
New approaches in the interpretation of deep sounding data along the “Naryn” transect in Kyrgyz Tian-Shan

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SUMMARY

The “Naryn” transect of electromagnetic soundings, observed by Kyrgyz and American teams, crosses for 700 km the Kyrgyz Tian-Shan. It includes 19 long period magnetotelluric sites simultaneously observed in 3 groups and tens of broad-band soundings. The impedance and tipper responses exhibit strong two-dimensional behavior for periods up to 3 hours. However, for the greater periods the accuracy of impedances and tippers fall down. We improve the accuracy of the long period estimates with multi-site processing tools, estimate geomagnetic inter-station responses, jointly analyze the invariants of all transfer functions selecting a proper input for profile interpretation and apply multi-component inversion techniques for reliable resolution of deep conductivity section.

New impedance and horizontal magnetic tensor estimates look stable for periods up to 6-8h. The horizontal magnetic tensor principle directions are fitting well to the corresponding impedance “phase tensor” invariants. Strikes are almost profile-perpendicular; skews are quite low for periods from hundreds of seconds till 4-6h and justify the use of impedance and horizontal magnetic tensor in profile inversion in a broad period range. To create data set we rotate the transfer function data to profile direction increasing error bars at sites and for periods with sufficient deviations of strike directions and 3D distortions.

New tipper estimates also became more stable and for the periods above 3h clearly demonstrate a concerted eastward rotation of induction arrows for all the sites (source effect or/and large-scale distortions). Nevertheless, the arrows well follow the profile direction for the periods of 900s–2.5h, and to this extent tippers participate in the inversion.

The application of modern two-dimensional inversion strategies is in the progress, including the inversion of pure geomagnetic ensembles, the successive inversion of single components, and the use of static shift correcting routines within bi-modal multi-component inversion. The first inversion experiments confirm the importance of geomagnetic responses in the resolution of deep structures.

Keywords: magnetotelluric and geomagnetic soundings, tensor invariant analysis, two-dimensional inversion.

INTRODUCTION

The “Naryn” transect of electromagnetic (EM) soundings, crossing for 700 km the Kyrgyz and China Tian Shan (Figure 1), became a promising object for investigation of the deep conductivity structure of this active region. The data set acquired by Kyrgyz and American teams includes 19 long period MT sites (large circles) simultaneously observed in 3 groups with perfect quality by LIMS equipment (S.K. Park, 1999-2000) and tens of local AMTs (small dark circles, CES-2 soundings, Scientific Station RAS, Bishkek,

nineties). A valuable experience of EM data interpretation on the transect has been presented in (Rybin et al., 2000) and (Bielinski et al., 2003).

The first approach consisted in a course of successive partial inversions of long period magnetotelluric (MT) and magnetovariational (MV) data (14 LIMS stations, 1999) with regularized bimodal inversion code (Varentsov, 2002). The priority of the MV data, which become free from the distorting influence of near-surface inhomogeneties with the lowering frequencies and outline the deep structures, constitutes the main advantage of the approach. The revealed regional

crustal conductors have appeared to be well correlated with the low velocity zones detected by seismic tomography. Unfortunately, the rough block approximation of the model and limited data ensemble have restricted the resolution.

The study of (Bielinski et al., 2003), based on Rodi and Mackie's regularized bimodal inversion of 19 MT and MV long period LIMS (1999-2000) and 30 broad-band soundings' data, looks like the most comprehensive approach. However, resulted "mosaic" structure of high and low conductive bodies still contains artifacts and reflects instability of this preliminary inverse problem solution, which was started from a homogeneous conductivity distribution in the upper 150 km.

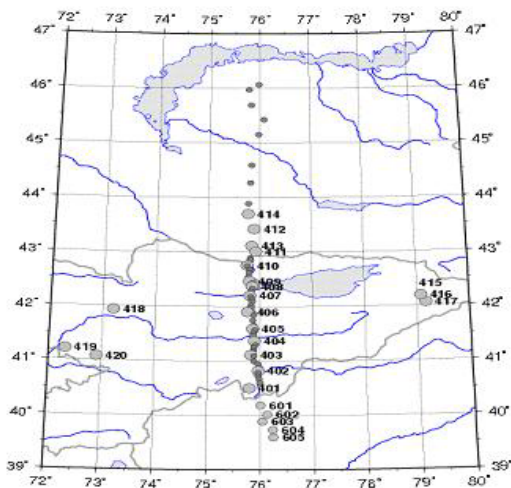


Figure 1. The "Naryn" transect. The large grey circles show long period MT sites and small dark circles - local AMTs.

The presented paper describes new developments in the rational complex of "Naryn" sounding data analysis, which are elaborated by "Naryn" Work Group to increase the reliability and resolving power of the EM method on the transect and finally to get new assumptions on the deep geoelectric structure of the Tian Shan region.

The primary step, done to achieve higher resolution, consisted in compiling of a new data ensemble, adequate in accuracy, comprehension and dimensionality to the goals of the study and modern requirements to the profile inversion quality.

The new methods of synchronous sounding data processing (Varentsov et al., 2003; Varentsov and Sokolova, 2004) were applied to construct the horizontal magnetic tensor (M) responses and to verify and improve available long period impedance (Z) and

tipplers (Wz) estimates, which together with conditional local broad-band Z and Wz data have completed the wide range multi-component profile data set.

The dimensionality and principal directions analysis for these transfer operators were done with a help of the phase tensor (Caldwell et al., 2004) and M tensor (Varentsov and EMTESZ-Pomerania WG, 2004) decompositions. It was approved that the most part of the impedance and horizontal magnetic tensor data are well satisfied to 2D approach in the whole frequency range considered, while the tipper data above 2,5-3 hour seriously deviate from the general direction of EM field polarization correspondent to the sub-latitude regional tectonics.

The general strategy of the 2D inversion implies the combination of the interactive successive partial inversions approach (Dmitriev et al., 2003) and the joint robust multi-component inversion (Varentsov, 2002), verifying and complimenting each other. The both approaches are based on the assumption of the priority of the geomagnetic and impedance phase data in the inversion course.

NEW APPROACHES TO "NARYN" EM DATA PROCESSING

The original tipper and impedance estimates were obtained with standard equipment software and adapted A. Chave's code (Rybin et al., 2000).

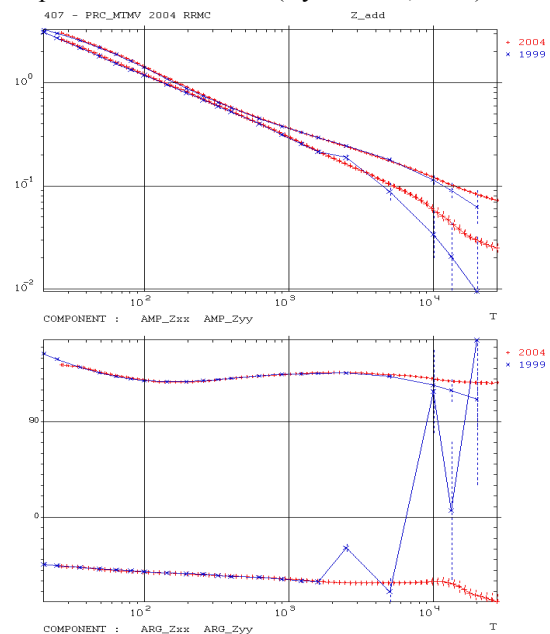


Figure 2. The comparison of the original processing results (1999) for site 407 with the new ones (2004), obtained in RRM mode: upper panel - the amplitudes of the additional impedance Zxx and the lower panel - the corresponding phases.

We have reprocessed LIMS data basing on the analysis of multi-site data records in estimation of local

impedances and tippers as well as synchronous geomagnetic operators in *Multi-Remote Reference* modes (MRR, robust averaging of several *Remote Reference* estimates for different *remote* sites, (Varentsov et al., 2003). MRR stacking offered an extra dimension for statistic averaging and improved the stability of responses at the longest periods.

In general, “Naryn” data are characterized by low level of noises, but in a number of sites a new sorting strategy based on the control of horizontal magnetic field spatial homogeneity (RRMC method, Varentsov and Sokolova, 2004) became useful and increased the accuracy of the estimates.

The comparison of the primary Z estimates (1999) for site 407 with the new ones (2004), obtained with a help of RRMC and MRR methods shows how the accuracy of estimation increases (Figure 2). The effects in additional impedances are observed very often and help to obtain later the stable invariant analysis results.

MT/GDS DATA SET ON “NARYN” TRANSECT

Local transfer operators

The ensemble of local transfer operators along “Naryn” profile includes for today long period impedances and tipper data (for 19 LIMS sites with the increased accuracy of the estimates) and broad-band impedances at 47 AMT sites. The combined range of this data set covers the diapason of 0.003-32680s. The data reflect a wide spectrum of inhomogenities on the different structural levels of geoelectric section.

Inter-station transfer operators

The “Naryn” data set was significantly extended with estimating of the inter-station geomagnetic responses: horizontal magnetic tensor M , $H(r) = M(r, r')H(r')$, and vertical S_z (regional tipper), $H_z(r) = S_z(r, r')H(r')$, where r is the local site and r' - the base one. These synchronous operators were reliably estimated for the periods from 20 up to 32680s for 12 LIMS sites with RRMC technique for two reference bases: 410 (for 10 sites of central synchronous array) and 411 (for 4 northern ones). The base sites were selected as the most close (about 20 km) sites from two synchronous arrays. These sites are situated in the “quite” (unanomalous) part of the profile and have similar tipper responses so in a first approximation they may be referred to as unified (common) base.

The pseudo sections of Mxx amplitude component of the horizontal magnetic tensor M presented in Figure 3 (top) and regional tipper S_z (amplitudes of the real induction vectors, bottom) show intensive and well correspondent in both responses short and long period

anomalies reflecting near surface and deep conductive structures of the Nikolaev-Line fault zone.

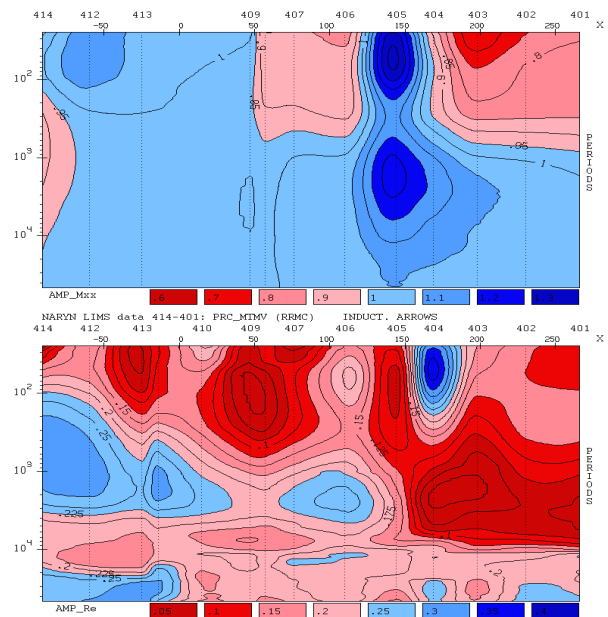


Figure 3. The pseudo sections of the amplitudes of Mxx component of the horizontal magnetic tensor (top) and of the real induction vectors for the regional tipper S_z (bottom).

INVARIANT ANALYSIS

Phase tensor (PHT) and horizontal magnetic tensor (HMT) decompositions (Caldwell et al., 2004; Varentsov, EMTESZ-Pomerania WG, 2004) became the preferable instruments of the invariant analysis in the study. Their results are essentially less dependent from the galvanic effects (compare with conventional “amplitude” transformations in Figure 4).

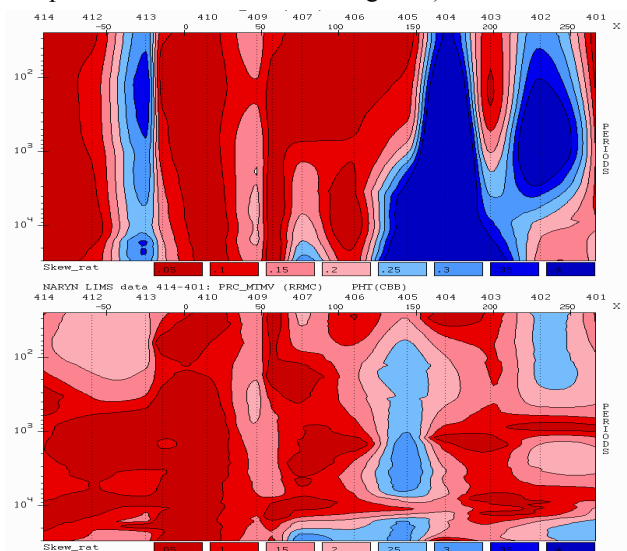


Figure 4. The pseudo sections of the impedance (top) and the phase tensor (bottom) skew data.

The invariant analysis shows that the skews in most of sites are quite low for periods from hundreds of seconds till 4-6h, strikes are almost profile-perpendicular. HMT principle directions are fitting well to correspondent impedance “phase tensor” invariants. Figure 5 illustrate (top and bottom panels) that Z and M data are rather well satisfied to 2D approach in the whole frequency range considered, while the tipper data above 2,5-3 hour (induction arrows in the middle panel) deviate from the general sub-meridional direction correspondent to the regional EM field polarization caused by regional tectonics. We apologize to the readers for the arrows pointing “from the conductor” in this Figure and below.

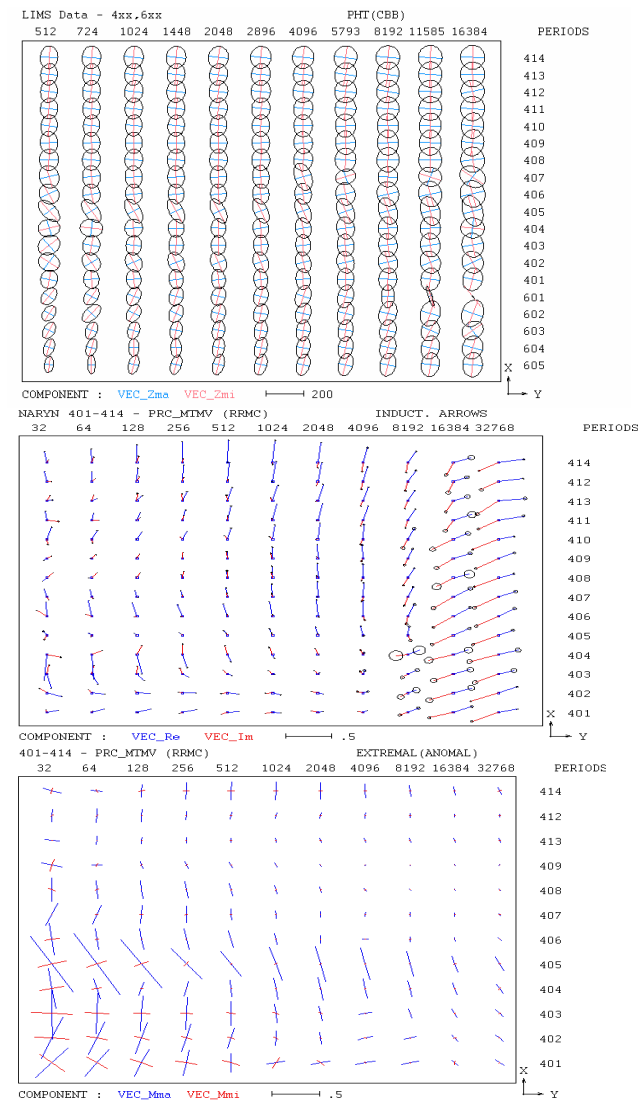


Figure 5. Vector diagram of max (blue) and min (red) impedances according to (Caldwell et al., 2004) (top); real (blue) and imaginary (red) induction vectors (middle) and anomalous horizontal magnetic perturbation vectors (bottom). Horizontal axes show the periods and the vertical ones – sounding sites along “Naryn” profile. The linear scale length is also shown on the bottom of the panels.

PROBLEMS OF THE LONG PERIOD DATA

The regular sublatitude direction of the induction vectors at daily harmonics at “Naryn” profile and in the surrounding area of Kyrgyz Tian Shan (Figure 6) are most probably due to Sq-source effect, nevertheless the regional 3D distortions may also take place. Somehow the long period behavior prevents the usage of Wz data in 2D inversion for the periods more then 2.5-3h.

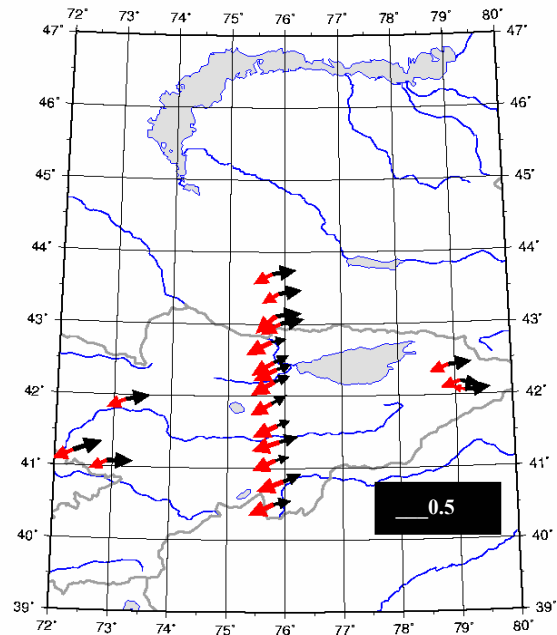


Figure 6. The map of real (black) and imaginary (red) induction vectors for T=32860s at “Naryn” profile and in the surrounding Kyrgyz Tian Shan region. The linear scale length is shown.

The presence of significant vertical component in the external field causes the problem for the application of the traditional plane-wave paradigm for the interpretation of long period Z and M data at “Naryn” profile in spite of their manifest 2D character and regular behavior (compare the polar source effect in BEAR sounding, Sokolova et al., 2004).

In the same time, high stability of the impedance amplitude/phase (dispersion) relations in a wide frequency range (Figure 7) and even approaching the MV global curve by MT ones at some “Naryn” sites suggest optimism.

The problem of an adequate approach to the interpretation of long period impedances at “Naryn” profile definitely needs further investigation. The estimation of the generalized (6-component) Z tensor (Dmitriev and Berdichevsky, 2002) will be the next step to clarify the situation. The regional 3D test

modeling with planar and nonplanar sources might be the following one.

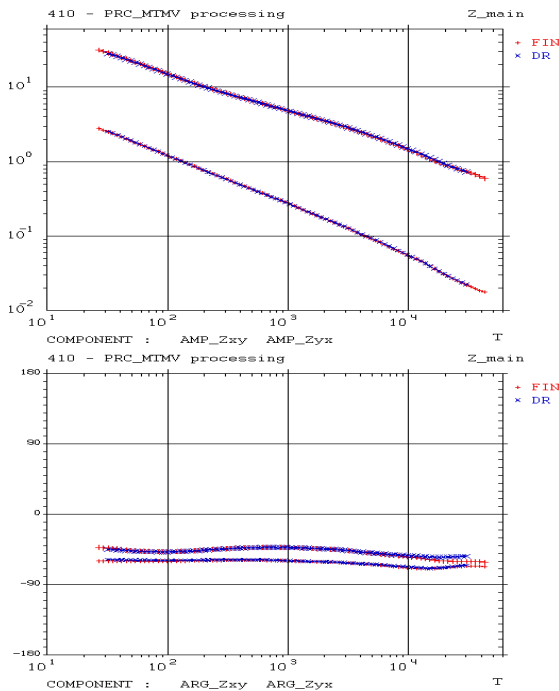


Figure 7. The dispersion relations for the main impedance estimates at site 410: **FIN** – frequency dependencies of initial responses and **DR** – their dispersion relation transforms.

INVERSION WITH THE PRIORITY OF THE GEOMAGNETIC DATA

Thus, the complete ensemble for profile inversion at “Naryn” transect includes the following amplitude and phase data: impedances (20-10000s) for both polarization; along profile tipper (900-10000s) and horizontal magnetic tensor (20-10000s) components. To create quasi-2D data set we rotate the transfer functions to profile direction increasing error bars at sites and for periods with sufficient deviations of strike directions and 3D distortions. High frequency Z and Wz data (0.003-20s) as well as Z and M data for the periods 10000-32680s may be used optionally with especial caution.

Our experience shows the efficiency of the interpretation scheme based on successive partial inversions of the data ensemble components with the priority of phase and geomagnetic data and reasonably chosen starting model (Berdichevsky et al., 2003).

The main advantage of MV data is that with lowering frequency the near-surface distortions of the magnetic field attenuate and vanish, and hence do not spoil the information on the deep structures. So, we avoid the difficulty associated with static shift of the apparent

resistivity curves, and the geoelectric constructions become more reliable.

Some current results are shown in Figure 8 (in the end of the text). Here and after we will use a new and promising regularized inversion technique, based on block and piece-wise continuous approximation of a conductivity media and specified by a variety of the resources for the solution stabilization (Varentsov, 2002). At the final stages of the interpretation this techniques will be used in multi-component bimodal scheme, applying static shift correcting routines.

CONCLUSIONS

Basing on the improved transfer operator estimates and the results of their invariant analysis, the multi-component data ensemble for profile bi-modal inversion for the “Naryn” transect have been created. The ensemble incorporates impedance amplitude and phase data, tipper and horizontal magnetic tensor components. Each data component is supplied with the updated weights, reflecting both the deviation from 2D structure (based on skew and strike angle parameters), the estimation accuracy and the inversion priorities. The applied inversion scheme suggests the priority of the phase invariants (in the whole frequency range) and of the geomagnetic data (in the middle period range) as they are more protected from disturbing subsurface galvanic effects.

The application of the elaborated 2D inversion strategies is on the way. The first experiments with separate TM/TE impedance and single tipper inversions confirm the importance of geomagnetic responses in the resolution of deep structures. The progress in the “Naryn” EM data inversion we connect with the application of the powerful inversion technique (Varentsov, 2002), combining the advantages of the traditional “block” parameterization with modern “scanning” schemes for the arbitrary conductivity distribution in the selected “windows” of the section.

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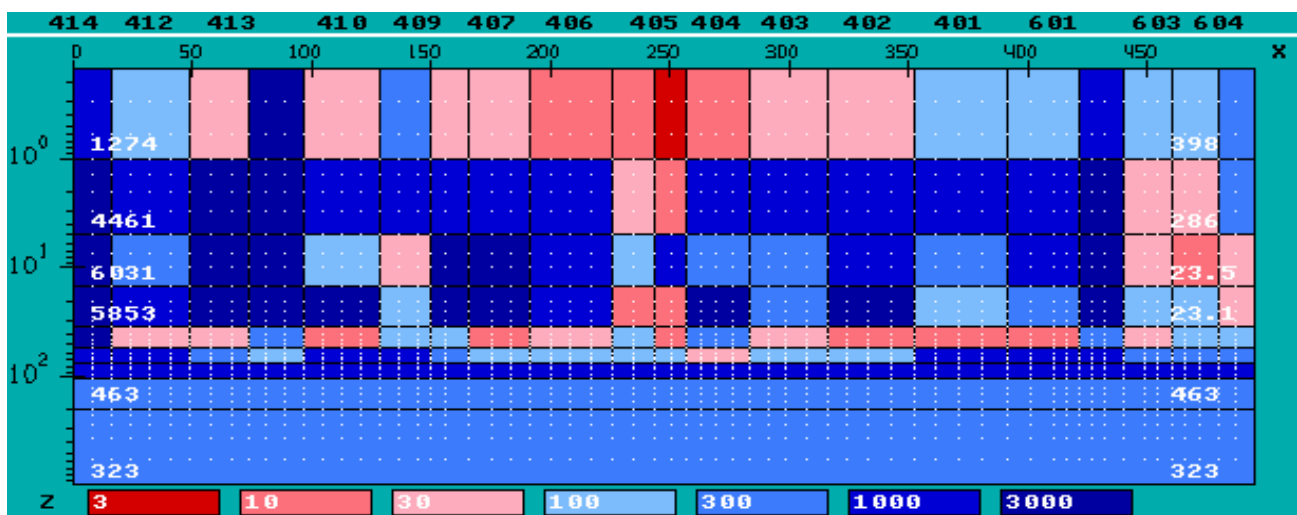


Figure 8. The geoelectrical section along "Naryn" transect obtained as a result of regularized inversion of the tipper data according (Varentsov, 2002). Re Wzx values at 19 sites in the frequency range of 25-1600s were inverted with the result of the same data REBOCC inversion being chosen as the starting model. The vertical scale shows the depth; horizontal scale – the distance along profile and sounding sites; the resistivities of the section are given in Omm. In the resulted model the sub-horizontal regional crustal conductor at the depths 30-40 km is distinguished as well as a sub-vertical conductor correspondent to Nikolaev Line fault zone (around site 405) and crustal conducting feature on the depth about 10 km in China part of the profile.