Advances in deep geoelectric modeling for SE Baltic shield with integrated geophysical and geological interpretation

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Summary

The Baltic (Fennoscandian) Shield is characterized by strongly inhomogeneous deep geoelectric structure with abundant conductors – well preserved bright markers of the Precambrian crustal architecture. The results of last decade MT experiments in the central part of the Shield have successfully underwent cross-verification with available CCP seismic data and helped to fill up seismic structural patterns by material properties (Figure 1). While in the absence of high resolution seismic data in SE Fennoscandia, the progress in crustal structure imaging has been achieved mostly due to the magnetotellurics.

The geoelectric modeling of Lake Ladoga conductivity anomaly (LLA) - one of the strongest crustal anomalies in East European Craton (EEC), studied already more then 3 decades - has proceeded to a new, modern, stage after recent MT measurement campaigns started 5 years ago from synchronous MT/MV soundings at Vydorg-Suojarvi (V-S) profile along the Northwestern bank of the lake, in strike to the main anomaly (Figure 2). The limitations of earlier MT data analyses have been mainly overcome due to increased resolution of new LLA resistivity cross-section enable thoughtful geological interpretation. The latter has demonstrated that the anomaly is caused not by a single source, but is due to several objects of different geological and structural identity, most probably connected with graphite in highly metamorphosed granulites of South Finland Granulite-Shist Belt and graphitized sedimentary and volcanic rocks of lower metamorphic stages in Raahe-Ladoga pericratonic zone.

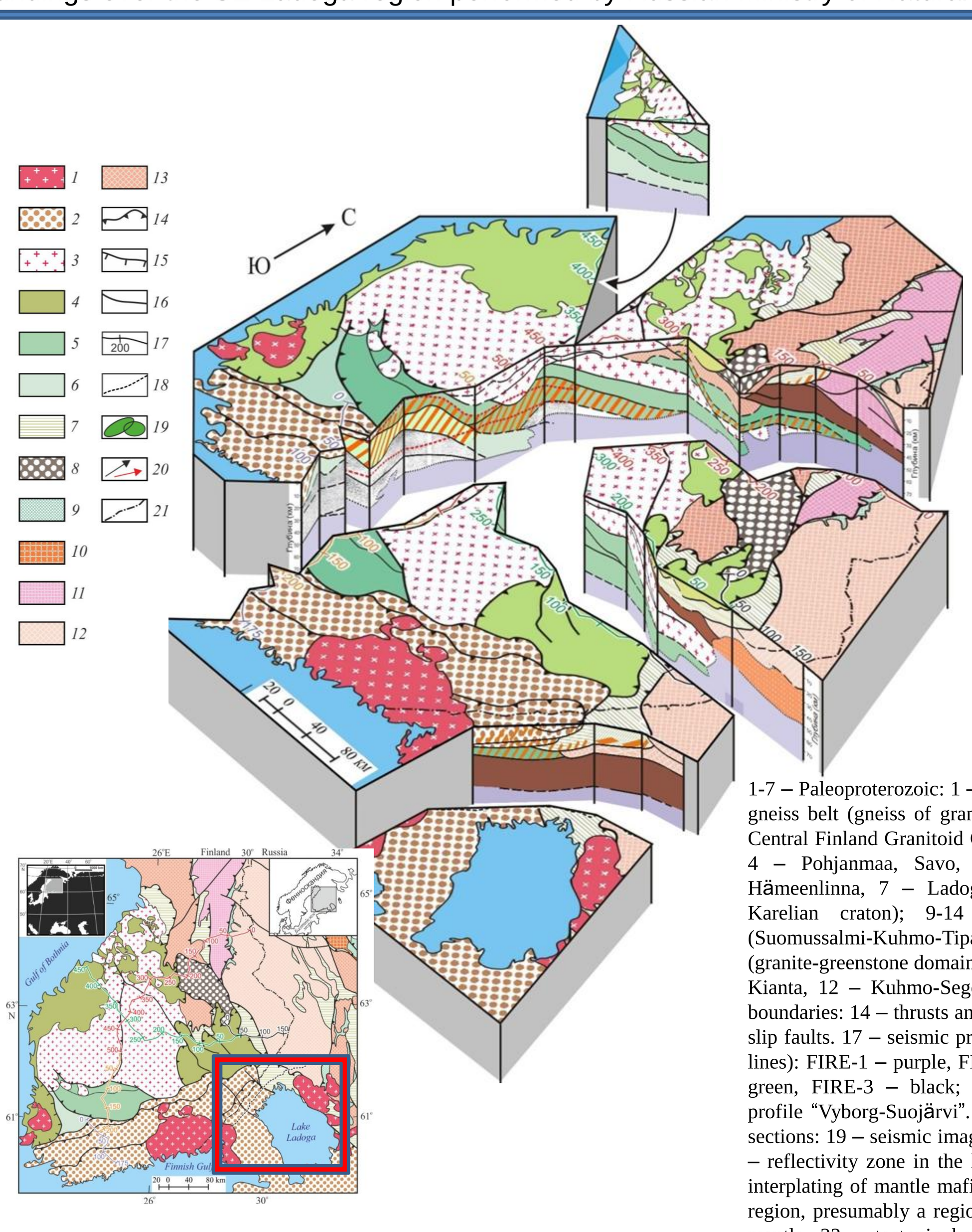
We present also recent advances in LLA area geophysical studies, including:

1). current results of 3D MT/MV inversion for V-S profile MT\MV data together with tipper array data over adjacent Finnish territory, which have generally verified former 2D cross-section and helped to recognise some 3D features of conductivity distribution out of profile (Figure 3);

2). analyses of the correspondence of LLA forming rock and crustal structure complexes with those causing potential field anomalies performed with a help of classification of potential fields' spatial patterns over LLA region and multi-component cluster analyses in the profile cross-sections with the interpretation of significant clusters in the terms of petrology (Figure 4,5);

3). quasi-3D inversion of the tipper data over all the LLA area, including pioneering data of I.I. Rokitiansky and 1-EU transect segment data, completed to by new long-period sounding data of 2016 year (Figure 6);

4). to follow with more resolution Eastern continuation of LLA conductors under the sedimentary cover of EEC we have just performed new 12 combined broad-band and LMT 5 component synchronous soundings and have managed to attract into our analyses the extended MT data set of prospecting soundings over the SE Ladoga region performed by Russian Ministry of Natural resources during last decade (Figure 7).



1-7 – Paleoproterozoic: 1 – rapakivi granite, 2 – South Finn granulite-gneiss belt (gneiss of granulite and amphibolite facies, granite), 3 – Central Finland Granitoid Complex, 4-7 – volcanic-sedimentary belts: 4 – Pohjanmaa, Savo, Saimaa, 5 – Pirkanmaa-Tampere, 6 – Hämeenlinna, 7 – Ladoga-Bothnian belt (passive margin of the Karelian craton); 9-14 – Archaean: 9 – greenstone belts (Suomussalmi-Kuhmo-Tipasjärvi, etc.), 10-14 – microcontinents (granite-greenstone domains): 10 – Ranua, Iisalmi and Vodlozero, 11 – Kianta, 12 – Kuhmo-Segozero, 13 – Kovdozero. 14-16 – tectonic boundaries: 14 – thrusts and upthrusts, 15 – normal faults, 16 – strike-slip faults. 17 – seismic profiles of FIRE project (highlighted in color lines): FIRE-1 – purple, FIRE-2a – orange, FIRE-2 – red, FIRE-3a – green, FIRE-3 – black; 18 – magnetotelluric sounding (MTS) profile "Vyborg-Suojärvi". 19-24 – additional symbols on geological sections: 19 – seismic image, suggested Peribaltica microcontinent; 20 – reflectivity zone in the lower crust, presumably by the under- and interplating of mantle mafic magmas; 21 – acoustically homogeneous region, presumably a region of intense metamorphic reworking; 22 – mantle, 23 – tectonic boundaries (a) and boundaries of structural domains (b), 24 – areas of increased electrical conductivity.

Figure 1. Integrated geotectonic model of SE Fennoscandian Shield, based on surface geology, reflectivity seismic data FIRE1,2,3 *[Kukkonen, Lahtinen (eds.), 2006]*, and 4 geoelectrical profiles: SVEKA *[Korja et al, 2002]*; FIRE1,2 [*Vaittinnen et al., 2013*]; LLA (Vyborg-Suojarvi profile*) [Sokolova et al., 2016, 2017*].

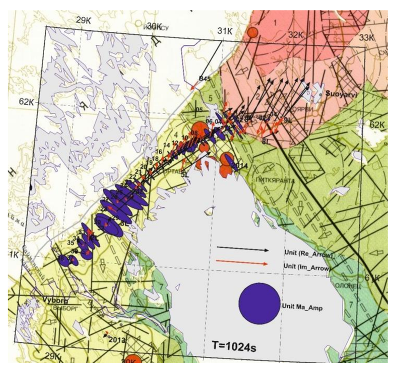


Figure 2a.

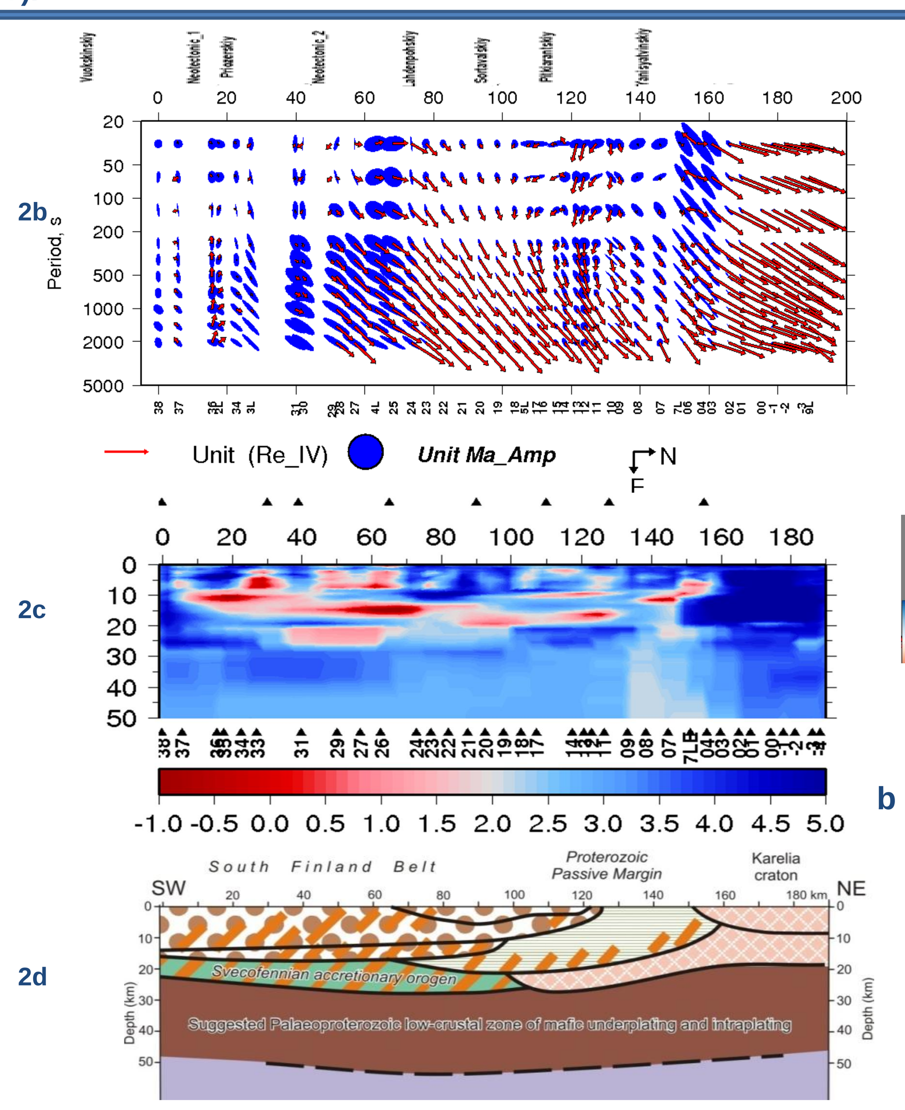
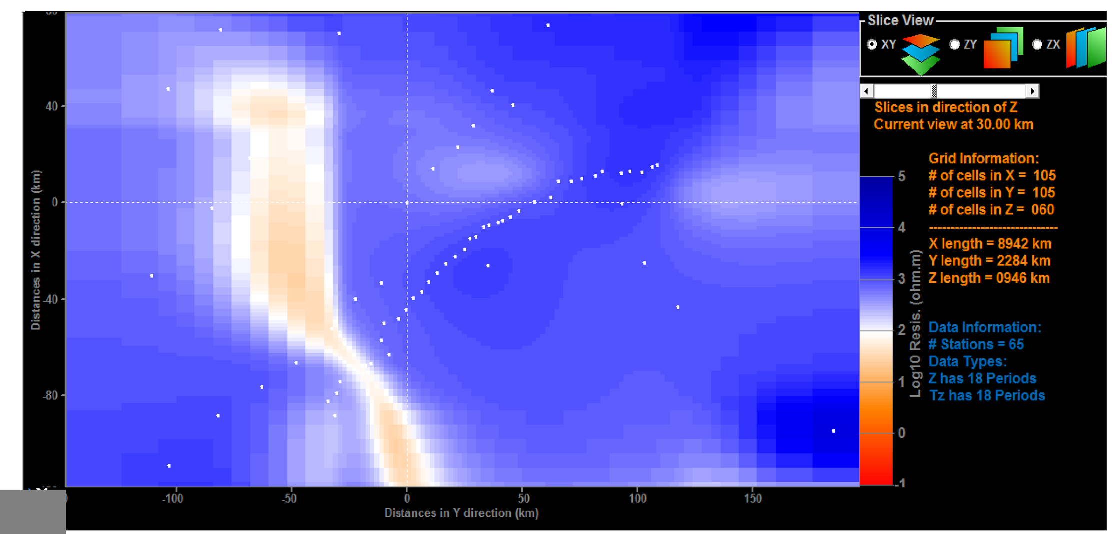
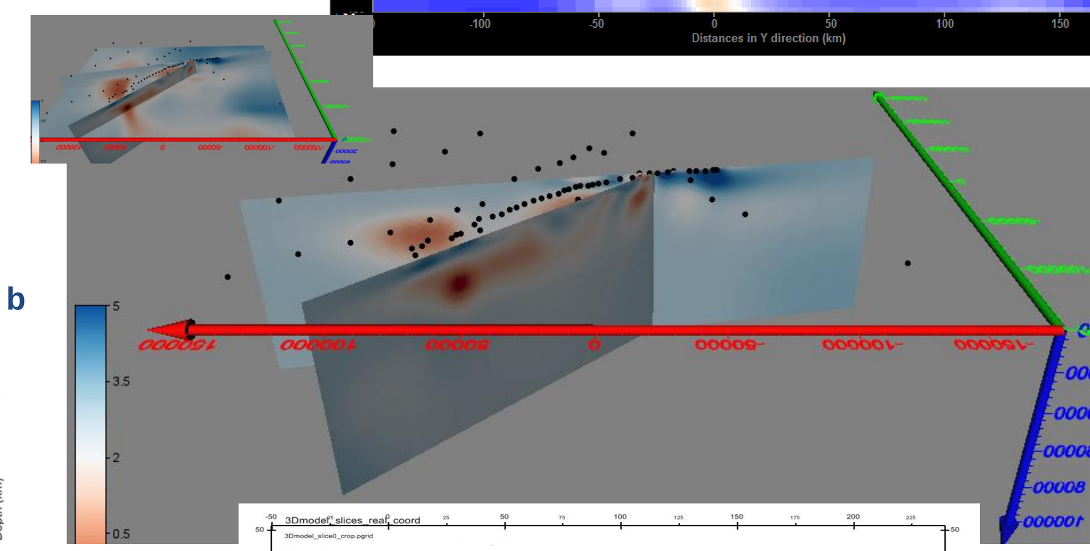


Figure 2. MT-MV soundings along Vyborg-Suojarvi profile (45 Phoenix, 8 LEMI): a (red box area of Figure 1) – locations of the sounding sites with real (black) and imaginari (red) induction vectors (in Wiese convention) and extremal anomalous horizontal magnetic tensor Ma ellipses (rotated 90°); b - period-profile distribution of long-period MV TFs: induction vectors (Re) and Ma-tensor ellipses; c- resistivity cross-section, obtained as a result of Z-determinant 2D inversion (code [Varentsov, 2007]) and d – geological interpretation of (c) according to the model of Figure 1.





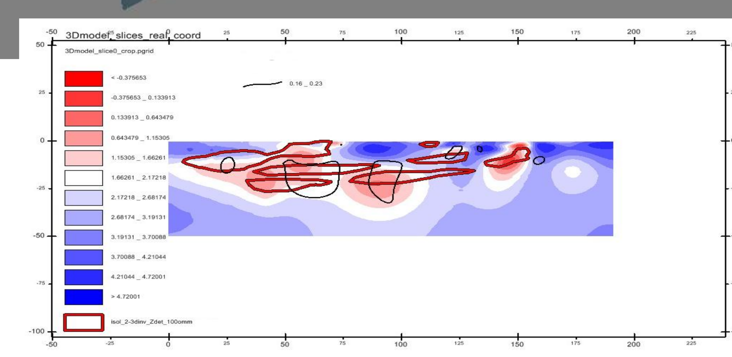
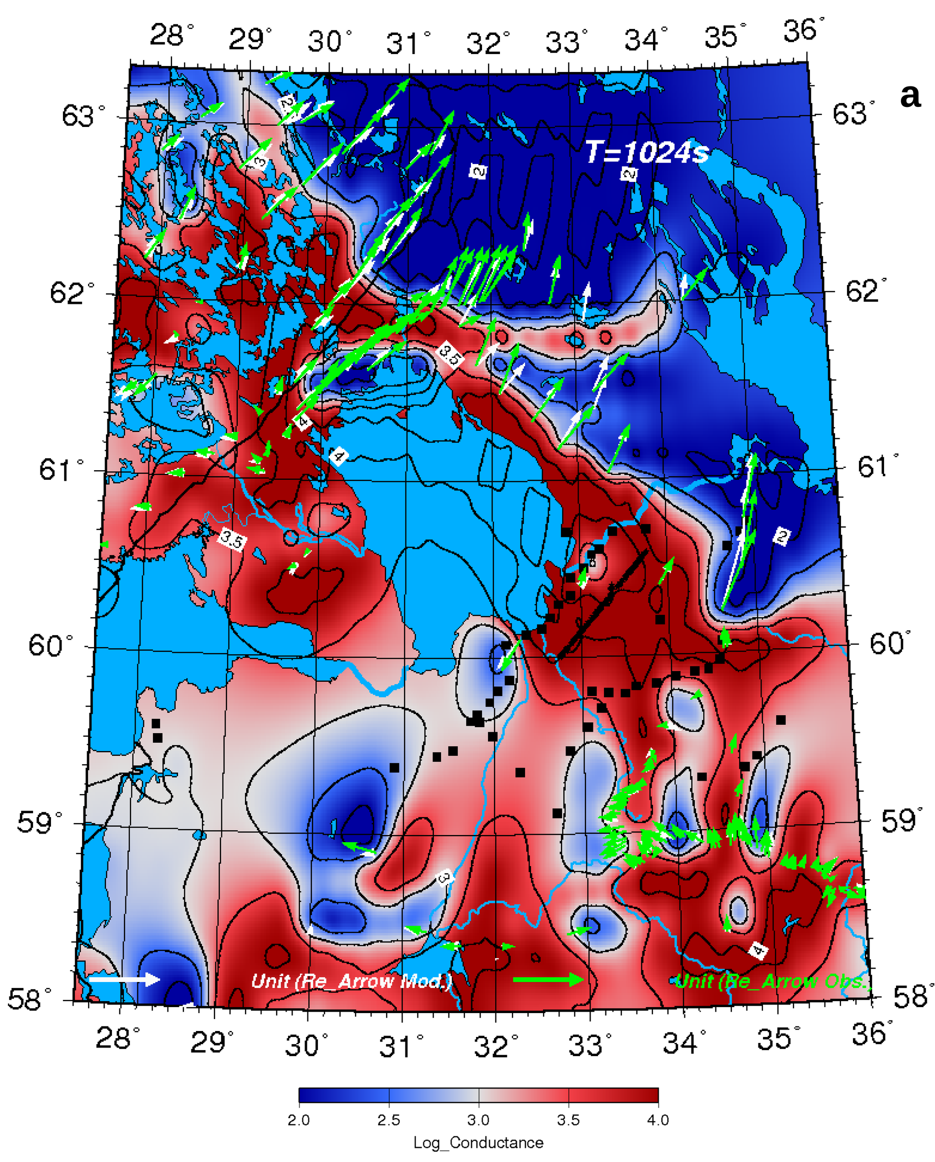


Figure 3. Two-stage 3D inversion results for V-S profile MT\MV data (Z, Wz for 35 station in the period range 0.015 – 4640s) and with limited data of tipper array data over adjacent Finnish territory (100, 300,1000s) with ModEM code[Egbert, Kelbert, 2012] . a, b,c - results for 43 iter. RMS=5.6 (plan horizontal slice for Z=30km with model description, volume views in vertical sections and verical section along Vyborg-Suojarvi line with 2D model features and extremal high effective density isolines superimposed), which have generally verified former 2D cross-section and helped to recognise some 3D features of conductivity distribution out of profile.



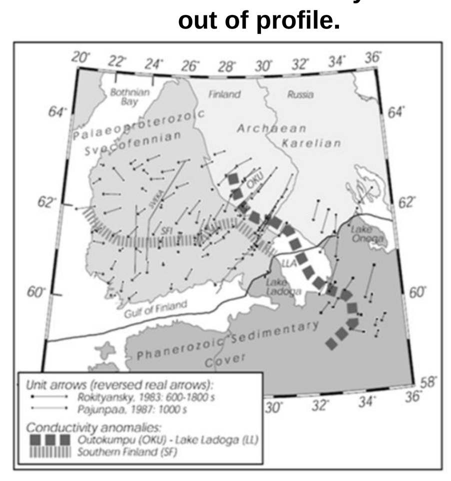
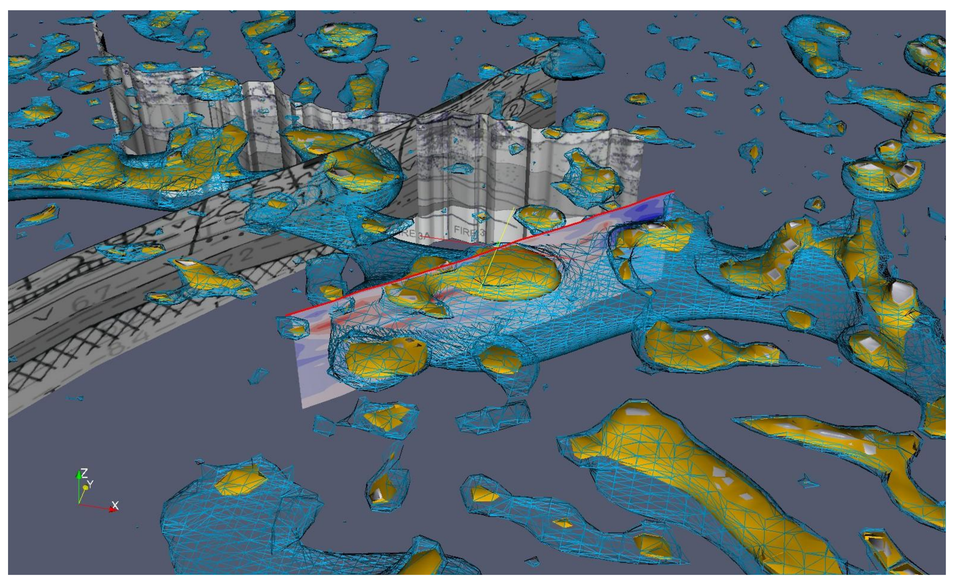
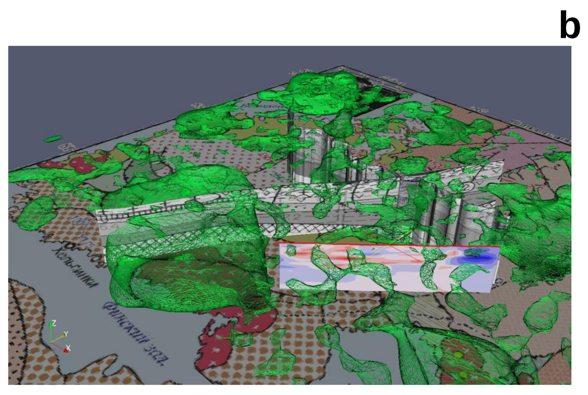


Figure 6.

a. Results of quasi-3D inversion of the tipper data over all the LLA area, including pioneering data of I.I. Rokitiansky and 1-EU transect segment data, completed to by new long-period sounding data of 2016 year. Black squares - prospecting sounding sites performed by Russian Ministry of Natural resources during last decade (report on "Ripheay" programm [I.S. Feldman, 2008]; smal blac stars – AMT sounding profile SPBGU [Antashchuk et al., 2016].

b. Spatial location of LLA conductor (dark dashed line) according to Finnish and Russian MV arrays of 80th. *[Korja et al., 2002].*





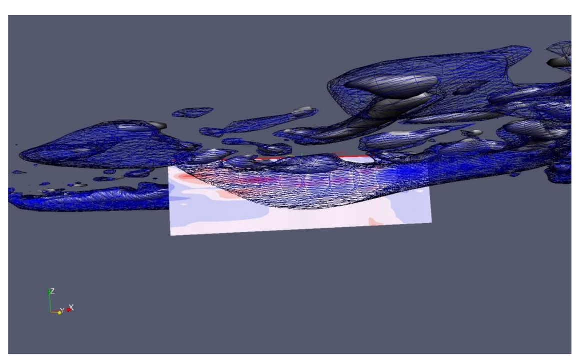


Figure 4. Verification of deep crustal geoelectric model by gravity feld data. Spatial views of the result of 3D inversion of gravity data 1:1000000 over the Eastern Fennoscandia (spatial spectral method with the GIS Integro tools [Galuev et al., 2015]) in correspondence with resistivity cross-section along Vyborg-Suojarvi profile (results of 2D detrminant inversion of Figure 2) and DSS profile SVEKA.
a- positive effective anomalous density surfaces (view from S)
b – negative effective anomalous density surfaces (view from S, with tectonic map of [Mints, Sokolova, 2016])
c –positive effective anomalous density surfaces (view from S-bottom)

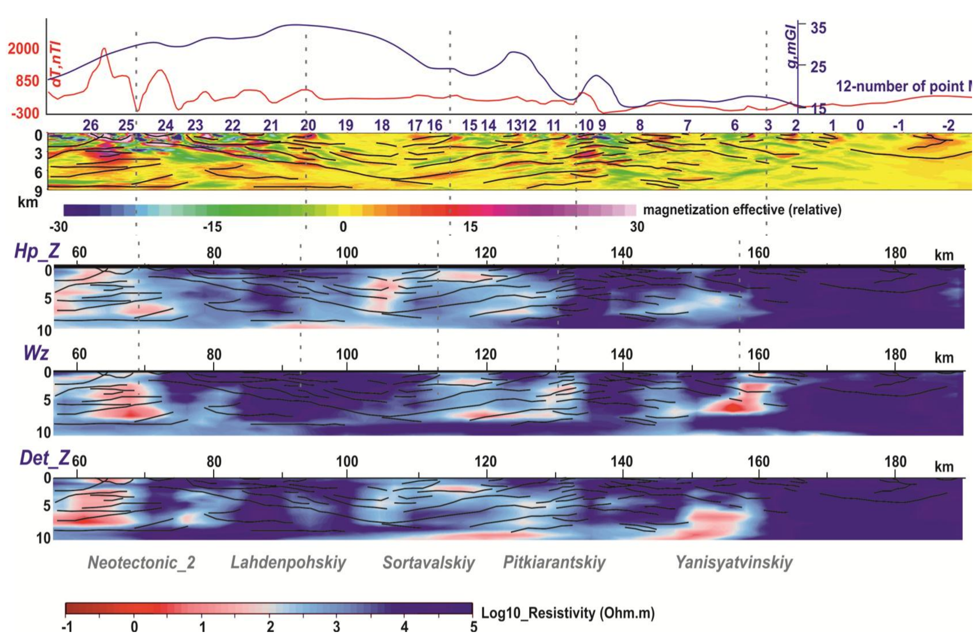
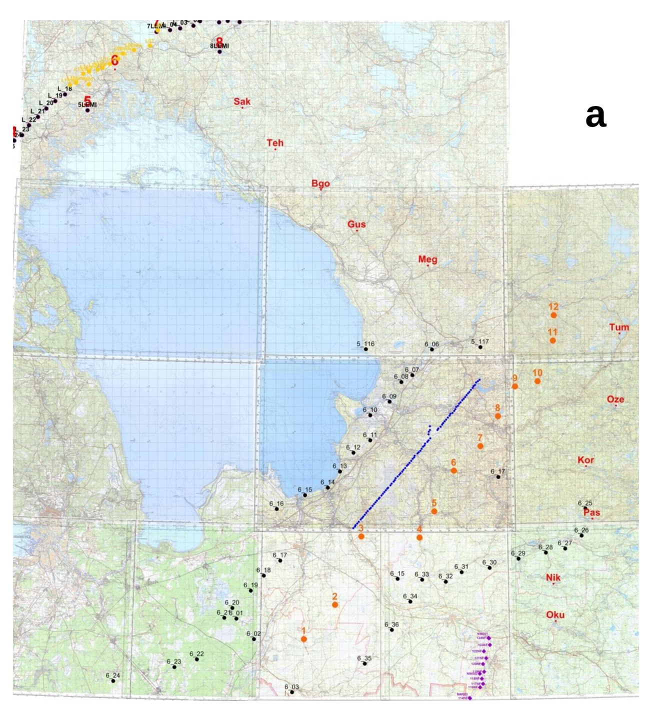


Figure 5. Verification of upper crustal geoelectric model by magnetic feld data. Vertical slice of the result of 3D inversion of magnetic data 1:200000 along Vyborg-suojarvi profile (upper panel) (spatial spectral method with the code KOSKAD *[Petrov, Trusov, 2000*]) and upper-crustal parts of 2D partial MT\MV inversions. It reveals well correspondence of EM and magnetic structural patters and 2 kind of Ro and magnetic succesibility correlation: - Ihala graphite field: interbedding of magnetic amphibolic shales, scarn rocks and non-magnetic graphite-bearing biotitic shales + sulfitization of fault zones.



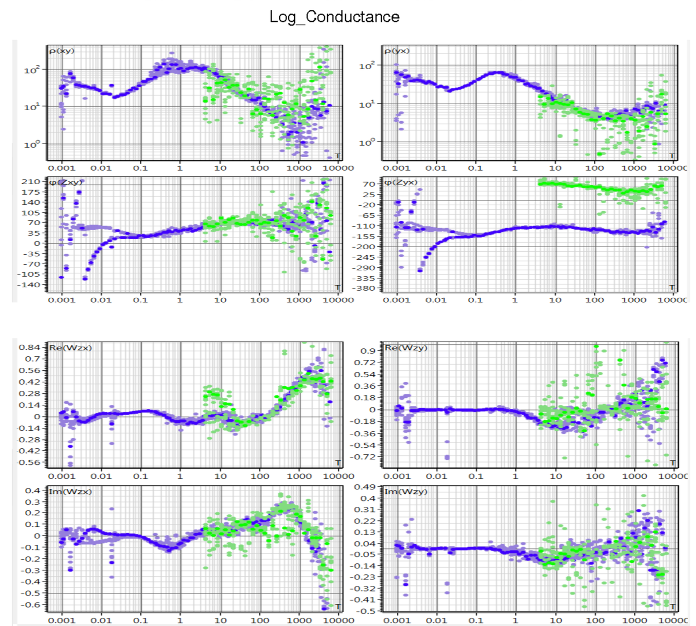


Figure 7. Working chart of 2018 August MT\MV campaign in ES Lake Ladoga region. 12 combined broad-band-LMT 5 component 2-days sounding have been carried out by field crew of LADOGA WG with LEMI amd MERI-Pro stations (red circles 1-12 in the map of figure 7a). b –combined plot of preliminary in-field estimates of main impedances and tippers on the observations of MERI-Pro (blue dots) and LEMI (green) in site 8 (in measuring geographic axies).

Conclusions

1. **New stage of LLA soundings has overcome limitations of the earlier MT data interpretations and produced more resolved resistivity section of the anomaly, supported by 3D inversion results and suitable for thoughtful geological interpretation. The latter has demonstrated, that LLA is caused not by a single source, but is due to several objects of different geological and structural identity: graphite of highly metamorphosed granulites and graphitized sedimentary and volcanic rocks of lower metamorphic stages in Raahe-Ladoga pericratonic zone. These inferences are also agree with potential field data analyses results.**

2. **In the absence of CCP seismic data at the SW of the Fennoscandian Shield new LLA geoelecrical model has became the main background for extension to the East of Svecafennian accretionary orogen geotectonic model. This model supports the hypothesis of collisional but not extensional tectonics' predominance in the area of LLA in PR time.**

Perspectives

Processing of new data, 3D inversion of the whole combined ensemble of MT\MV data, design of integrated geophysical model of LLA area.

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Developers of effective inversion tooles used.

All field crews, participated in LADOGA WG expeditions.