# Chapter 13

# Regional Magnetotelluric Explorations in Russia

V.P. Bubnov[1], A.G. Yakovlev[1], E.D. Aleksanova[1], D.V. Yakovlev[1],
M.N. Berdichevsky[2] and P.Yu. Pushkarev[2]

[1]North-West Ltd., Moscow, Russia
[2]Geological Faculty of Moscow University, Russia

## 13.1. INTRODUCTION

Electromagnetic (EM) geophysical methods (telluric current method, magnetotelluric sounding, frequency sounding, and transient sounding) have been used in the erstwhile USSR to study a deep structure of sedimentary basins and of the consolidated crust since the 1950s. Tectonic schemes of the principal sedimentary basins of the USSR were constructed and several large hydrocarbon deposits, for example, the Urengoy gas field, were discovered using the telluric currents method and magnetotelluric soundings, in combination with other geophysical methods. In the 1970s and 1980s, extensive magnetotelluric data characterizing the electrical conductivity of the Earth's crust were collected, and maps of crustal anomalies of electron-conducting and fluid origin were constructed. A review of major results obtained up to the 1990s is presented in Berdichevsky (1994). The review shows that a strong scientific community of researchers, applying EM methods to study the Earth, appeared in the country.

In the 1990s, due to economic problems, EM investigations were reduced. However, an abrupt expansion began in 2000 (Berdichevsky et al., 2002), caused by the depletion of established resources and increase of prices for hydrocarbons and other mineral resources.

---

Methods in Geochemistry and Geophysics, Volume 40
V.V. Spichak, Editor

ISSN: 0076-6895
DOI: 10.1016/S0076-6895(06)40013-5

Nowadays, EM methods, ensuring an exploration depth of more than 100 m, are widely adopted in Russia in three main fields: regional exploration; oil and gas prospecting; and solid mineral prospecting.

Regional surveys are conducted at the request of the Russian Ministry of Natural Resources, while hydrocarbon and other mineral prospecting is being mainly funded by private companies holding licenses for particular regions. During recent years, the third area of application associated with studies of the upper few 100 m by means of the high-frequency (audio) magnetotelluric method has been developing rapidly. Audio-magnetotellurics proved to be one of the most efficient geophysical methods for the exploration of ore minerals and kimberlite pipes (Alekseev et al., 2004).

Regional geophysical land surveys in Russia are performed along separate profiles ranging from a few hundreds to several thousand kilometers in length and running through deep boreholes. The locations of the most extensive profiles, called geo-traverses, are shown in Fig. 13.1.

Investigations along regional profiles provide information about the deep structure of vast regions and help solve applied tasks such as the prognosis of oil-and-gas content in sedimentary basins and the location of promising solid mineral zones. In active tectonic regions, data required to study geodynamic conditions and to predict seismic activity are collected.

The combined application of geophysical methods is characteristic for regional surveys. The combination includes CDP (common-depth-point) seismic, EM, gravity and magnetic prospecting, and other methods. Seismic prospecting plays the

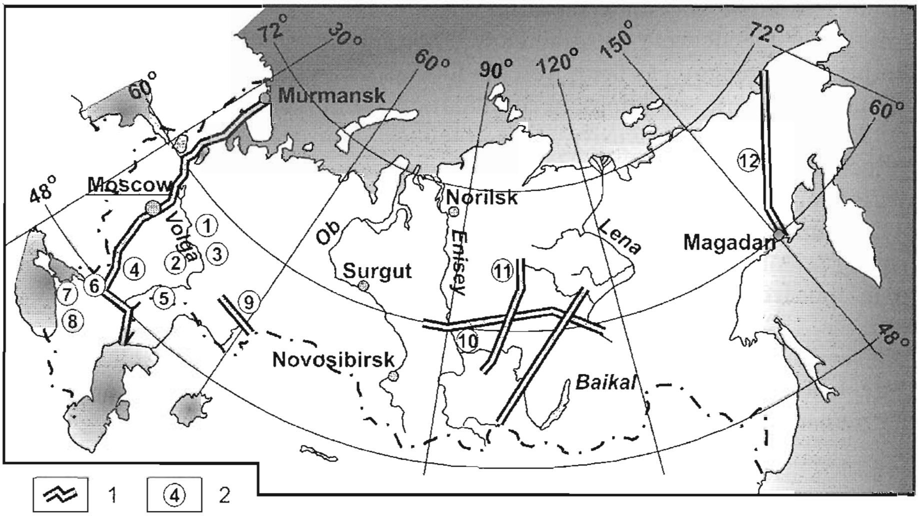

Fig. 13.1. Location map of geotraverses (1) and regions considered in the paper (2). 1 – Soligalich aulacogen, 2 – Tokmov arch and Melekes depression, 3 – Kotelnich arch and Kazansko-Kazhimsky aulacogen, 4 – Voronezh anteclise, 5 – Pre-Caspian syneclise, 6 – Karpinsky swell, 7 – Western Caucasus forelands, 8 – Central Caucasus, 9 – "Uralseis" profile, 10 – 1-SB profile, 11 – 3-SB profile, 12 – 2-DV profile.

leading role – in most cases it determines the location of geological boundaries rather precisely. Other methods, in particular EM, supplement this data with information about the physical properties of rocks characterizing their lithology, fluid content, rheological state, etc.

The total length of regional profiles studied by EM methods each year is about 3000–4000 km, while the spacing between the sites is 1–3 km.In the European part of Russia, surveys are performed mainly by the State enterprise Spetsgeofizika; in the Caucasus, by the State enterprises "Kavkazgeolsyemka" and "GEON Centre"; in Siberia, by the State enterprises Irkutskgeofizika and Eniseygeofizika. Among private companies, the most active are North-West Ltd. and CEMI Ltd. In this paper, we present some results obtained within a few last years by North-West Ltd. in cooperation with the organizations mentioned above and the Geological faculty of Moscow University.

## 13.2. OBSERVATION TECHNOLOGY

The basic regional EM method is the magnetotelluric (MT) method. MT provides the largest exploration depth and is inexpensive and mobile, as it does not require an artificial field source. Different kinds of equipment are used for measurements. In the USSR, CES-2 receivers and their later modifications were applied. In the 1990s domestic CES-M, SGS, EIN, AKF, and other kinds of equipment were widely used in Russia. Since 2000, regional MT surveys have usually been conducted by means of receivers produced by the Canadian company Phoenix Geophysics Ltd. This equipment is characterized by high sensitivity and broad dynamic range, unattended operation, synchronization using the GPS satellite system, reliability, and simplicity.

The MT method is applied in three ways:

- high-frequency (frequencies from 20,000 to 1 Hz, 1-km spacing between sites);
- standard (periods down to 5,000 s, 3-km spacing); and
- low-frequency (periods down to 50,000 s, 10-km spacing).

At observation sites, either all five components of the natural electromagnetic field ($E_x$, $E_y$, $H_x$, $H_y$ and $H_z$) or only the two electric-field components ($E_x$ and $E_y$) are measured. In the latter case, magnetic field records obtained at adjacent sites are used. As a rule, a receiver at some reference site operates synchronously with the receivers at a profile.

A difficult problem of MT soundings is connected with industrial electromagnetic inductive and galvanic noises. The inductive noise is caused by electric power lines. The galvanic noise caused by current leakages from electrified railroads is usually more intense. If resistive layers are present producing gradual attenuation of the electric field when moving away from the railroad, this noise source influences the measurements performed several tens of kilometers away. Fig. 13.2 shows that near an electrified railroad, the galvanic noise caused by the electric circuit between the locomotive and the nearest power substation dominates the weaker MT signal at high frequencies. Note that this "noise" can be used to acquire information

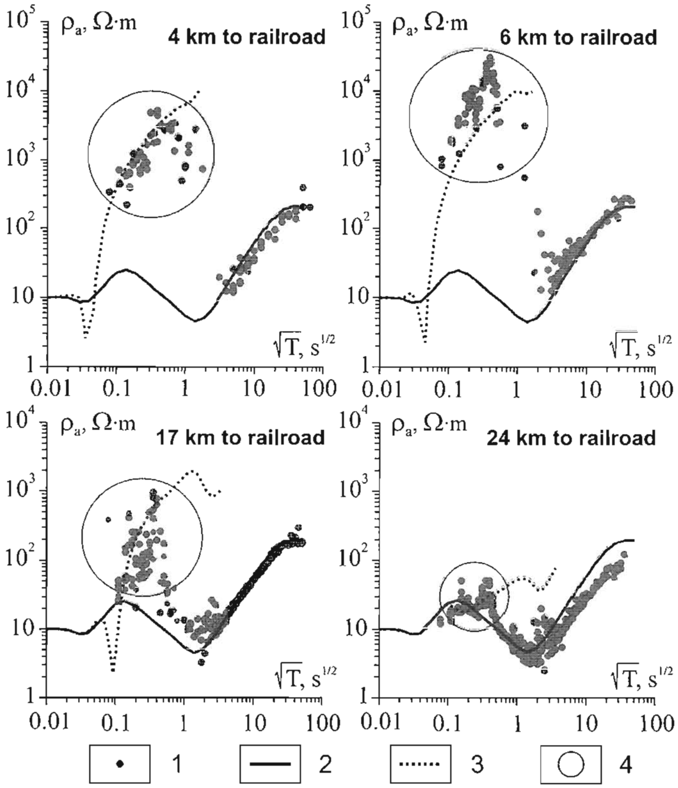

Fig. 13.2. Observed and modeled apparent resistivity curves near the Moscow–Kazan electrified railroad. 1 – Observed curves, 2 – result of forward modeling using plane wave source, 3 – the same using horizontal electric dipole as a source, 4 – zones where apparent resistivity is influenced by the electrified railroad field.

about resistive layers (Aleksanova et al., 2003). With the increase in the distance to the railroad, galvanic noise diminishes, and MT curves return to normal.

If industrial noise is very strong, controlled-source measurements are performed. In most cases, time-domain soundings with coaxial transmitting and receiving loops are used. Frequency-domain soundings having very high tolerance to the industrial noise are still seldom applied. They require a large distance between transmitter and receiver, and if the medium changes significantly in this interval then simplified (one-dimensional, 1-D) approaches to data interpretation become inapplicable.

## 13.3. MT-DATA PROCESSING, ANALYSIS AND INTERPRETATION

As a rule, MT data processing is performed in remote reference mode, allowing the suppression of uncorrelated noise. In addition, robust statistical approaches are used to increase the reliability of results. Rejection of data values according to different criteria, such as dispersion relations between apparent resistivity and impedance phase, gives considerable improvement.

Manual editing of the impedance and tipper response function plays an important role. This stage is necessary because automated processing algorithms often do not allow the suppression of industrial noise or at least require time-consuming adjustment of parameters. Manual editing is used to eliminate both outliers and stable branches of response functions caused by industrial field sources.

Another problem is associated with the distortion of MT curves by local subsurface inhomogeneities, producing uninterpretable geoelectric noise. This noise appears as a static shift of apparent resistivity curves along the vertical axis. If we have a dense observation network, this noise can be reasonably decreased by the spatial smoothing of apparent resistivity at some period and further shift of apparent resistivity curves to this smooth level. Another way to normalize MT curves is to adjust them to the levels of the time-domain sounding curves obtained when using a magnetic excitation and magnetic measurements of the EM field. If geoelectric noise is suppressed insufficiently, the interpretation is performed with the priority of impedance phases and tipper, which become free from subsurface distortions with lowering frequency.

MT data interpretation is performed in terms of Tikhonov's theory of ill-posed problems. The most important stage of interpretation is the construction of an interpretational model combining all possible inverse problem solutions. The interpretational model is based on *a priori* information about the medium and on the MT data analysis. In the course of data analysis, pseudo cross sections of MT and magnetovariational parameters characterizing dimensionality of the medium are constructed. In addition, we determine the principal values and directions of the impedance tensor and analyze impedance polar diagrams and induction arrows showing the location and strike of resistivity structures. Impedance tensor decomposition methods describing the relation between regional and local structures are also applied.

As a result of data analysis, the acceptable dimensionality of inversion methods is determined: usually one- or two-dimensional (2-D). In regional investigations, three-dimensional (3-D) inversion methods are not applied because observations are performed along separate profiles. However, to verify the reliability of 1- and 2-D approaches, 3-D modeling is used to study 3-D effects and possible errors.

Data interpretation is usually performed in two stages. At the first stage, rough smoothed-structure inversion is applied. At the second stage, we deal with piecewise-uniform models to define the resistivity structure more precisely. All MT data components are used for interpretation, although their simultaneous inversion is not always effective because of their differing sensitivity to resistivity structures and differing robustness against 3-D distortions. We suppose that in regions with complicated geoelectric conditions, better results can often be obtained using a succession of partial inversions with tipper and impedance phases priority (see Chapter 2 for details), although this approach is still rarely used in industrial surveys.

Interpretation is concluded by a geological and geophysical analysis of the resistivity models obtained. At this stage, EM results are considered together with other geophysical data. Specialists in the integrated application of geophysical methods as well as geologists are involved in this work.

## 13.4. CASE HISTORIES

### *13.4.1. East-European craton*

We start the review with some results obtained at the East-European craton where a large number of MT soundings were performed within the last few years. In this region, the following geoelectric complexes are present (from top to bottom):

- inhomogeneous Mesozoic – Cenozoic (rather conductive);
- Upper Devonian – Carboniferous including mainly carbonate rocks (resistive);
- mainly terrigenous, including Meso- and Neo-Proterozoic and Devonian rocks, saturated by mineralized water (conductive);
- metamorphic basement consisting of Archean and Paleo-Proterozoic rocks (resistive).

New geoelectric information about the Moscow syneclise, the largest tectonic structure of the craton, was obtained along profile IV of the RIFEY exploration program (region 1 in Fig. 13.1). The profile consisting of 160 MT sites has length of 650 km.The resistivity cross section constructed using borehole and seismic information (Fig. 13.3) includes the basement depression – the Soligalich aulacogen and the superimposed uplift in sediments (Bubnov et al., 2003). Owing to the resistive layer that resists the flow of transverse electric currents, this uplift strongly influences the transverse impedance data (TM-mode). At the same time, the longitudinal impedance (TE-mode) provides information about deeper layers and reveals conductive Meso- and Neo-Proterozoic and Devonian rocks. Their total rock thickness in the Soligalich aulacogen is about 2–3 km, and their low resistivity indicates good

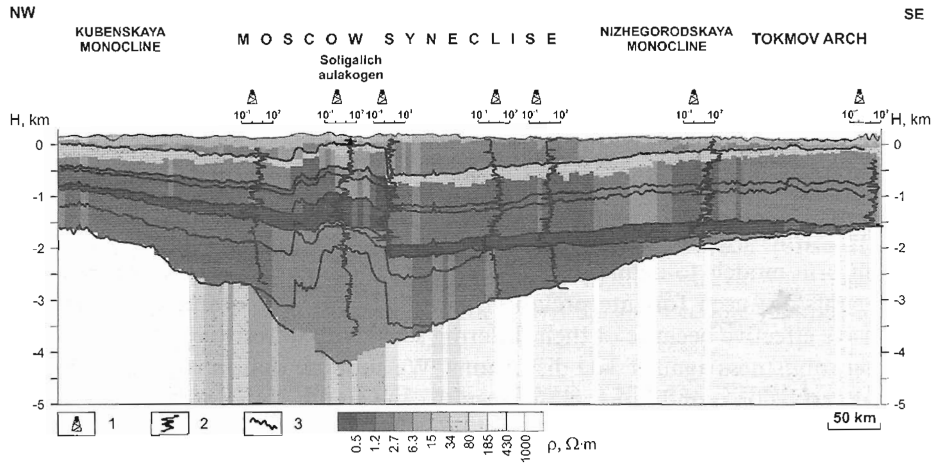

Fig. 13.3. Resistivity cross section of the Moscow syneclise, profile IV of the "Rifey" program. 1 – Boreholes, 2 – electrical logging results, 3 – seismic boundaries.

reservoir properties. The resistive basement consists of large blocks of different resistivity. On the sides of the Moscow syneclise, the basement is presented by resistive, probably Archean rocks. In the central part of the syneclise, it is more conductive, due to the Paleo-Proterozoic rocks present.

Fig. 13.4 presents the resistivity cross section of the Tokmov arch and the Melekes depression (region 2 in Fig. 13.1). Here, the resistive crystalline basement lies at a depth of approximately 2 km.The use of borehole and seismic data revealed quite a number of layers in the sedimentary cover. It is notable that horizontal variations in the resistivity were revealed. The valuable information that supplements seismic data is that the resistivity diminishes from west to east reflecting the increase in porosity and fluid mineralization.

The next example demonstrates the ability of the MT method to locate reefs in the junction zone of the Kotelnich arch and the Kazansko–Kazhimsky aulacogen (region 3 in Fig. 13.1). Here, the integrated interpretation of seismic and MT data was performed to supplement the cross section with geoelectric parameters based on seismic data. Within large lithological complexes potentially productive of oil and gas, several zones presumably containing reef traps were revealed using seismic data. To verify and refine this result, variations of layer conductance determined using MT data were studied. Fig. 13.5 shows characteristic fragments of geological cross sections predicted from seismic data, and graphs of conductance of the appropriate lithological complexes. In the layers between $P_1$ and $C_2vr$ seismic reflectors, as well as between $C_2vr$ and $C_1jp$ reflectors, the conductive anomalies correlate well with supposed reefs. These anomalies are explained by the high porosity and permeability of reefs with compared with host rocks.

2-D inversion of MT data obtained in the Voronezh anteclise (region 4 in Fig. 13.1), where sediment thickness is small, revealed striking conductive anomalies in the consolidated crust (Fig. 13.6). Here, the resistivity decreases to fractions of an ohm m (Ω m), allowing these anomalies to be explained by graphitization of Paleo-Proterozoic rocks. They are of practical interest as zones of probable ore mineralization. One of them is connected with the deep fault outlined according to geological data.

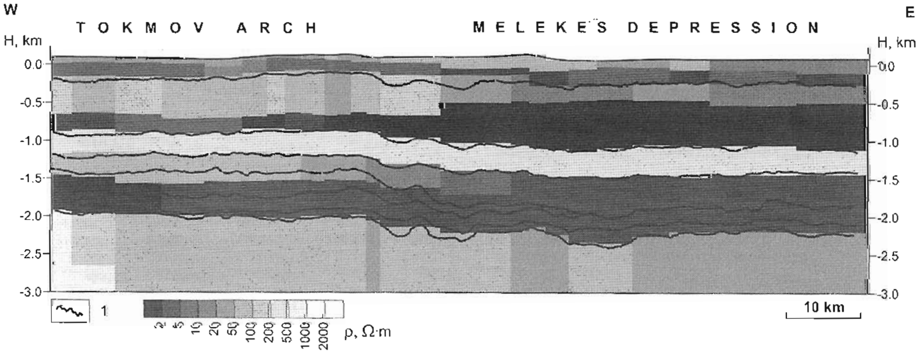

Fig. 13.4. Resistivity cross section of the Tokmov Arch and the Melekes depression. (1) – Seismic boundaries.

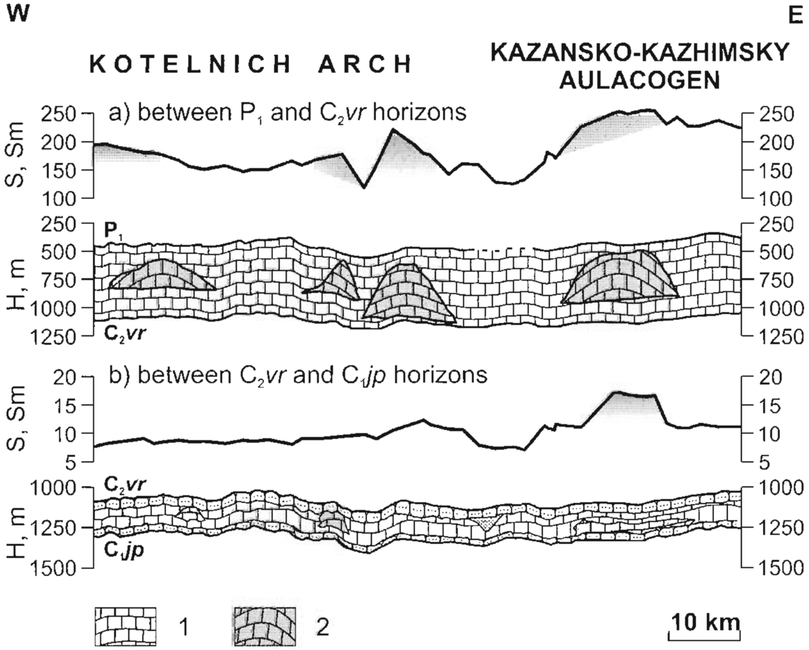

Fig. 13.5. Fragments of geological cross section obtained using seismic data and graphs of total conductance of the named layers (junction zone of Kotelnich Arch and Kazansko–Kazhimsky aulacogen). 1 – Limestones, 2 – prospective reefs.

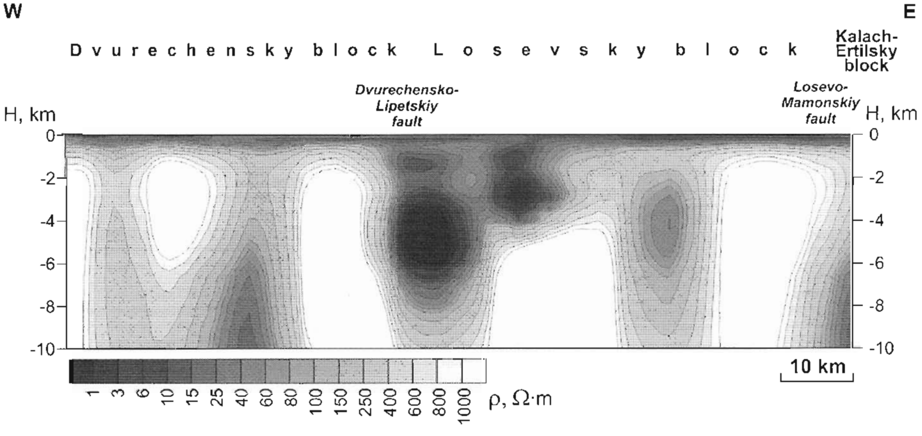

Fig. 13.6. Resistivity cross section along the profile in the Voronezh anteclise.

Now, we move to the northern part of the Pre-Caspian syneclise (region 5 in Fig. 13.1). This area is promising for hydrocarbons, and salt-dome structures are common here. Fig. 13.7 displays the resistivity cross section obtained using 2-D inversion of MT data along one of the profiles oriented across the structures. In the conductive sedimentary cover, resistive salt domes approximately 6 km thick are easily seen. Some of them have a mushroom-like shape, producing salt overhang. Such zones in terrigenous rocks above the salt layer can be oil and gas traps. As the result of interpretation, areas of high and low conductance of the complex beneath the salt layer were also revealed. Accordingly, they correspond to zones of mainly terrigenous and carbonate composition. Delineation of carbonate bodies in this complex is an important task, because in similar areas to the East in Kazakhstan, such bodies contain large hydrocarbon deposits.

To conclude the review of recent MT investigations of the East-European craton, we consider the result obtained at its southern flank in the Karpinsky swell area (region 6 in Fig. 13.1). The observations were performed along a 190-km profile comprising 71 MT sites (Berzin et al., 2005). On the basis of MT data and *a priori* geological and geophysical data analysis, a conclusion was drawn about strong horizontal inhomogeneity of the medium. A large isometric subsurface depression filled by sediments is superimposed on regional elongated (quasi-2D) structures. In this case, quasi-longitudinal (TE mode) impedance suffers from galvanic distortions that are much larger than the effect of deep structures. In contrast, quasi-transverse (TM mode) impedance has a low sensitivity to deep structures, although it contains information about shallow ones. In this situation, the deep conductive anomalies were studied using tipper data weakly distorted by the influence of isometric near-surface inhomogeneities and quite sensitive to deep conductive structures.

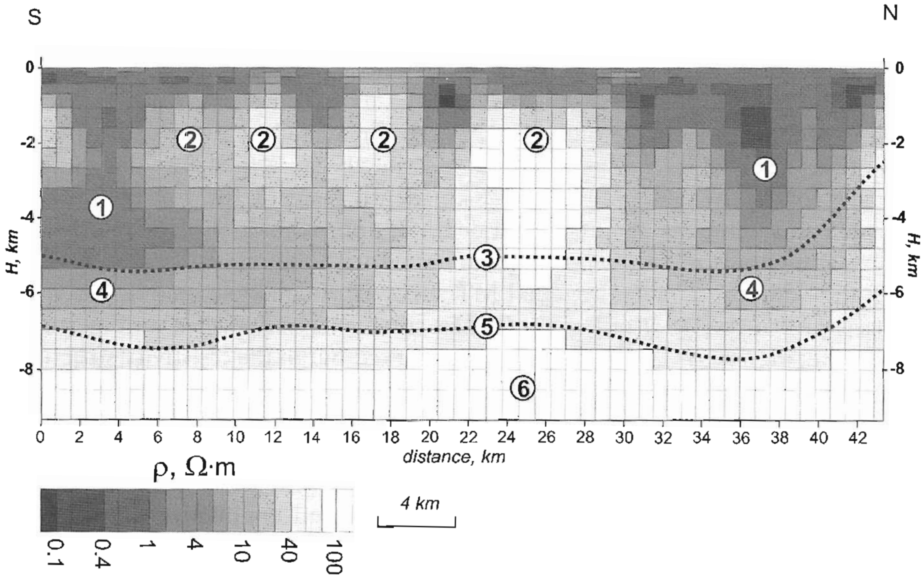

Fig. 13.7. Resistivity cross section along the profile in the Pre-Caspian syneclise. 1 – Layer above the salt, 2 – salt domes, 3 – top of the layer below the salt, 4 – layer below the salt, 5 – basement top, 6 – basement.

The cross section obtained by means of 2-D inversion of tipper and transverse impedance data is shown in Fig. 13.8. The cross section includes two conductive zones. The upper conductor constructed using transverse impedance occurs at approximately a 1-km depth. These are terrigenous Cretaceous and Cenozoic sediments, mainly clays. Beneath them there are more resistive, mainly carbonate rocks. The lower conductor occurs at a depth of about 15 km.It probably represents the southeastern extension of the Donbass conductivity anomaly (Rokityansky et al., 1989) covered by thick young sediments. The total conductance of this anomaly is several thousand Siemens, and it can be associated with the presence of both electron-conducting minerals and increased fluid content.

### *13.4.2. Caucasus, the Urals, Siberia, and North East Russia*

In the Greater Caucasus mountains and in the Caucasus forelands, MT measurements were recently conducted along 10 profiles of a total length of 2000 km.Consider the profile in Western Caucasus forelands. It stretches from the Black sea to the Scythian plate, crossing the Caucasus Mountains and the Kuban depression (region 7 in Fig. 13.1). Fig. 13.9 displays a geophysical cross section along the profile based on 2-D MT data inversion results and seismic data. Its remarkable feature is that at the northern border of the Kuban depression, an unexpected deep trough filled with conductive (supposedly terrigenous Jurassic) rocks is revealed.

Let us also consider the profile in the central part of the Greater Caucasus, crossing the Elbrus mountain (region 8 in Fig. 13.1). The resistivity cross section (Fig. 13.10) clearly displays the transition from the folded belt of the Greater Caucasus to the Scythian plate and the associated gradual increase of sediment thickness (Arbuzkin et al., 2003). Within the limits of these tectonic structures, the Hercynian basement is heterogeneous, and the most complicated geoelectric situation is observed in the tectonic block of the Greater Caucasus. Known tectonic disruptions are seen as conductive zones, possibly because they are fluid-saturated. A small conductive anomaly at a 2–8 km depth beneath the Elbrus volcano is interpreted as a magma chamber; at a depth of approximately 30 km another conductive anomaly is revealed, possibly connected with the magma center.

In the Southern Urals, a regional MT survey was conducted along the 510-km Uralseis profile (region 9 in Fig. 13.1). Measurements at 500 sites were performed (Kulikov et al., 2005). Three domains were marked out in the resistivity structure of the Southern Ural: Western Ural, being a part of the East European craton edge; Eastern Ural formed by Paleozoic volcanic and Plutonic basic and ultrabasic complexes; and Trans-Ural, which is part of the Kazakhstan Caledonian plate. According to MT data 2-D inversion results, the Earth's crust is resistive beneath the East-European craton and the Kazakhstan plate, and conductive between them (Fig. 13.11).

The southern Urals show a divergent structure. In its western part, nappes and thrusts moved westwards, and in the eastern part they moved eastwards. The most striking conductivity anomalies are associated with the Main Ural fault and the

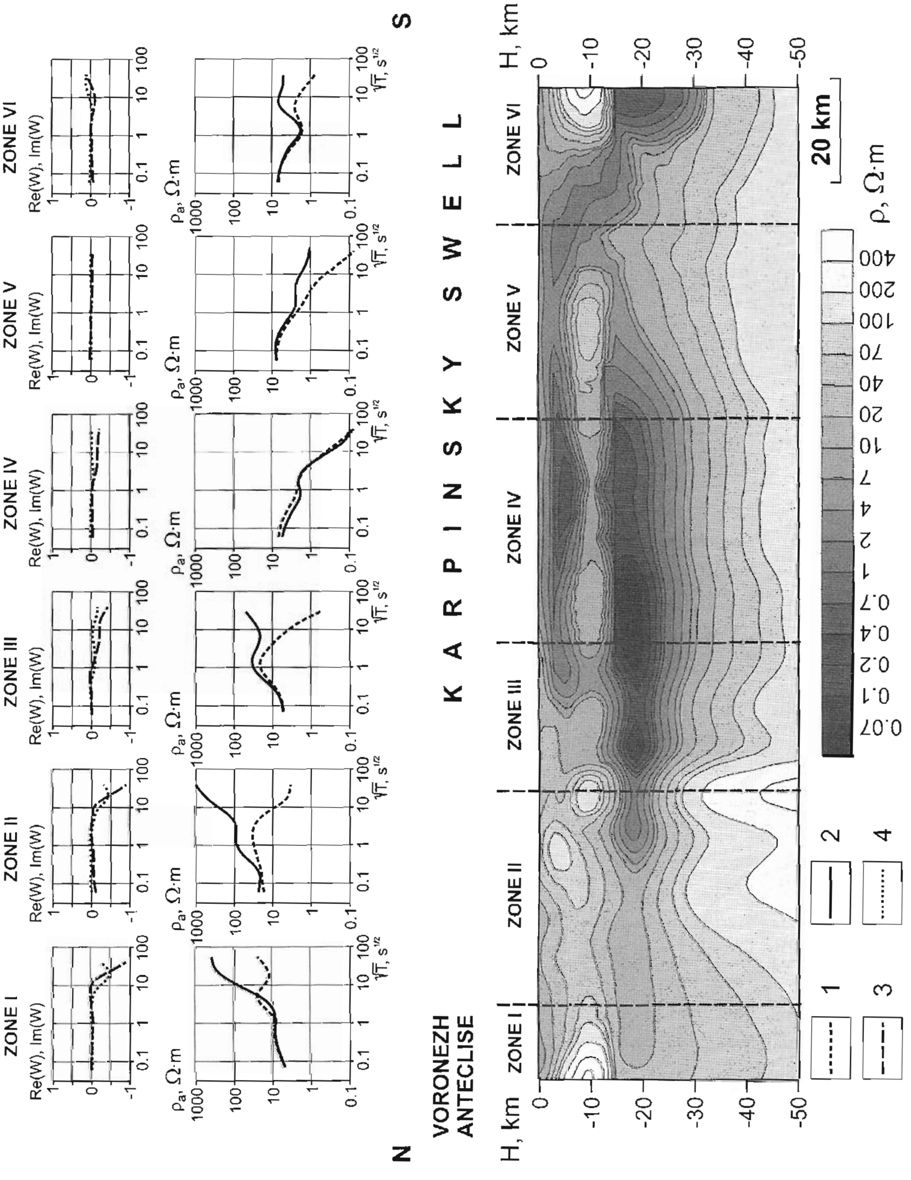

Fig. 13.8. Typical MT curves and resistivity cross-section of the Karpinsky swell. 1 – $\rho_{XY}$, 2 – $\rho_{YX}$, 3 – $\mathrm{ReW}_{ZY}$, 4 – $\mathrm{Im}(W_{ZY})$.

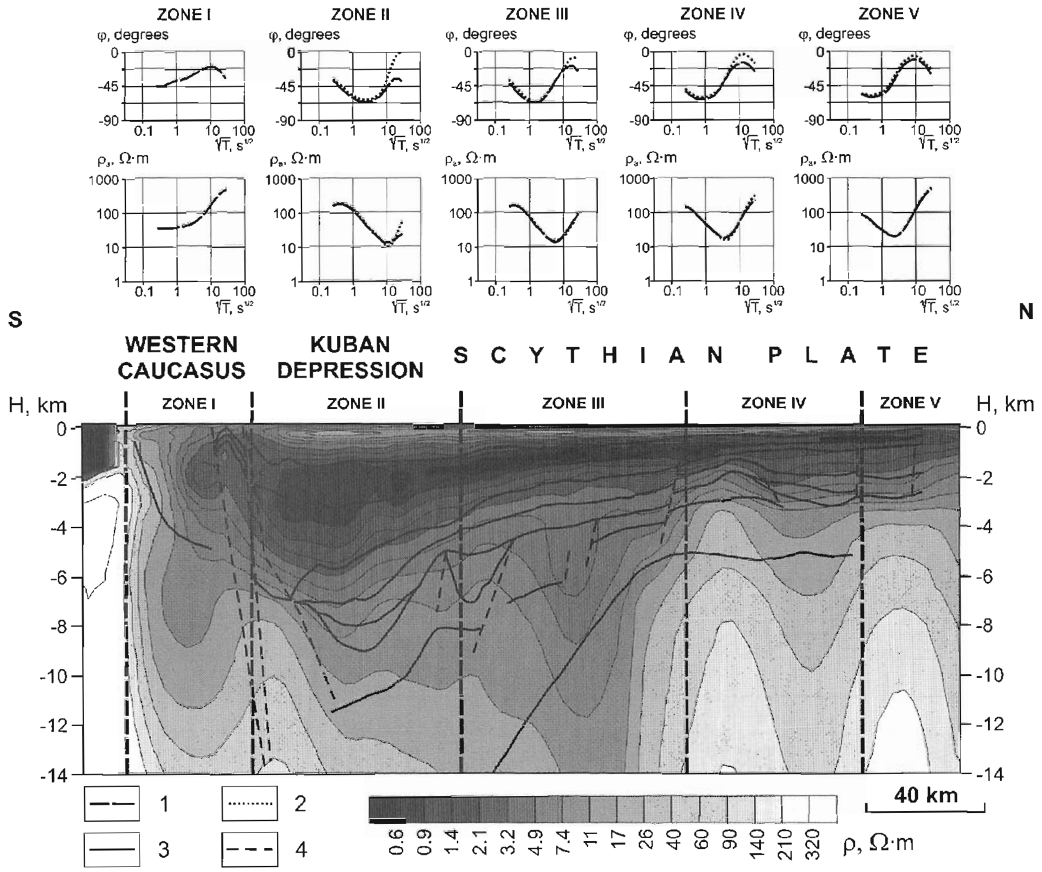

Fig. 13.9. Typical MT curves and resistivity cross section of the Kuban depression and zones. 1 – Observed TE curves, 2 – observed TM curves, 3 – geological boundaries according to seismics, 4 – tectonic disruptions according to seismics.

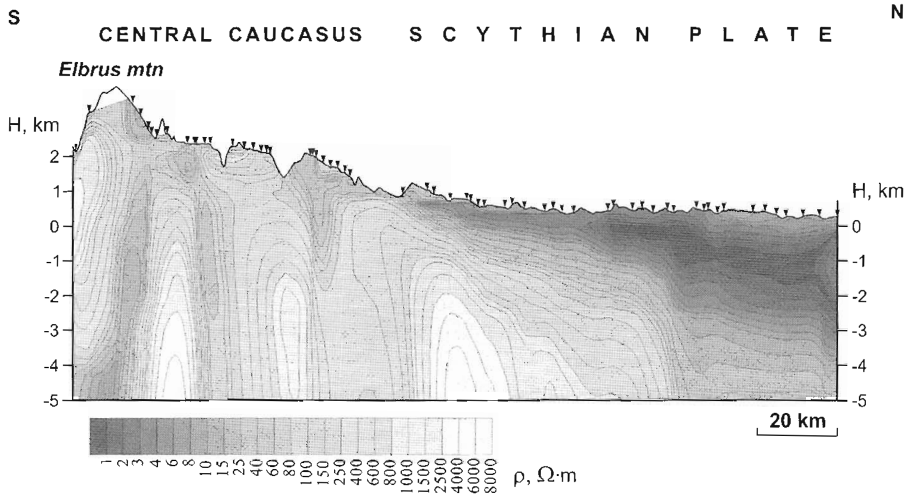

Fig. 13.10. Resistivity cross section along the profile in Central Caucasus.

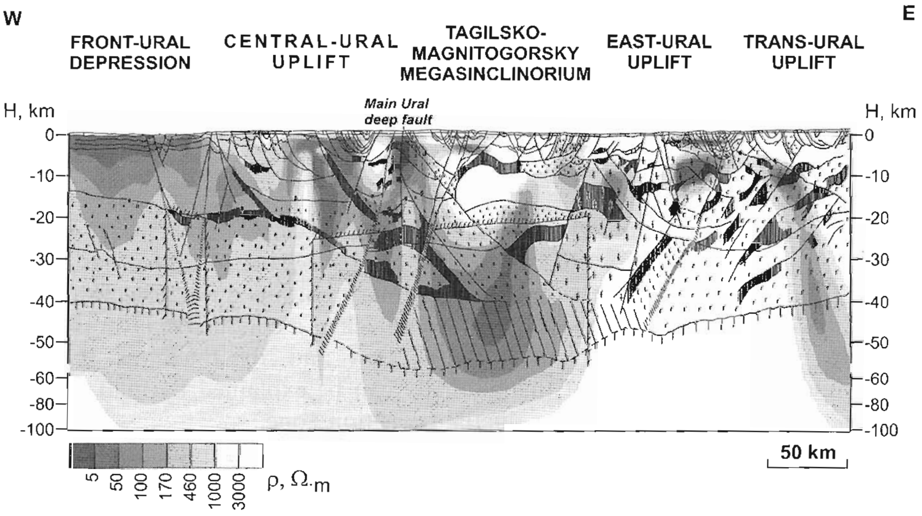

Fig. 13.11. Resistivity cross section of the Southern Ural ("Uralseis" profile) and the results of seismic data interpretation.

Zuratkulsky, Zapadno–Uraltaussky, and Kartalinsky faults. Here, the resistivity of rocks goes down to a few Ω m, probably characterizing their fluid saturation. Chrome and gold deposits of the Magnitogorskaya metallogenic zone occur in areas where these deep faults rise to the surface. In the Magnitogorskaya and Trans-Ural zones, crustal conductive layers were also revealed. A conductor in the first zone occurs at 15–25 km depth; it is about 30 km thick and its conductance is

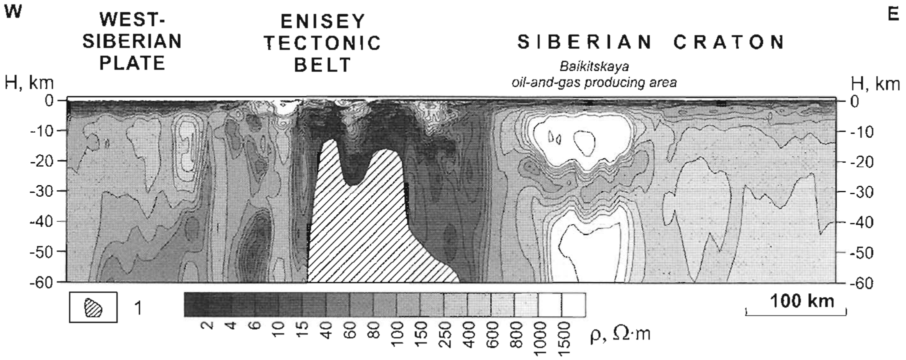

Fig. 13.12. Resistivity cross section along part of the 1-SB profile to 60 km depth. 1 – Low sensitivity zone.

above 1000 Siemens (S). A crustal conductor of the Trans-Ural zone dips eastward from the Kartalinsky fault, its conductance exceeding 150 S.

A significant geophysical event of recent years was a study of the Earth's crust in the Asian part of Russia along geotraverses 1-SB, 2-SB, 3-SB and 2-DV (Fig. 13.1). Fig. 13.12 shows the 800-km-long resistivity cross section along the 1-SB geotraverse (Aleksanova et al., 2005). The cross section starts at the West-Siberian plate, crosses the Yeniseisky range, and ends at the Siberian craton (profile 10 in Fig. 13.1). Within the limits of the West-Siberian plate, the conductance of the sedimentary cover reaches 1000 S. Against this background, the details of the resistivity structure of the consolidated crust are uindistinguishable. In the Yeniseisky range area beneath the resistive Proterozoic metamorphic rocks, a conductive zone of unknown nature is present. MT data analysis demonstrated that it has a complicated 3-D structure, so that 1- or 2-D data interpretation is not acceptable here. At the Siberian craton within the Baikitskaya anteclise, a conductive layer is clearly seen. Its resistivity is approximately 100 Ωm and its thickness is about 10–15 km.Possibly the nature of this anomaly can be explained by fluid presence in disintegrated rocks in the brittle–ductile transition zone.

Currently, a special study of crustal conductivity structures in oil-and-gas provinces is being performed. In this connection, the mid-crustal conductive layer detected in the Baikitskaya anteclise (where the Yurubcheno–Tokhomskoe oil field, the largest in Eastern Siberia, is situated), and also in the region of the gigantic Romashkinskoye oil field at the East-European craton, can be of great practical interest.

A cross section of the sedimentary cover of the Siberian craton along a 700-km-long part of the 3-SB geotraverse (profile 11 in Fig. 13.1) is displayed in Fig. 13.13. In the south of the profile, within the Irkenyevsky aulacogen, conductive Meso-Proterozoic rocks are present at 7–11 km depth. According to borehole data from the adjoining Baikitskaya anteclise, these are mainly carbonates. Their low resistivity is probably caused by high porosity and mineralized water content. Within

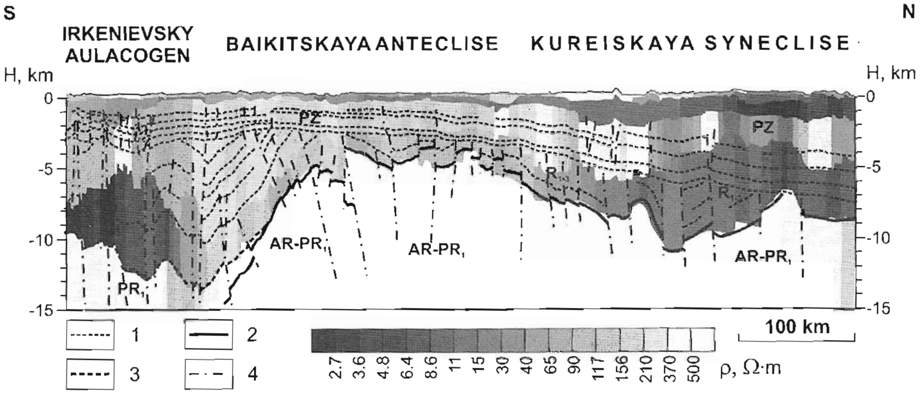

Fig. 13.13. Resistivity cross section along part of the 3-SB profile to 15 km depth, constructed using MT and seismic data. 1 – Seismic boundaries in the sedimentary cover, 2 – top of the AR-PR$_1$ complex, 3 – top of the PR$_1$ complex, 4 – faults according to seismic data.

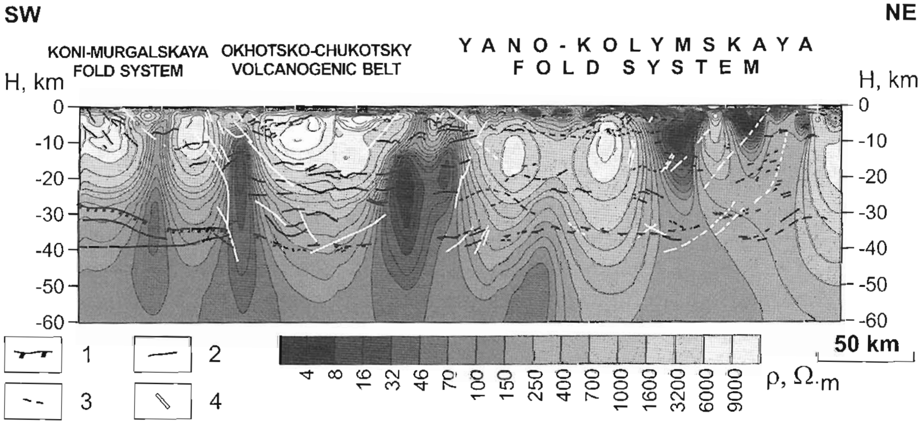

Fig. 13.14. Resistivity cross section along part of the 2-DV profile (North-East Russia) and the results of seismic data interpretation. 1 – Moho boundary, 2 – reflecting boundaries, 3 – reflecting surfaces, 4 – fault zones.

the Kureiskaya syneclise, conductive layers that probably include reservoir rocks were also revealed.

The 2-DV geotraverse crosses the Magadan and Chukotka regions (profile 12 in Fig. 13.1). Three variations of the MT method (low frequency, standard, and high frequency) were applied, and spacing between sites was 1 km (Berzin et al., 2002). To date, more than 2000 soundings have been performed. Fig. 13.14 displays the resistivity cross section along the southern part of the geotraverse. In the Koni–Murgalskaya fold system and in the Okhotsko–Chukotsky volcanogenic belt, several deep conductive anomalies were outlined. There is a strong correlation of these anomalies with areas in which the intensity of seismic reflections from the Moho boundary is small. Possibly, they are connected with paleo-subduction zones and correspond to permeable rocks that provided the migration of mantle fluids to the Earth's surface. Major gold and silver deposits of the region are situated in the vicinity of these anomalies. Further north, in the Yano–Kolymskaya fold system, conductive anomalies mainly correspond to areas with thick sediments or graphitized rocks in the upper crust.

## 13.5. CONCLUSION

MT investigations essentially expand the existing ideas about the structure and geodynamics of the Earth's interior, based on the results of drilling and of seismic, gravity, and magnetic studies. MT investigations provide unique information about the structure and reservoir properties of sedimentary complexes, the state of active geodynamic regions, the graphitization and fluid regime of the consolidated crust, and the permeable and fluid-saturated crustal zones.

The generalization of all electromagnetic data obtained on the territory of Russia is currently being performed. Maps of sediment conductance and other parameters of large sedimentary complexes and lithospheric conductive layers are being constructed (Sheinkman et al., 2003; Feldman et al., 2005).

### *Acknowledgements*

The authors wish to acknowledge A.V. Lipilin, Head, Department of ROSNEDRA Federal Agency, for the support of regional electromagnetic explorations. We are also grateful to I.S. Feldman, A.V. Pospeev, A.K. Suleimanov, V.V. Belyavskiy, V.V. Lifshits, and other leading experts of industrial geophysical companies for fruitful collaboration, as well as to V.A. Kulikov, E.V. Andreeva, A.G. Morozova, D.A. Alekseev, and other specialists of North-West Ltd. for taking part in the studies considered. The scientific effort of authors from Moscow University was supported by RFBR (project 05-05-65082). P.Yu. Pushkarev also thanks INTAS for support (project 03-55-2126).

## REFERENCES

Aleksanova, E.D., Bubnov, V.P., Kaplan, S.A., Lifshits, V.V., Pospeev, A.V., and Yakovlev, A.G., 2005. Deep magnetotelluric studies along geotraverses in the East-Siberian craton (in Russian): Abstr. 7th V.V. Fedynsky Geophysical readings, Moscow.

Aleksanova, E.D., Kulikov, V.A., Pushkarev, P.Yu. and Yakovlev, A.G., 2003. Application of electromagnetic fields created by electrified railroads for electromagnetic soundings (in Russian). Izvestiya VUZov (Geology and Prospecting), 4: 60–64.

Alekseev, D.A., Kulikov, V.A., Yakovlev, A.G., Grebnev, V.P., Koryavko, A.I. and Matrosov, V.A., 2004. Application of AMT method for mineral prospecting (in Russian). Prospect. Preserving Interiors., 5: 40–44.

Arbuzkin, V.N., Kampaniets, M.A., Andreeva, E.V., Morozova, A.G., Yakovlev, A.G. and Yakovlev, D.V., 2003. Magnetotelluric soundings along a profile in Elbrus region (in Russian): Abstr., 5th V.V. Fedynsky Geophysical Readings, Moscow.

Berdichevsky, M.N., 1994. Role of geoelectric methods in hydrocarbon and deep structural investigations in Russia. Geophys. Trans., 39: 3–33.

Berdichevsky, M.N., Fox, L., Yakovlev, A.G, Bubnov, V.P., Kulikov, V.A. and Pushkarev, P.Yu., 2002. Russian Oil and Gas Geoelectric Surveys: Abstr. 16th Workshop on Electromagnetic Induction in the Earth, Santa Fe.

Berzin, R.G., Suleimanov, A.K., Berdichevsky, M.N., Yakovlev, D.V., Andreeva, E.V., Sborshchikov, I.M. and Yakovlev, A.G., 2002. Results of electromagnetic prospecting in the southern part of 2-DV profile (in Russian). Proc. All-Russian Conference "Geodynamics, Magmatism and Mineragenу of Northern Pacific Continental Margins", **1**, Magadan.

Berzin, R.G., Suleimanov, A.K., Filin, S.I., Bubnov, V.P., Aleksanova, E.D., Yakovlev, A.G. and Pushkarev, P.Yu., 2005. Electromagnetic explorations using MT method along the "Morozovsk-Kamyshev" profile" (in Russian). Proc. 5th and 6th V.V. Fedynsky Geophysical Readings, Moscow, pp. 185–189.

Bubnov, V.P., Aleksanova, E.D., Morozova, A.G., Yakovlev, A.G. and Andreeva, E.V., 2003. Results of electromagnetic prospecting using MT method along profile IV of the "Rifey" exploration program in the Moscow syneclise(in Russian): Abstr. 5th V.V. Fedynsky Geophysical Readings, Moscow, pp. 110–111.

Feldman, I.S., Lipilin, A.V., Shpak, I.P. and Erinchek, Yu.M., 2005. Geological interpretation of electromagnetic prospecting results on the territory of the European part of Russia (in Russian): Abstr. 7th V.V. Fedynsky Geophysical Readings, Moscow, pp. 31–32.

Kulikov, V.A., Yakovlev, A.G., Morozova, A.G., Svistova, E.L. and Kamkov, A.A., 2005. Deep resistivity cross-section along "Uralseis" profile (in Russian): Proc. 5th and 6th V.V. Fedynsky Geophysical Readings, Moscow, pp. 180–184.

Rokityansky, I.I., Ingerov, A.I. and Baisarovich, M.N., 1989. Donbass conductivity anomaly (in Russian). Geophys. J., 3: 30–40.

Sheinkman, A.L., Narskiy, N.V. and Lipilin, A.V., 2003. Map of the total conductance of the sedimentary cover on the territory of the European part of Russia, scale 1 : 2 500 000. Abstr. Intern. Geophysical Conference "Geophysics of the XXI Century – the Leap into the Future", Moscow.