Magnetotelluric investigation across the Kola Super Deep Hole area

Litvinenko, V.S.[1], Ermoln E.[1], Ingerov O.[2], Egorov A.S.[1], Zhamaletdinov, A.A.[3].
[1] National Mineral Researches University, Saint-Petersburg, Russia, rectorat@spmi.ru
[2] Phoenix-Geophysics, Canada, Toronto, Ontario, oingerov@phoenix-geophysics.com
[3] Kola Science Center, RAS, Russia, abd.zham@mail.ru

SUMMARY

Along the regional profile crossing the head of the Kola Super Deep Hole (audio)magnetotelluric soundings ((A)MTS) and magnetic-variation profiling (MVP) were executed in the duration of 19 June to 3 July 2012. The 45-km long profile intersected the Early Proterozoic Pechenga zone from the southwest to the northeast, and emerged in the Archaean framing. The measurements were executed using modern hardware systems by Canadian companies: Phoenix Geophysics and AGCOS. The field time series of data were made by multifunctional wide-range recorders, MTU-5a using the (A)MT3-MVP methods. The profile measurement interval is 1 km. The best (A)MTS geophysical inversion was implemented in the two-dimensional approach. The parameters of the modeled geoelectric cross-section are well correlated with the results of the Kola Super Deep Hole drilling, and with the position of the main geological boundaries mapped in the study area. In particular, the suture style of the Pechenga zone is confirmed, Its outer boundaries plunge southwards and flatten at a depth of 7 to 11 km. The research have helped in specifying the behavior at the depth of the phyllitic schists marker of the fourth volcano-sedimentary horizon, or the productive series, to which all deposits of the Pechenga copper-nickel ores are confined. The structure of the Pechenga zone in the area of the Porjitash fault is the most debating point.

Keywords: Kola Super Deep Hole, magnetotelluric, regional investigation, Cu-Ni ore.

INTRODUCTION

The study of the deep-seated earth crust structure in the area of the Kola Super Deep Hole is of particular interest defined by the unique depth (12 km 262 m), and intersection with the Pechenga zone, where large reserves of copper and nickel ores are concentrated [Gorbunov 1968]. Ample deep research has been executed using refraction (DSS) and reflection (CDP) seismic [Smithson 2000]. Along with this, gravimagnetic methods, geophysical well logging, and deep geoelectrics with the use of powerful MHD generator [Velikhov et al., 1986] are of importance.

Figure 1 demonstrates tectonics of the Pechenga zone. It conventionally encompasses the Northern and Southern volcano-sedimentary series intensively deformed by implicated upthrusts and overthrusts and divided by the Porjitash fault. Regardless of the ample research, many deep-seated structure-related issues of the Pechenga zone are still to be solved. The morphological study of the Early Proterozoic Pechenga zone outer boundaries represent highest scientific and practical interest against the background of the Archaean crystalline basement, as well as deep tracing of the Zhdanov sedimentary suite (or so-called productive series) composed of electronically-conducting phyllitic schists, and containing main reserves of copper-nickel ores.

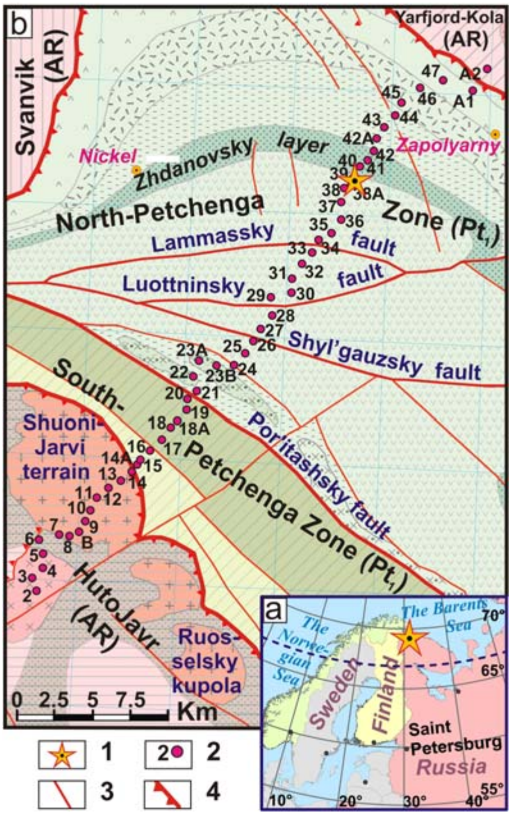


Figure 1. a – common view of the field work area. b – tectonic scheme of Petchenga structure. Legend: 1 – The Kola Super Deep Hole position, 2 – (A)MTS-MVP sites and numbers, 3 – fault zones, 4 – AR-Pt1 boundaries.

To solve these issues, in the period of 19 June to 3

July 2012, Saint-Petersburg Mining University in collaboration with the Kola branch of the RAS performed profiling using (audio) magnetotelluric sounding ((A)MTS) and magnetic-variation profiling (MVP) methods [Berdichevsky and Dmitriev 2008]. The 45-km long profile intersects the Pechenga zone from the northeast to the southwest (Fig. 1). This paper shows preliminary data processing and interpretation results.

Method

The observations were made using the hardware by Phoenix-Geophysics LTD (Canada, Toronto, Ontatio). Induction sensors were installed on precision tripods by AGCOS. The field works method is detailed in [Ingerov and Ermolin 2011]. The observations were performed in a permanent reference point scheme. The method is noted for preliminary direct current electric profiling along the total observation line. This has allowed positioning sounding (A)MTS-MVP sites away from surface conducting zones creating static distortions.

Data processing. The initial field files were processed using the SSMT2000 software by Phoenix-Geophysics LTD. The curve splines are generated and edited using the SSMTBASE software (created by Andrey Elbakidze).

Interpretation. The quantitative data processing is made using the WinGLink software. The shape and level of the resultant amplitude and phase (A)MTS-MVP curves significantly varies along the profile reflecting the style of the geoelectric cross-section. For the purpose of various geoelectric units classification, six groups of apparent-resistivity curves and impedance phases (a, b, c, d, e, f groups in Fig. 2) are distinguished.

The group 2a curves describe the high resistance unit located in the southern profile part and composed predominantly of granites. At high frequencies of 10 000 to 1 000 Hz, the amplitude curves level is a few dozens of thousands of Ohm-m, and phase curves fall to 15 degrees. Flat ascending curves end with a clear peak at frequencies of 1 000 to 700 Hz. The peak is followed by long descending branches with a few bends recording the sequential interchange in the relatively deep-seated cross-section of conducting and high-Ohm layers at depth of over 5 kilometers. The descending branches flatten at low frequencies of 0.03-0.003 Hz. The amplitude curves level reaches 1-200 Ohm-m. Steep ascending branches of phase curves within 3 000 to 200 Hz validate significant reduction in the resistance values with depth. The phase curves level rises from 10-20 to 65-85 degree. The group 2b curves indicate strong heterogeneity of the South-Pechenga zone cross-section, and resistance level reduction when approaching the Porjitash fault (curve 20). The variety of the shape is observed along with significant fluctuations of the amplitude curve level embracing 5 orders of resistance. Longitudinal amplitude curves (TE-mode, solid) underlie the transverse ones to indicate limited horizontal bodies dimensions and strike concordant with the South-Pechenga zone. The group 2c curves have no principal differences from the group 2b ones, and record numerous subvertically falling conductors. In general, 2c curves demonstrate the transfer from the conductive rocks of the Porjitash fault to poorly conductive structures in the southern part of the Northern zone. The curves level varies from 0.1 kOhm·m to 3-10 kOhm·m. The groups 2d and 2e curves show relatively regular shape, and a short ascending branch in the frequencies range of 10 to 1 kHz. The least level (0.3 to 1.0 kOhm·m) is typical of the curves in the area of the Zhdanov suite cropping-out. Further, there is a descending branch with a few bends reflecting the alteration of several units of conductive and non-conductive layers gently dipping to the south. A slight rise of conductive structures in the area of sites 35-36 (Lammass fault area) is possible. For groups d and e, high level of impedance phase curves are typical (65-80 degrees) to indicate high conductivity of the geoelectric cross-section and contrast electric rock properties. The group 2f curves are in stark contrast to other curves of the profile in significantly higher values of apparent resistivity in almost the total frequency range (1-50 kOhm·мм) reflecting poorly conducting rocks of the northern Pechenga flank, including Archaean, including Archaean granite-gneiss of the Yarfjord-Kola unit. These MTS curves show clear extremes and bends reproducing the dissected geoelectric cross-section. The impedance phase curves have quite complicated shape with a few extremes. The phase curves level smoothly rises from 10 degrees at a frequency of 10 kHz to 65 degrees at a frequency of 0.001 Hz. The similarity of longitudinal (TE) and transverse (TM) curves shape gives grounds to imply narrow angle of the boundaries slope. Figure 3a shows Parkinson induction vectors at a frequency of 100 Hz. The vector arrows point to the conductor. At this frequency, no interferences in the magnetic field vertical component have been observed. The vectors reliably indicate two main zones: Porjitash fault (sites 17-23) and Zhdanov suite cropping-out area (sites 38-42).

2D Inversion. The best modeling was obtained using the 2D R.Mackie smooth inversion. Longitudinal (TE-mode, azimuth of -45 degrees) and transverse (TM-mode, azimuth of +45 degrees) resistivity curves and impedance phases were used in the frequency range of 10 kHz to 0.1 Hz.

No 2D processing was conducted below 0.1 Hz due to the complicated three-dimensional field parameters. In total, over 200 inversions were made with over 30 iterations each. Figure 3c shows pseudovertical sections and impedance phases for directions along geological units (azimuth of -45 degrees, TE-mode). Good correlation of field (Org) and calculated (Calc) MTS curves is observed.

RESULTS

The resultant geoelectric cross-section is shown in Figure 3b. The Early Proterozoic Pechenga zone behaves as a reduced resistance area against the background of the poorly conductive Archaean framing. The Pechenga zone is wedge-shaped dipping southwestwards and flattening at a depth of 7-11 km. The electric sounding data for the Kola Super Deep Hole (Figure 3b, sites 38-39) are well correlated in two horizons with reduced resistance (down to 10 Ohm-m) at depths of 1.7 and 2.2 km in a log sheet with the position of the conductive layer distinguished on the geoelectric cross-section. It is obvious that this conductive layer on the geoelectric cross-section corresponds to the electronic conductors of the Zhdanov suite since it crops out in the area of copper-nickel ore deposits (sites 40-42). The log sheet well shows the boundary of the Archaean and Early Proterozoic units (Pechenga zone base) intersected by a borehole at a depth of 6 800 m. Below this level on the geoelectric cross-section, a poorly conductive layer is traced (over 10^4 Ohm-m). Due to the fact that this boundary crops out near site 47, we consider this as the Pechenga zone base. Deeper thin conductive layers demonstrated on the log sheet (9 km and 10.2 km deep) are not visible on the geoelectric cross-section due to their quite shallow thickness. The southern boundary of the Pechenga zone is traced as a steeply southwestwards dipping narrow zone of reduced electrical resistivity values (site 14).

The northern Pechenga zone is characterized by relatively concordant occurrence of well and poorly conductive southwestwards dipping interlayers. Strongly conductive units with the resistivity of 1 to 100 Ohm-m near sites 28-29 (3 km deep) and 35-36 (1-2 km deep) are of principal interest. The nature of these conductors may be checked only by drilling. Quite low resistance may indicate relation with the graphitized schists typical of this area.

The lowest resistance are pertinent to the conductors system distinguished near the Porjitash fault (sites 19-23). The conductors in this profile area dip subvertically. The deep structure of this zone is a lively debatable challenge related to the high resistivity of the upper part and limited (A)MTS frequency range used in case of inversion.

CONCLUSIONS

Along the profile line intersecting the Early Proterozoic Pechenga zone in the range of the Kola Super Deep Hole, SG-3, (A)MTS soundings are made in line with MVP using the hardware by Phoenix-Geophysics LTD. The measurements are executed along the 45-km long profile with a step o 1 km. The 2D inversion results well correlate with the SG-3 logging data and position of main geological boundaries traced by CDP seismic prospecting and mapped on the surface. A series of new structural and compositional features of the Pechenga zone has been identified:
- the suture style is established for the Pechenga zone, which boundaries plunge southwards and flatten at a depth of 7 to 11 km;
- stark contrast is observed for the deep structure of the South and North Pechenga zones divided by a conductivity anomaly along the Porjitash fault line;
- two conductive units are indentified in the central part of the North-Pechenga zone at a depth of 1.5-2 km. The nature of conductors is tentatively related with graphitized schists.

ACKNOWLEDGEMENTS

The authors express gratitude to the members of the survey company: Maxim Pechyonkin, Alexander Yankilevich, Alexander Yakovlev, Alexander Shevtsov, and Alexey Skorokhodov.

REFERENCES

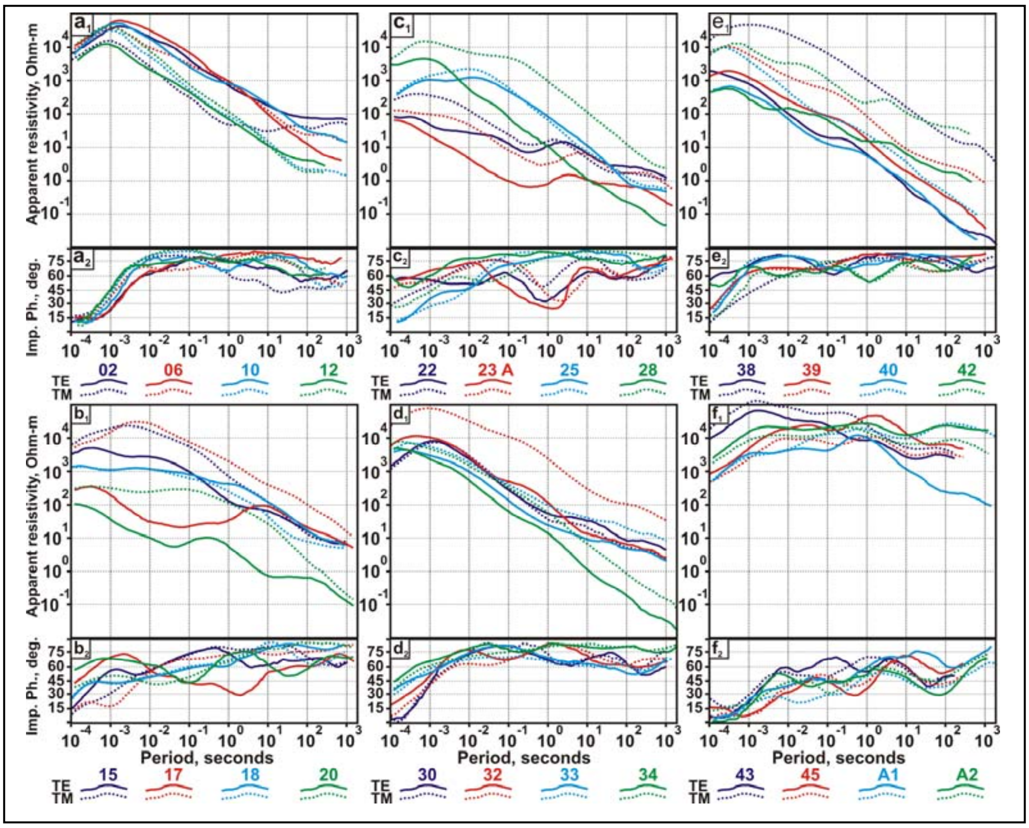
Berdichevsky MN and Dmitriev VI (2008), Models and methods of magnetotellurics: springer-Verlag, Berlin, Heidelberg, 563 pp.

Gorbunov GI (1968). Geology and genesis of the Pechenga sulfide copper-nickel deposits. // Nedra Publishers, M., 352 p.

Ingerov O and Ermolin E (2011). The results of AMT survey at Patomsky crater. 73rd EAGE Conference & Exhibition incorporating SPE EUROPEC in Vienna, Austria 23-26 P. 303-306.

Smithson S, Wenzel F, Ganchin YV, Morazov IB (2000). Seismic results at Kola and KTB deep scientific boreholes; velocities, reflections, fluids and crustal composition. Tectonophysics V.329.P. 301-317.

Velikhov YP, Zhamaletdinov AA et al., (1986). Electromagnetic Studies on the Kola Peninsula and in Northern Finland by Means of a Powerfull Controlled source. Journal of Geodynamics 5, P.237-256.



6

Figure 2. The group of (A)MTS apparent resistivity (index 1) curves and impedance phase (index 2) curves for different parts of the profile. Numbers of curves are given under period axis.

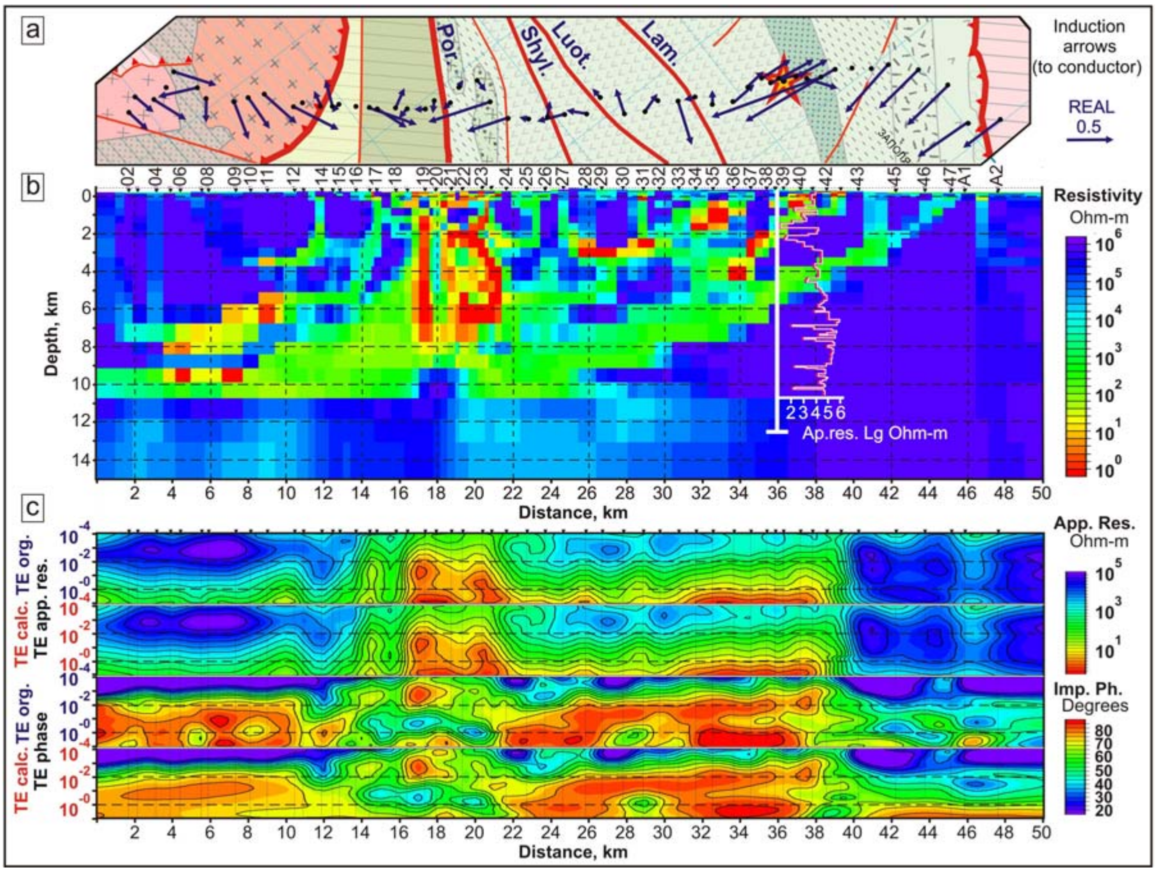


Figure 3. Correlation results. a – induction arrows at 100 Hz on; b - geoelectrical cross-section (2D inversion result) and Kola Super Deep Hole logging result; c - field data (TE org.) and 2D inversion result (TE calc.) TE mode comparison, vertical scale is period in seconds.