different-type equipment (Phoenix and GIPP) in two frequency bands—abyssal and wide-band. The SSMT2000 software was intentionally designed by the specialists of the same company for processing the data received by Phoenix MTU-5 stations. The data processing software is not based on the method of narrow-band filtering; conversely it is a correlation method-oriented version, which suggests the computing of all the functions of mutual correlation for all the components of electromagnetic field. Then Fourier transformation is done, in the result we obtain power spectra within a broad frequency range, which are recalculated into components of impedance tensor and Vise–Parkinson matrix.

For the recent years, several magnetotelluric profiles have been obtained within the Pamir–Hissar–Alai zone by efforts of the RS RAS, as follows: "Daraut-Kurgan", "TIPAGE-ALAI" and "Nura" (Fig. 1) with near N-S intersection of the main tectonic elements of the Alai depression and its mountain surroundings in the area of the Pamir–Tien Shan maximum convergence. Profile sampling interval equaled about 0.5–0.8 km, the total number of sounding cycles along "Daraut-Kurgan" profile was 9, along "TIPAGE-ALAI" profile—111 and along "Nura"—22. Five components of natural electromagnetic Earth's field were registered in MT and GMT sounding modes: Ex, Ey, Hx, Hy, and Hz. Electrical signals were recorded with dipoles, which were 50-m-long and spaced orthogonally in NS and E–W azimuths. The observation sites coordinates were determined by means of GPS. To improve the quality of MT sounding results, the technique of synchronous measurements was applied.

It is supposed that basic changes in the distribution of lithosphere electrical properties will occur in Northsouth direction within the Pamir–Tien Shan suture zone (Varentsov, 2011), i.e., along MT/MV profile lines and, consequently, across the strike of geologic-tectonic regional structures (Fig. 1). Meanwhile, it will be necessary to estimate spatial nonuniformity of the geoelectric structure of the region under study in E–W direction. The estimation procedure has been fulfilled with the use of MT/MV sounding results and series of profiles obtained in the territory of the Pamir–Alai zone.

GIPP data processing technique. To do the survey along the main "TIPAGE-ALAI" profile, GIPP software system was used; the system was developed in the Center for Technical Geoscience (Potsdam). EMERALD standard software suite was used for processing the data obtained by GIPP system. The results of processing and interpretation of MT sounding along "TIPAGE" profile are presented in the papers written in cooperation with German colleagues (Sass et al., 2011, 2014). The software for data processing focuses on calculation of mutual correlation function for all the components of electromagnetic field. Then Fourier transformation is done, in the result power spectra tend to form within a broad range of frequencies, after that they are recalculated into components of impedance tensor.

The software suite is used for processing the data of MT/MV sounding obtained in the explored region by GIPP system, which standard data processing is accomplished in two modes—"local" and "remote reference", where the latter implements new algorithm of spectral analysis (Fig. 2). Once obtained by GIPP system, components of impedance tensor and geomagnetic tipper were used in the set of input data for further numeric modeling.

Phoenix MTU-5 data processing technique. From the start of use of the Phoenix MTU-5 system for Tien Shan exploration by Mt sounding technique, we also began to apply the SSMT2000 software intentionally developed for Phoenix MTU-5 by the specialists from the same company. The program of data processing is based on correlation method but not on narrow-band filtering, which is widely applied in other program suites. According to this method, the functions of mutual correlation of all the electromagnetic field components have to be calculated. Then Fourier transformation is executed, in the result we obtain power

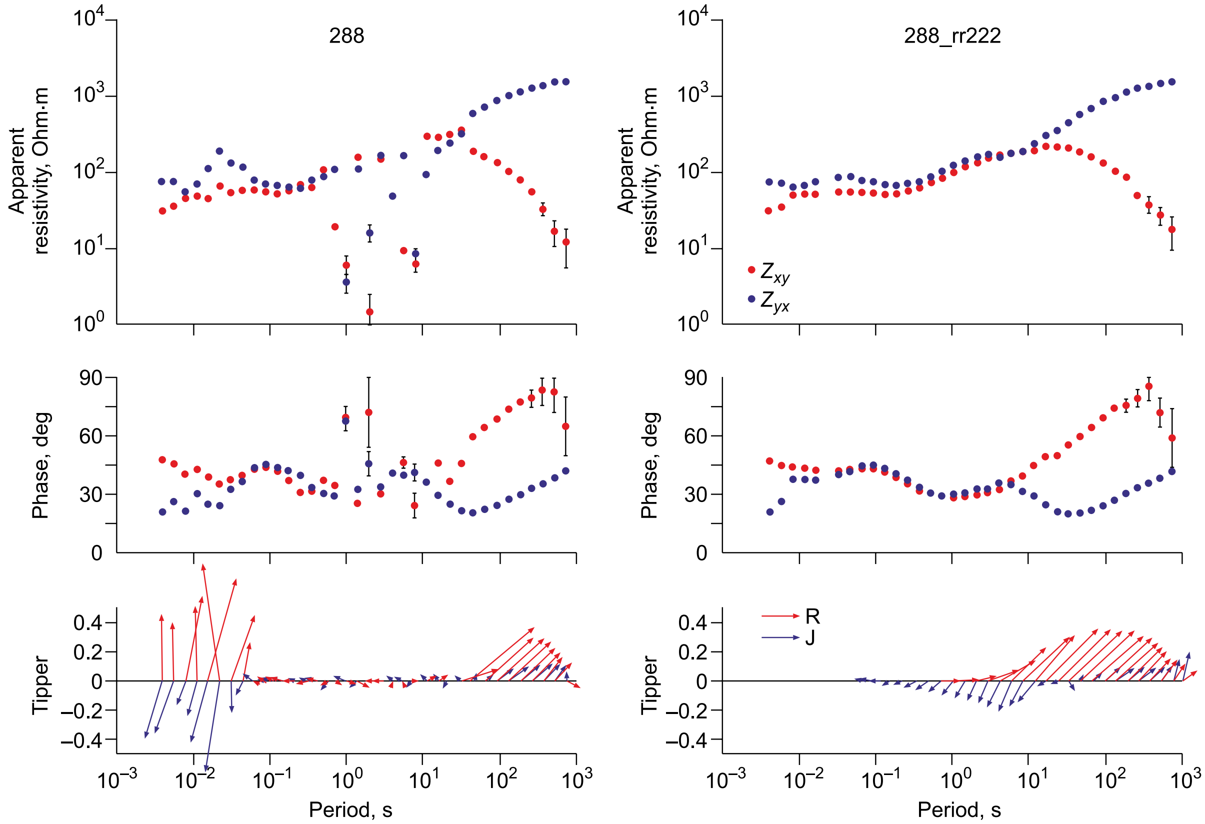

Fig. 2. Example of processing modes: "local" (left part) and "remote reference" (right part) for amplitude curves $\rho_к$, impedance phase and tippers for latitudinal and meridian directions along the "TIPAGE-ALAI" profile. Color arrows show real (R) and imaginary (J) parts of Vise vector.

spectra within a broad frequency range, which are recalculated into components of impedance tensor and Vise–Parkinson matrix (Fig. 3).

The program suite is designed for processing MT/MV sounding data, which are obtained by Phoenix MTU-5 equipment. The suite comprises the SSMT2000 program, which is executed in modes—"local" and "remote reference" (similar to algorithm used in EMERALD software suite) and implements new algorithms of spectral analysis. Here, the MT-Corrector Program is optionally used for suppressing industrial noise and smoothing transfer functions in the low-frequency range. The program was developed by the staff-members of Geophysical Surveying Company (Severo-Zapad, Moscow). For final selection of impedance estimates, specialized processing procedure implies the use of all the solutions with separable analysis of all impedance and admittance estimates. Then the program executes screening of the most "noise-contaminated" estimates, which is followed by combining and smoothing the most valid solutions for resultant curves (Fig. 4).

The MT-Corrector program package is used for browsing, estimating and editing the frequency dependences of impedance tensor components. This program package also allows prospectors to verify dispersion relations of the second order, which characterize $\rho_к$ relation and impedance phases (Berdichevsky and Dmitriev, 2009). With the use of the MT-Corrector we can also compute phase curves by corresponding frequency dependences values of the impedance module. A deviation value of observation spline and a computed value of phase curves characterize the feasibility degree of dispersion relations. For the "Nura" profile, dispersion relations of the second order are derived nearly in the whole frequency range within the accuracy of observation (Fig. 4); that leads to RMS error reduction for further procedure of 2D-data inversion.

Accuracy verification for the constructed geoelectrical models. For the models actuated by electric field and polarized *across* the axis of geoelectric uniformity (TM-mode), MT-transfer functions have closure errors or discrepancies not exceeding 20% across the module and 6° in phase for the most grid nodes.

For the models actuated by electric field and polarized *along* the axis of geoelectric uniformity (TE-mode), MT-transfer functions have higher discrepancies because the selected weight coefficients for this mode significantly exceed the error limit of the TM-mode. Small values of the MV transfer function (tippers) are obtained within the model, and they are consistent with small values (<0.1) of the experimental data, but the errors estimates are rather high because of low "signal-noise" ratio in the source data (Fig. 5).

Geoelectrical model construction. After completion of the sounding cycle on the heterogenous observation net-

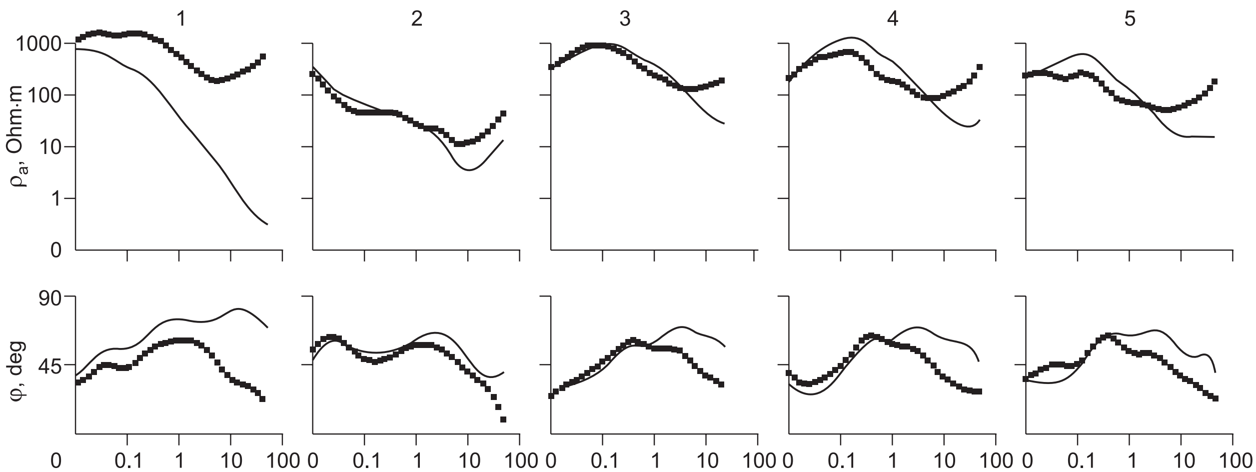

Fig. 3. Example of amplitude curves ρ_κ ($\sqrt{T}$) and impedance phase φ ($\sqrt{T}$) for latitudinal (solid line) and for meridian direction (dashed line) along the "Nura" profile. ($\sqrt{T}$) laid off on the horizontal axis is measured in $s^{1/2}$. 1—5, zoning points, from N to S.

work, a multicomponent array of estimates transfer operators (impedance and tipper) was derived, which includes one-point (local) and two-point (remote reference) estimates of the transfer function in the integrated range of periods T = 0.001–10,000 s. Quantitative interpretation was carried out on the basis of the data obtained, i.e., 2D-inversion done with the use of the Rodi–Mackie program (Rodi and Mackie, 2001), where the method of nonlinear conjugate gradients has been implemented, and the "TIPAGE-ALAI" 2D-geoelectrical model has been constructed. The model represents a structural-geoelectrical profile of the Earth's crust in the Pamir–Tien Shan suture zone longitudinally 73.4 E (Matyukov, 2013).

The input array of inverted data is comprised of: observed estimates—ρ_κ, impedance phases for two polarizations of the magnetic field, and geomagnetic tipper values indicated as Re and Im and given in 78 points on the profile, at length of 170 km for 30 sounding periods in the interval from 1000 Hz to 2000 s.

The model grid approximation includes 228 nodes and 128 layers with lateral alterations, which are smaller in size compared with the coefficient of 1.07 between any adjacent cells in order to conform to the limits imposed by the program of 2D-inversion. Most layers are assigned for the adequate representation of the topographic irregularity/relief in the model, which height alteration along the profile line will equal about 1.5 km. This detailed relief approximation is necessary to provide data retrieval at high frequencies (from 100 Hz). Having performed several test calculations, we find the magnitude of regularization parameter τ = 3.0. Error limits (weight coefficients) of inverted data are set as follows: ρ_κ module (TE-mode) 30%, ρ_κ module (TM-mode) 30%, impedance phase (TE-mode) 5°, impedance phase (TM-mode) 5°, tipper (Hz) 0.1%.

The starting model for 2D-inversion represents a medium with electrical resistivity of 100 Ohm·m up to the depth of 100 km. It should be noted that the density and geometry of grid approximation applied for the computer-aided inversion procedure, as well as the inclusion of dissection cells

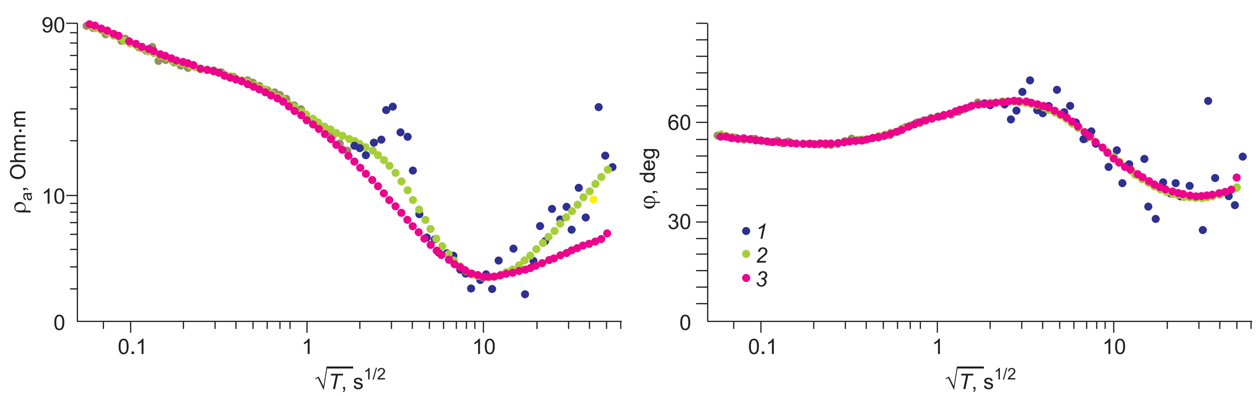

Fig. 4. Example of suppressing industrial noise and smoothing transfer functions of ρ_κ curves (upper part of the drawing), and impedance phases (lower part of the drawing), and execution control of the relations of the second order which connect amplitude curve ρ_κ and impedance phase for site No. 2 of the "Nura" profile with the use of the MT-Corrector program. *1*, points on the reference curve; *2*, smoothed curve; *3*, approximation splines with the account of dispersion relations.

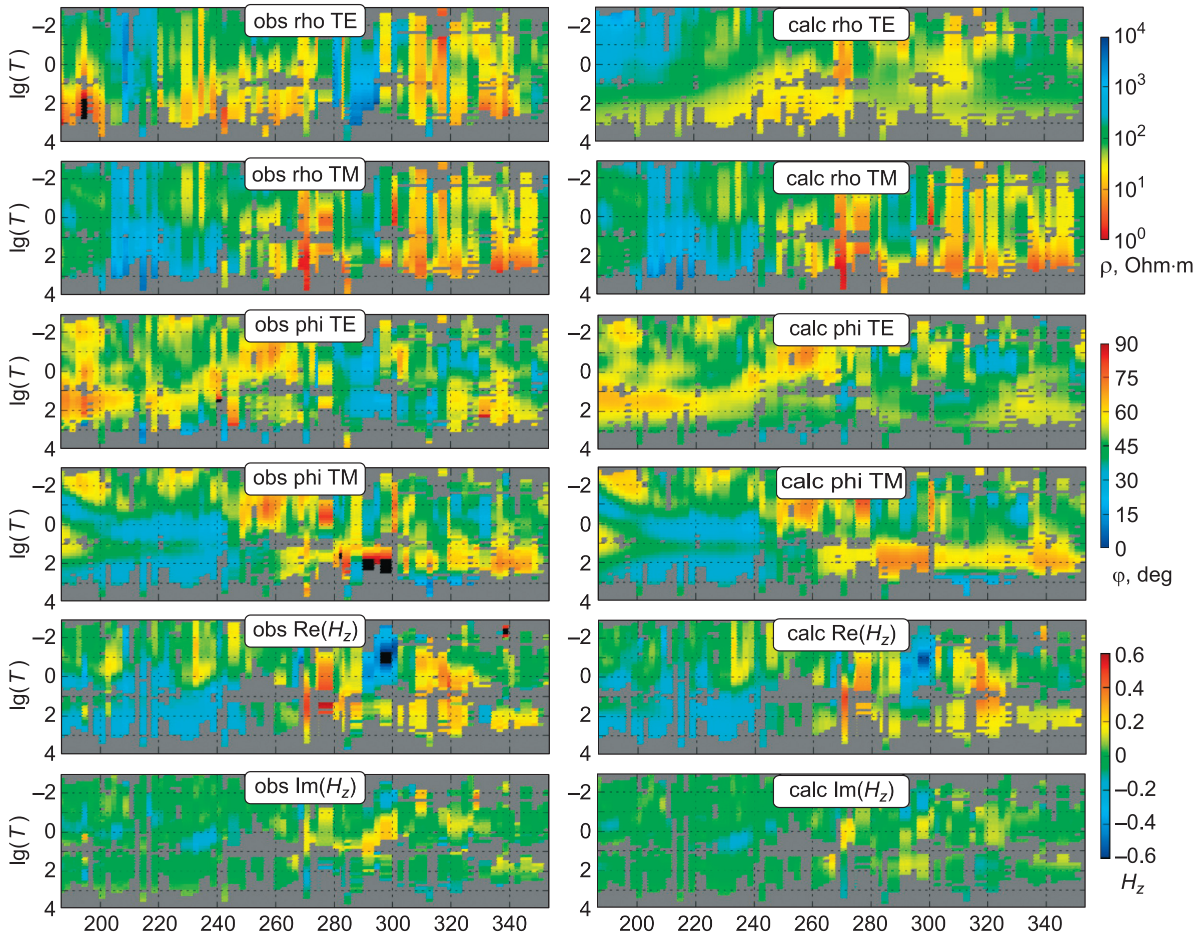

Fig. 5. Comparison of the observed parameters (left part) and model (right part) values $\rho_к$, of impedance and tipper. Horizontal axis: sounding sites numbers; vertical axis: period logarithm.

into optimization sorting will ensure smoothness of geoelectric structures construction and the lack of limits imposed on the diversified hypotheses representing deep structure of the region under study. Then sequential bimodal 2D-inversion of the multicomponent data array is fulfilled; the array is comprised of $\rho_к$ amplitudes, impedance phases and tippers for the "ALAI-TIPAGE" profile. Finally, 300 internal iterations have been carried out in the process of sequential parallel inversion of the whole input data array; data retrieval error for all the components (RMS-divergence) has totaled 1.52.

A conductor (1) with resistance of 2–3 Ohm·m is the most distinguished at depth of 15 to 30 km in southern part (in the area of Kara-Kul Lake) of the "TIPAGE-ALAI" profile (Fig. 6) on the constructed geoelectrical model. A conduction area (2) is clearly seen under the Trans-Alai Range, and it corresponds to the Main Pamir thrust. A powerful near-vertical conduction area (3) is detected under the Alai depression at depth of 100 km and it has a few branches in the uppermost part of the section at depth of 5–10 km. A near-horizontal conducting structure (4) is located in the northern part of the profile, it starts under the north slope of the Trans-Alai Ridge at depth of 80 km and ends under the Fergana depression when ascending up to depth of 15–20 km. 2D-inversion of observation data along the "Daraut-Kurgan" and "Nura" profiles was fulfilled in the same way with the use of Rodi–Mackie program (Rodi and Mackie, 2001) The inversion results are presented in Fig. 7. A linear, sublatitudinal conducting structure is being traced on all the sections obtained within the depth interval of 0–25 km; the structure corresponds to the Main Pamir thrust zone. Along with this, maximum electrical "activity" (dimensions and conductivity) of this longitudinal conductor is determined in the western and central cross-sections ("Daraut-Kurgan" and "TIPAGE" profiles). In the eastern part of the Alai zone (along the "Nura" cross-section) the width and conductivity reduction are being traced for this conducting structure. The total near-vertical direction of this conducting area (spatially assigned to the Main Pamir thrust) stays practically the same for the three cross-sections being considered.

On the nature of crust conductivity. The main objective of the study is elucidation of the nature of anomalous crustal conductivity. Interpretation of MT data combined with the results of other deep geophysical explorations and laboratory experiments will permit us to get nearer to the

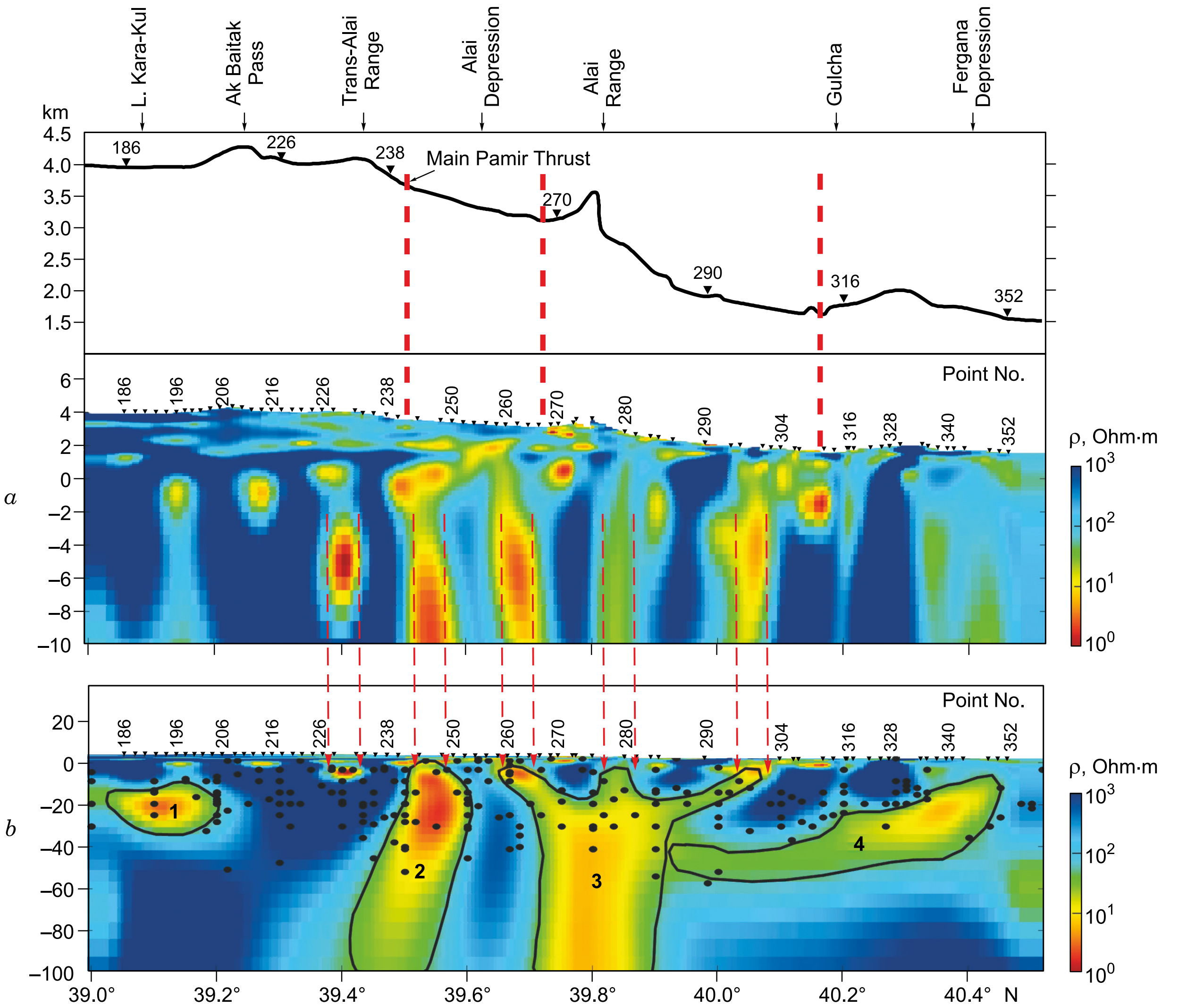

Fig. 6. Geoelectric section of the 2D TIPAGE-ALAI model. *a*, Upper part of the section, *b*, the whole cross-section. Earthquake hypocenters of energy class K > 11 along the zone with the width of ±50 km from the TIPAGE-ALAI profile line are labeled with dark circles (in accord with the data of RS NAS KR seismological network). The total number of seismic events: 102.

problem solution at different spatial—scale levels of the Central Tien Shan lithosphere. For example, the decrease of seismic velocities and simultaneous conductivity increase in the lithosphere is usually interpreted by the presence of a waveguide. This is a lithosphere conducting layer located in the middle–lower part of the Northern Tien Shan Earth's crust, which was detected by MT-sounding in the late 80s of the last century (Batalev et al., 1989). Later, a crustal conducting layer was found in the whole territory of the Central Tien Shan owing to its shallow formation (25–45 km) and significant electrical conductivity contrast (Trapeznikov et al., 1997). The findings of the explorations conducted by the Research Station of the RAS have proved that the crustal conducting layer is sporadically distributed under the whole territory of Central Tien Shan, stratification depth varies from 45 km (north) to 20 km (south), but the values of total longitudinal conductivity tend to vary from N to S within the range from 450 to 2000 S (Rybin et al., 2005). The main feature of the geoelectrical model of the Tien Shan–Pamir suture area appears to be the zone of enormously low resistance, which coincides with the northern part of the Alai depression and the Alai Range. The high conductivity of the rocks could be dependent on the occurrence of minerals possessing electronic conductivity; the most typical representatives of such rocks are known to be carbonaceous shale rocks, sulfide-containing gneisses, and metamorphic rocks that underwent a phase of low pressures, e.g., serpentized peridotite (Kulik, 2009). The bodies with electron conductivity are marked by limited distribution in the total volume of hard rocks. Nevertheless, the impact which faults-zones and the zones with high medium permeability have on the conductivity of the Earth's upper crust could be considered as one of the main factors defining the electrical structure of the geological medium. There is enough evidence for occurrence of graphitized rocks in the upper crust formations (Babadzhanov, 1986; Ashirmatov, 1990). Graphite could be

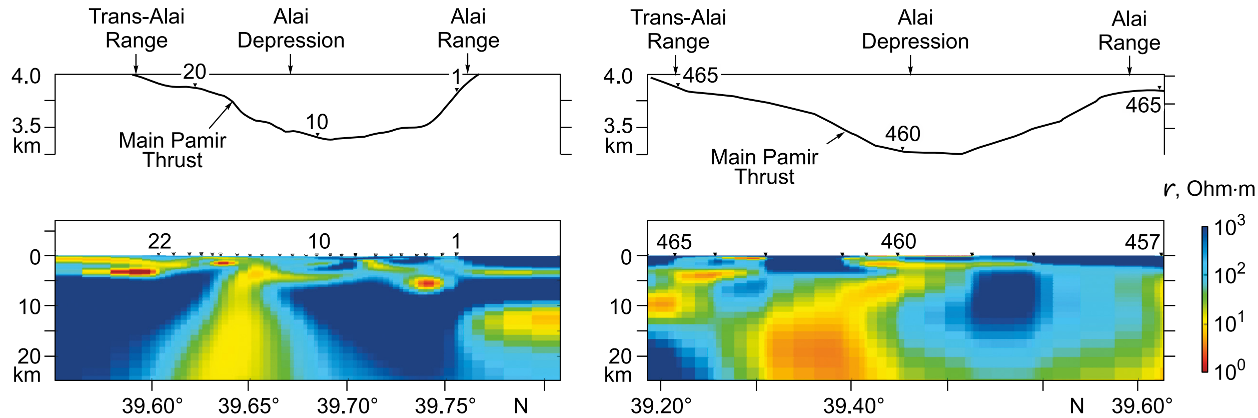

Fig. 7. Geoelectrical cross-sections along local profiles: Nura (on the left) and Daraut-Kurgan (on the right).

used as a “lubricant” in the tectonic process or appear as a product of tectonic processes. Electrical conductivity anomalies often arise in suture zones, e.g., Nikolayev’s Line (Bataleva et al., 2006b). Moreover, the occurrence of fluid conductivity should be taken into consideration, since it is peculiar to today’s tectonically active regions with high seismic intensity.

Pamir–Alai seismicity. The Pamir–Tien Shan Region, including the exploration target—the Pamir–Alai zone, almost entirely lies in the area of seismic intensity at magnitude (M) ~ 8–9 (Tectonic Map…, 1987). For the recent one hundred years over 15 earthquakes at M > 8 have taken place in this area. Thorough analysis of the map of earthquake origin allocation enables us to find out certain regularity of seismic field distribution in this territory. It is delineated from the east and the north to highlight the areas where seismic events with M > 7 were not recorded. The most epicenters of powerful earthquakes at M > 5 are regularly stretched by forming two seismogenic zones—the Northern Tien Shan and the Southern Tien Shan (Hissar–Kokshaalsky) assigned to the northern and southern suture parts of orogen with the Turanian Plate and Kazakh Shield bounding it in the north, and with the Pamirs and the Tarim Platform in the south. Seismogenic zones are spatially confined to the interaction regions of these largest tectonic elements belonging to the geodynamic system of Central Asia. Being a seismically active zone, the Southern Tien Shan is marked by abnormally high seismic intensity in the suture area of the Pamir and Tien Shen (Yudakhin et al., 1991).

The strongest earthquakes that happened in the Pamir–Alai zone include the Markansuisk earthquake (August 11, 1974; $\varphi = 39.40$, $\lambda = 73.80$, M = 7.3), the Daraut-Kurgan earthquake (November 1, 1978; $\varphi = 39.40$, $\lambda = 72.60$, M = 6.9), the Nurinsk earthquake (October 5, 2008; $\varphi = 39.50$, $\lambda = 73.64$, M = 6.9) (Mamyrov, 2014). To obtain overall seismicity estimates of the explored territory, we have to analyze background (weak) seismicity data. Let’s examine the map of earthquake epicenters in the Pamir–Alai Region (Fig. 8), constructed in accord with the materials from earthquakes catalogue prepared at the Institute of Seismology, National Academy of Sciences of the Kyrgyz Republic (IS NAS KR). Fig. 8 illustrates nonuniformity of spatial seismicity distribution in the region. At the same time the most earthquakes are seen concentrating on the narrow line delineated along the southern flank of the Alai basin. This seismically-active zone is spatially assigned to the suture area of the Tien Shan and Pamir.

Figure 9 represents latitudinal distribution by the depth of earthquakes origin of energy class K > 6; the earthquakes epicenters are shown in Fig. 8. Nonuniformity of the distribution character should be recognized; and the most earthquakes have to be assigned to the depth interval of 7–20 km.

Analysis of correlation between geoelectric structure parameters and seismicity distribution. A number of researchers managed to carry out the analyses of correlation between the parameters of seismically active zones and the characteristics of geophysical field of electrical nonuniformities in the Tien Shan Region (Kissin and Ruzaikin, 1997; Bragin et al., 2001; Rybin, 2011; Zubovich et al., 2001). The study (Kissin and Ruzaikin, 1997) gives evidence of the fact that most crustal earthquakes origins in the Central Tien Shan tend to concentrate towards subvertical conducting zone imitating fluid-saturated faults.

In the study (Bragin et al., 2001) based on comparison of depth profiles of low seismicity field and geoelectric structure of near-surface fault zones in the Bishkek geodynamic test area (Chuya basin and Kyrgyz Range), the authors come to conclusion that there are no reasonable grounds to assign earthquakes hypocenters distribution to near-surface fault zones in the territory of exploration.

Interesting conclusions are given in (Zubovich et al., 2001), where the focus is on: the deformation field, the deep structure of the Earth’s crust, Tien Shan spatial seismicity distribution, and surface geometry of the crustal conducting layer found under the Tien Shan in accord with MT-sounding data. It was determined that the most intensive horizontal Earth’s crustal deformations correspond to the areas with higher gradient of formation depth of the conducting layer

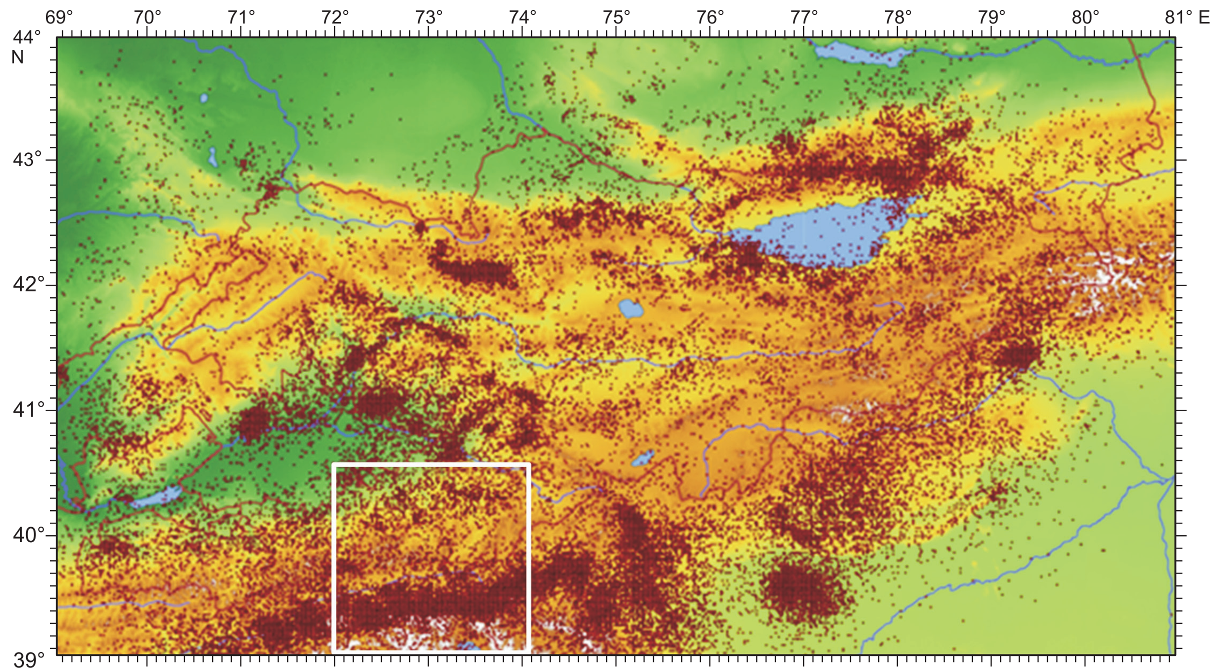

Fig. 8. Map of the earthquakes epicenters distribution (K > 6) in the Pamir–Tien Shan Region for the observation period from 1978 to 2013 (in accord with the data of RS NAS KR seismological network). The total number of seismic events: 33,631.

top and coincide with the area of higher seismic intensity. Moreover, it was determined that hypocenters of almost all the seismic events were located above the layer of higher electrical conductivity (from 7621 earthquakes of energy class K ≥ 6, only 151 earthquakes occurred in the crustal conductive layer, and 14 below it). This distribution of hypocenters is related to the brittle nature of the upper Earth's crust in comparison with the middle and lower crustal parts, which possess greater plasticity.

In (Rybin, 2011) the conclusion was drawn that the distribution of the earthquakes of energy class K > 10 observed in the Bishkek geodynamic test area could be explained by geoelectric properties of the Earth's crust, such as detected high resistance gradients due to the occurrence of high-resistivity bodies and low resistance zones, and the presence of the lower crustal conductive layer, and a conductive "channel" binding the lower and upper structures. This geoelectric structure creates favorable conditions for fluid diffusion from the lower crustal horizon up to the Earth's surface.

Figure 6 shows a geoelectrical lithosphere cross-section constructed along the "TIPAGE-ALAI" profile for the Pamir–Alai Region being explored; it also illustrates distribution of seismic origins in depth along the zone with the width of ±50 km from the profile line. Almost all the earthquake origins of energy class K > 11 are distributed above the conductive horizon. The earthquake origins localize within the high resistivity layer and noses of near-vertical conductive bodies penetrating into the upper crust. This way they tend to concentrate near the borderlines between the noses of conductive bodies and adjacent high resistivity blocks, and also

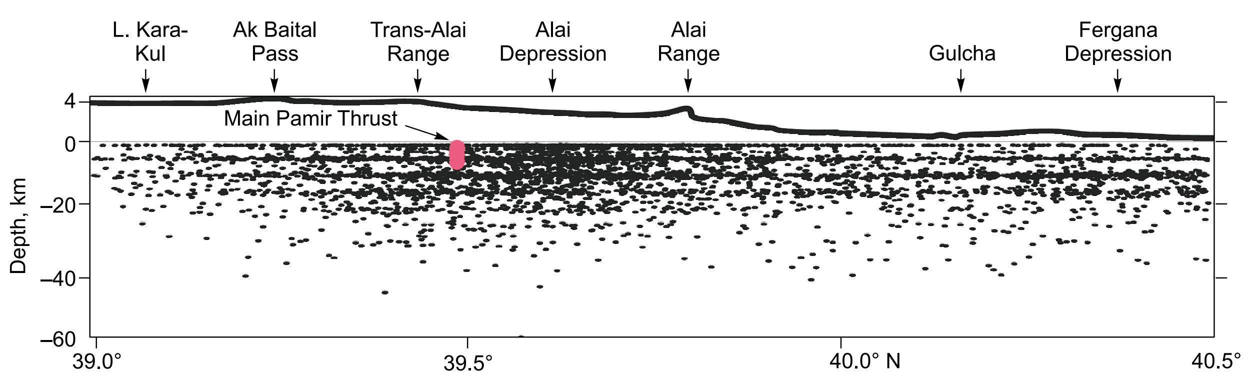

Fig. 9. Latitudinal distribution by the depth of earthquakes origins (K > 6) along the zone with the width of ±50 km from the "TIPAGE-ALAI" profile line (in accord with the data of RS NAS KR seismological network for the observation period from 1978 to 2013). The total number of seismic events: 5631.

localize in the areas with the depth drops of the conductive layer. Consequently, the contact between the blocks and bodies with contrasting geoelectrical parameters could be considered as a feasible objects of higher seismic activity.

CONCLUSIONS

Thus we can draw a conclusion that in the result of the present studies we managed to define the general features of the deep structure of the Pamir–Tien Shan–Alai depression suture area for the most part of which the occurrence of the higher crustal conductivity zone was also confirmed. The electrical conductive layer is clearly distinguished in the middle-lower crust of the northern part of "TIPAGE-ALAI" profile; this layer has several branches in the upper section part. The southern part of the conductor lies under the northern slope of the Alai Ridge at depth of ~80 km, but to the north, this conductive structure tends to ascend to the depth of 15–20 km under the Fergana valley. A powerful near-vertical conductive zone is detected under the Alai depression at depth of 100 km. The main Pamir thrust zone manifests itself in the geoelectrical profile as a deep body with lower resistance.

The analysis of the latitudinal strike of the defined conductive bodies was carried out. The bodies were constructed in 2D-geoelectrical cross-sections along "TIPAGE-ALAI", "Daraut-Kurgan" and "Nura" profiles crossing the Alai basin in the lateral direction. A linear near-latitudinal conductive structure is traced on all the profile cross-section in-depth interval of 0–25 km; the structure is spatially confined to the Main Pamir thrust. The estimates of its spatial non-uniformity were also obtained, i.e., power decrease and resistance increase from east to west.

The spatial correlation was determined for earthquakes hypocenters occurred in the Pamir–Alai territory with the characteristics of the Earth's crust geoelectric structure in the given region. The conclusion was drawn that earthquake origins tend to localize in the gradient areas in proximity to the contacts between blocks or bodies with contrasting geoelectrical parameters.

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