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# Preliminary results of MHD test registrations in northern Finland

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**Abstract.** Joint Finnish-Soviet registrations using a magnetohydrodynamic (MHD) generator were carried out in northern Finland as a part of the international ELAS project. A powerful MHD generator situated on the Kola peninsula feeds current pulses of 14–20 kA through a 7-km-long electric line into the Barents Sea. These pulses can be received in Finland up to distances of about 450 km. Pulses generated by diesel generators can still be indentified at distances of 200 km.

Because of low industrial noise level and due to the presence of large resistive areas like granites, the MHD method is suitable for studying the crustal electrical structure of the Baltic Shield in northern Finland. Since the field is registered far from the dipole source, the results approach those of plane wave methods. Low frequency parts of the MHD curves indicate a decreasing resistivity in the upper mantle.

**Key words:** MHD generator – Electromagnetic deep sounding – Audiomagnetotellurics – Electromagnetic investigation of the Baltic Shield

## Introduction

From the beginning of the 1970s Soviet geophysicists have used powerful impulsive MHD generators for deep electromagnetic soundings (Velikhov et al., 1975). Several experiments were made in the Urals (Astrakhanchev et al., 1977; 1982), on the Kola peninsula (Pavlovsky and Zhamaletdinov, 1980; Gorbunov et al., 1982) and in some other regions (Velikhov, 1982). In 1982 the first test recordings of MHD signals were organized in Finland, in the framework of the international ELAS (Electrical conductivity of the asthenosphere) project. Measurements were carried out by the Department of Geophysics of the University of Oulu, the Institute of Geology of the Kola Branch of the Academy of Sciences of the USSR and the Institute of Oceanology of the Academy of Sciences of the USSR. The main purpose was to study how well signals of the MHD generator, situated on the Ribatchy peninsula in Kola in the USSR (Fig. 1), can be applied to crustal conductivity investigations of the Baltic Shield in northern Finland.

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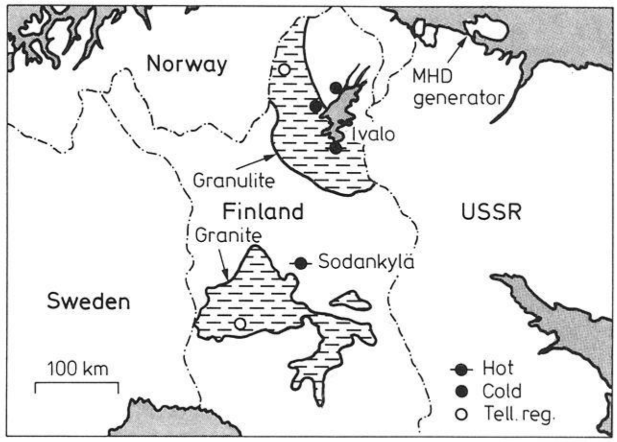


**Fig. 1.** The location of the MHD generator and the stations of the test registrations in 1982

## Primary current pulses

The MHD generator is the newest source of energy in electrical prospecting. It has a capacity of about 80 MW. Its output current is fed into a aluminium cable about 7 km in length and 160 tons in weight (Fig. 2) and grounded in the sea on opposite sides of the isthmus between the Sredny and Kola peninsula (Fig. 2). With this system, called "Khibiny" source, the current pulse can achieve an amplitude of 22 kA. The most common current was 14–20 kA and 5–8 s duration. A typical shape of the primary pulse from the MHD generator (also called "hot pulse") is shown in Fig. 3a. Figure 3b shows the shape of pulses produced by means of an accumulator system, connected to the same cable instead of the MHD generator (so-called "cold" pulses).

Because of its location and its cable geometry, the "Khibiny" system consists of two types of transmitting sources for electromagnetic fields. The first one (magnetic type) is connected with the current that penetrates into the sea gulfs. The velocity of the current penetration can be calculated by means of the equation $V$ (km/s) = 1,600/$S$. $S$ is the longitudinal conductivity of the sea (thin sheet). As $S = 500$ S, then $V = 3$–4 km/s. The magnetic type source is characterized by very low frequencies. The equivalent magnetic moment $I \times A$ reaches $10^{14}$ Am$^2$ according to experimental measurements (Gorbunov et al., 1982).

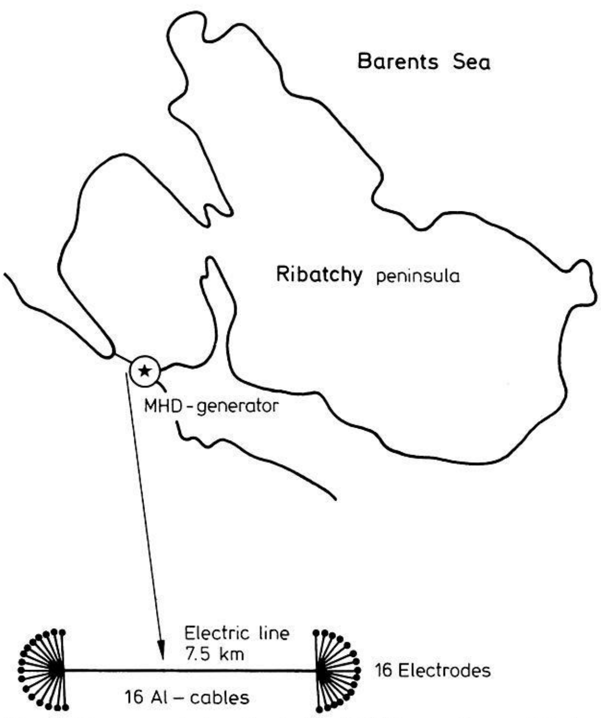


**Fig. 2.** The transmitting dipole for MHD sounding and its location

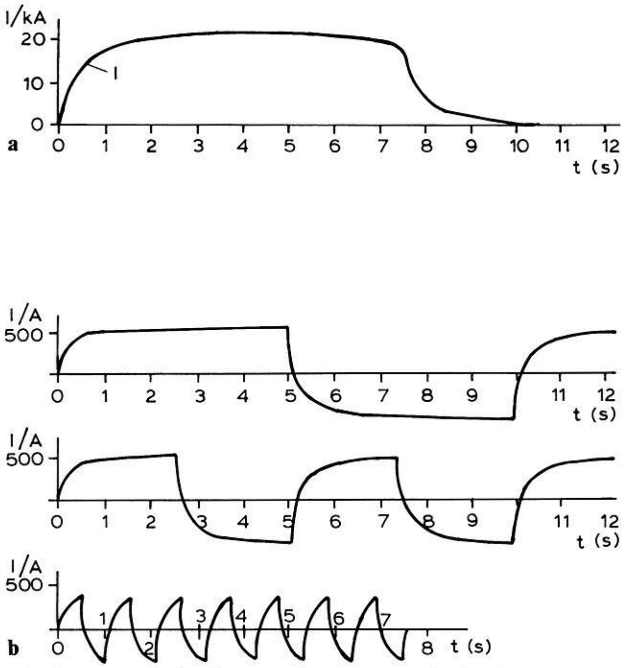


**Fig. 3 a, b.** Typical primary pulses generated. **a** by the MHD generator, **b** by accumulators

The other part of the source (electric type) is connected with the current that penetrates galvanically into the Earth through the sea bottom. It is not more than 15% of the total current. It is necessary to take into account the "prolongation effect": the current penetrating into the sea gulfs forms non-equipotential electrodes and their mutual distance increases with time. According to calculations made

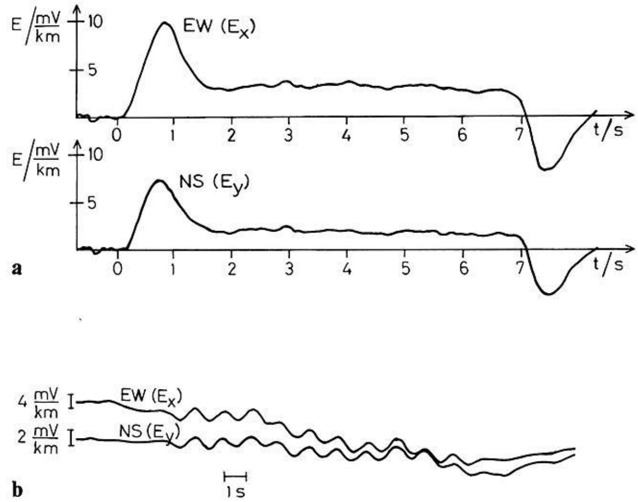


**Fig. 4 a, b.** Examples of registered electric pulse fields. **a** MHD field in Sodankylä, 330 km from the MHD generator, 28 September, 1982 13.00 UT, primary pulse – current 4.6 kA, duration 7.1 s. **b** Accumulator field in Inari, 170 km from the source, 27 September, 1982 08.00 UT, primary pulses – current 400 A, 1 Hz (natural telluric signal variation included)

from field measurements (Zhamaletdinov, 1982), the effective moment $P = I \times L$ of the electric source is taken as $3.5 \times 10^7$ Am for the case when the total current is 20 kA. The electric type source is characterized by high frequencies and is most suitable for studying the upper part of the crystalline basement. As the basement has a very high resistivity ($10^5$ Ohm·m) the skin depth only 0.2 s after switching on the pulse ($f \simeq 1$ Hz) can be

$$h_s = \frac{\lambda}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{10\rho}{f}} = 150\,\text{km}. \qquad (1)$$

In this test work (1982) we registered only electric field components $E_x$ (EW) and $E_y$ (NS) by using 500-m-long telluric lines. The signals were registered analogically by a EPO-9 oscillograph system. A filter, constructed at the Oulu University worked in two bands: 0–3 Hz and 0.05–3 Hz. The first one was applied while measuring "hot" pulses and the second one for "cold" pulses. In Fig. 4 there are examples of telluric registrations of both kinds of pulses.

The measurement sites were chosen on the basis of the geological map. MHD pulses were measured at two points (Fig. 1) situated near the central Lapland granite massive (Sodankylä, $r = 333$ km) and on the granulite belt (Ivalo, $r = 193$ km). "Cold" pulses were also measured at two points situated on the granulite arch (Kaamanen, $r =$ 210 km) and its northern margin (Inari, $r = 180$ km). Only registrations at 1 Hz were performed because of the great distance from the source. At stations Sodankylä and Ivalo we carried out VLF-R measurements of frequencies 15–16 kHz using Geonics EM16R and scalar audiomagnetotelluric (AMT) soundings in the frequency band 2300–7.3 Hz at 11 fixed frequencies using the equipment ECA 542–0. The lowest frequency, 7.3 Hz, is about 5 times the highest frequency which can be calculated from "hot" pulse registrations.

### Data processing and calculations of apparent resistivities

The first stage in processing the MHD data was to digitize the primary field $I(t)$ and the registered electric fields $E_x(t)$ and $E_y(t)$. The sampling frequency was about 6 Hz. Discrete Fourier transformations $I(\omega)$, $E_x(\omega)$ and $E_y(\omega)$ have been calculated from the digitized samples, which were about five times as long as the pulses. Raw Fourier spectra $I(\omega)$, $E_x(\omega)$, $E_y(\omega)$ were smoothed by a box-car function with a width seven times the base harmonic frequency. The highest frequency taken into account in Fourier spectra was about 1 Hz due to aliasing effects at higher frequencies. In these measurements the field was nearly linearily polarized, so the phase difference between $E_x$ and $E_y$ was negligible.

For calculating the apparent resistivity we used the electric part of the "Khibiny" source described above. The azimuthal ($E_x$) and axial ($E_y$) components of the electric field of an electric dipole on the surface of a uniform isotropic half-space are (Veshev, 1980)

$$E_\theta = E_\theta^{wz} \cdot \left[1-(1-kr)\cdot\frac{e^{-kr}}{2}\right] \cdot \sin\theta, \qquad (2)$$

$$E_r = E_r^{wz} \cdot [1+(1+kr)e^{-kr}] \cdot \cos\theta, \qquad (3)$$

where

$k = \sqrt{i\omega\mu_0/\rho}$ = the wave parameter,

$\omega = 2\pi f$ = frequency,

$r$ = the distance between source dipole and measuring point,

$\theta$ = the angle between the AB and direction to the measuring point.

In the wave zone, where $|kr| \gg 1$, these equations reduce to

$$E_\theta = E_\theta^{wz} \cdot \sin\theta = \frac{P \cdot \rho}{\pi r^3} \sin\theta, \qquad (4)$$

$$E_r = E_r^{wz} \cdot \cos\theta = \frac{P \cdot \rho}{2\pi r^3} \cos\theta. \qquad (5)$$

The electric moment $P = I \times L$ is taken, in our case, to be equal to $3.5 \times 10^7$ Am. In the near zone, where $|kr| \ll 1$, these equations reduce to

$$E_\theta = E_\theta^{wz} \cdot \frac{1}{2} \cdot \sin\theta, \qquad (6)$$

$$E_\theta = E_\theta^{wz} \cdot \cos\theta. \qquad (7)$$

The measured total field $|\mathbf{E}_\omega|$ was calculated from the Fourier transformed spectral components $E_x(\omega)$ and $E_y(\omega)$. The equation for apparent resistivity is

$$\rho_a(\omega) = K \sqrt{\left[\frac{E_x(\omega)}{I(\omega)}\right]^2 + \left[\frac{E_y(\omega)}{I(\omega)}\right]^2}, \qquad (8)$$

where the geometric factor $K$ was taken for the total vector of horizontal electrical field calculated for the wave zone according to Eqs. 4 and 5. Close to the equatorial line of the transmitter dipole the geometric factor is equal to

$$K = \frac{2\pi r^3}{L(\cos^2\theta - 3)}. \qquad (9)$$

The transient region between the wave zone and the near zone was estimated by means of Eqs. 2 and 3.

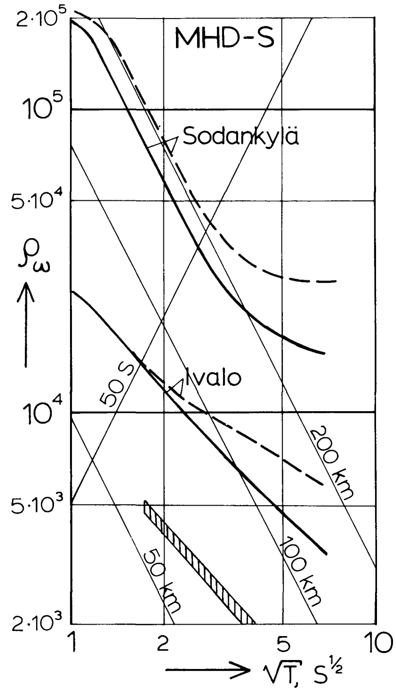


**Fig. 5.** Apparent resistivity curves for Sodankylä and Ivalo stations calculated from MHD and accumulator pulse registrations. *Full line:* $\rho_\omega$ calculated by Eqs. (4) and (5). *Dashed line:* $\tilde{\rho}$ corrected for the effect of the transient region using Eqs. (2) and (3). *Depth lines:* depth to an ideal horizontal conductor. *Hashed region:* global sounding curve (Vanyan et al., 1977)

### Results

The analysis of the data obtained after the first experimental measurements in 1982 showed that the electrical structure of the Earth's crust in the northern part of Finland is rather complicated. The northernmost region of the granulite arch stands out as a more conductive part. The apparent resistivity at the frequency 1 Hz varies from $5 \times 10^3$ to $3 \times 10^4$ Ωm here (Ivalo, Kaamanen, Inari). At the farthest point, Sodankylä, a higher resistivity was recognized ($\simeq 2 \times 10^5$ Ωm at the frequency 1 Hz). This is in agreement with our preliminary supposition, that these should be the most favourable conditions for deep sounding due to absence of sharp electrical heterogeneities.

The results of calculation of the apparent resistivity curves from MHD signals, as a function of frequency, are shown in Fig. 5. The result shows that in Sodankylä the far zone $\rho_a$ curve (solid line) is located high up on the scale. The curve $\tilde{\rho}$ (corrected resistivity for the influence of the transient zone) lies somewhat above. This indicates that at this measuring point, due to high resistivity of the section, we do not achieve the wave zone even at the highest frequency (1 Hz). But the difference between the curves is not very great (much less than a factor two) and we can use approximately plane wave calculations. The preliminary interpretation of the $\rho_a$ curve gives us the depth to the conducting boundary as 150–200 km, but this conclusion needs to be confirmed by new experimental measurements and theoretical calculations. Measurements should include the registration of the magnetic field components in order to enable alternative apparent resistivity calculations.

At Ivalo the $\rho_a$ curve is at a much lower level. The registrations made with different electrode directions differ

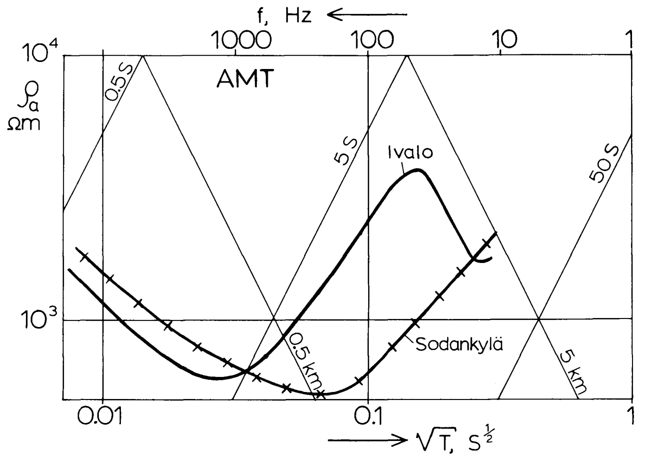


**Fig. 6.** Apparent resistivity curves calculated from scalar AMT measurements. Geometric mean of two perpendicular $\rho_a$ curves are shown

sharply from each other. This points towards an influence of anisotropy. In spite of the short distance (193 km) the $\rho_a$ curve is almost totally in the wave zone, we can not interpret it by a layer model because it is influenced by horizontal heterogeneities.

At both points, Sodankylä and Ivalo, AMT soundings were carried out. The results are shown in the Fig. 6. These curves are on the same scale as Fig. 5. The apparent resistivities are on the same level at these points, but they differ in level from MHD data. This is most probably connected with the differences in the nature of sources, but this difference will need further study.

## Conclusions

The use of the MHD generator signals seems suitable for studying deep conductivity structure of the Baltic Shield in northern Finland. The measured signal levels are favourable, mostly because of negligible sedimentary cover and a high resistivity of large parts of the basement. The noise level was also low during the experiment.

The results for natural field plane wave (AMT) soundings seem to differ from those of the controlled source soundings. The apparent resistivities of the MHD sounding give values which are higher than the global normal curve (Vanyan et al., 1977). This interesting, although still preliminary result, must be thoroughly checked by future measurements.

In this study, only the analysis of the electric dipole source field has been considered. It seems natural to conduct further studies, where close attention must be paid to the better use of the two source types of the MHD generator system "Khibiny".

Systematic five-component measurements in Finland have already been started, in autumn 1983 (Heikka, 1983). The results of these registrations will be discussed in our future publications.

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## References

Astrakhanchev, G.V., Babakov, Yu.P., Bulashevich, Yu.P., Velikhov, Ye.P., Volkov, Yu.M., Dyakonov, B.P., Zhukov, B.P., Zotov, A.V., Krasnobayeva, A.G., Kuksa, Yu.I., Pisakin, A.V., Titlin, V.S., Ulitin, R.V. and Khachai, O.A.: Induction sounding of the Earth's crust in the Urals using an MHD generator (in Russian). Moscow Dokladi Akademii Nauk SSSR, Acad. of Sci. USSR, Vol. **237**, No. 5., 808–811, 1977

Astrakhanchev, G.V., Dyakonov, B.P., Skachkov, P.P., Titlinov, V.S. and Ulitin, R.V.: Deep electromagnetic sounding in the Urals with MHD generator (in Russian). Geomagnetic Researches, Acad. of Sci. USSR, No. 28, 46–52, 1982

Gorbunov, G.I., Belkov, I.V., Pavlovsky , V.I., Zhamaletdinov, A.A., Velikhov, Ye.P., Volkov, Yu.M. and Dreizin, Yu.A.: On the character of electroconductivity of Earth's crust of the Kola Peninsula from the sounding data obtained by MHD generator (in Russian). Geomagnetic Researches, Acad. of Sci. USSR, No. 28, 85–93, 1982

Heikka, J.: 5-component MHD registrations in Northern Finland in 1983. Paper read at the Symposium "The geoelectric model of the Baltic Shield", Oulu, Finland, 1983

Pavlovsky, V.I., Zhamaletdinov, A.A.: Geological results based on soundings by means of MHD generator in the Kola Peninsula. In: A method and results of geophysical research in the northeastern part of the Baltic Shield (in Russian). Apatity, Publ. of the Kola Branch, 1980

Vanyan, L.L., Berdichevsky, M.N., Fainberg, E.B., Fiskina, M.V.: The study of the asthenosphere of the East European platform by electromagnetic sounding. Phys. Earth Planet. Inter. **14**, 1–2, 1977

Velikhov, Ye.P. (ed.): Deep electromagnetic soundings with impulsive MHD generators. Publ. of the Kola Branch of the USSR Acad. Sci., Apatity, 1982

Velikhov, Ye.P., Volkov, Yu.M., et al.: Proc. VI International Conference on MHD generators. Vol. 5, 211–222. Washington, 1975

Veshev, A.V.: Electrical profiling with direct and alternating currents (in Russian). Leningrad, 1980

Zhamaletdinov, A.A.: Normal electric section of the crystalline basement and its geothermal interpretations according to MHD sounding on the Kola Peninsula. In: Deep electromagnetic soundings with impulsive MHD generators, Ye.P. Velikhov, ed.: pp 35–46. (in Russian) Publ. of the Kola Branch of the USSR Acad. Sci., Apatity 1982

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