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ELECTRICAL GEOPHYSICS IN THE USSR

Technical summary of visit to USSR by B.R. Spies, under the Australia-USSR Agreement on Scientific and Technical Cooperation, 14/9/79 to 2/11/79

by

B.R. Spies

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1. INTRODUCTION

During the period 14/9/79 to 2/11/79 a visit was made to the USSR by B.R. Spies of the Australian Bureau of Mineral Resources, Geology and Geophysics (BMR). The visit was made under the auspices of the Australia-USSR Agreement on Scientific and Technical Co-operation, and the host institution was the Ministry of Geology of the USSR.

The objective of the visit was to review the application and interpretation of the electromagnetic, resistivity and induced polarisation methods of geophysical prospecting, as applied to metalliferous and petroliferous problems. Visits were made to various institutes of the Ministry of Geology and the Academy of Sciences of the USSR, at Moscow, Novosibirsk and Leningrad. A list of the institutions visited and itinerary is given in Table 1.

Whilst in Novosibirsk, there was discussion on further areas of co-operation with officers of SNIIGGIMS. Suggestions arising from these discussions were incorporated in a Protocol for the Ministry of Geology and is reproduced in Appendix 3.

This report is based on handwritten notes taken via an interpreter during discussions with scientists, except in one case where an interpreter was not required. As with all translations, there may be certain misunderstandings or inaccuracies. However, for the sake of completeness and so that the reader may reap the maximum benefit from the trip, all items discussed have been included. In addition, the report has been supplemented by the inclusion of various case-histories, field examples and other data obtained from Russian books collected during the trip.

The next section of this report contains a list of geophysical organisations in the USSR. This is followed by the summary of the main findings of the visit. Appendix 1 contains a glossary of terms and abbreviations commonly used in electrical geophysics in the USSR, which will be useful when reading following sections of the report. The detailed discussions, together with the examples from the books mentioned above, are given in Appendix 2. This appendix is subdivided into sections which deal with topics discussed at the various institutions. Common Russian terms, literally translated, are sometimes used, to aid the reader in understanding translations given later in the report.

Appendices 4 and 5 give details of the scientists and addresses of their institutions. Appendix 6 contains selected translations of contents lists, abstracts and chapters of books collected during the visit. All the references are available in BMR's library.

Table 1. ITINERARY

17/9 - 20/9, 31/10	VNII - Geofizika (All-Union Geophysical Institute of Ministry of Geology), Moscow
21/9	IZMIRAN (Institute of Earth Magnetism, Ionospheric and Space Physics), Academgorodok, Moscow
25/9	Institute of Oceanology, Academy of Sciences, Moscow
26/9 - 27/9	TSNIGRI (Central Research Institute of Geological Exploration), Moscow
1/10 - 2/10	MGRI (Moscow Geological Research Institute), Moscow
4/10 - 10/10	SNIIGGIMS (Siberian Research Institute of Geology, Geophysics, and Mineral Resources), Novosibirsk
11/10 - 17/10	IGG (Institute of Geology and Geophysics), Siberian Division of Academy of Sciences, Academgorodok, Novosibirsk
18/10 - 29/10	VITR (All-Union Institute of Techniques and Methods of Exploration), Leningrad
1/11	Machinoexport, Moscow

GEOPHYSICAL ORGANISATIONS IN THE USSR

Geophysical studies are carried out by various institutions in the USSR. These are generally part of the Ministry of Geology or the Academy of Sciences of the USSR. The role of the Ministry of Geology is similar to that of the BMR in Australia, but it is composed of All-Union institutes (those dealing with the whole of the USSR) and other institutions which concentrate on individual Republics. The Academy of Sciences is more concerned with fundamental research, and often works closely in conjunction with organisations in the Ministry of Geology. In addition, various teaching institutes are involved in geophysical studies.

MINISTRY OF GEOLOGY

The Ministry of Geology has a staff of 500 000 and is divided into various departments/institutions, as shown in Figure 1. Those discussed in this report, and their field of interest, are:

TSNIGRI (Central Research Institute of Geological Exploration).
- specializes in methodology of geology, geophysics, mining and processing. Geology is the major activity, and the institute does not design apparatus.

VNII-Geofizika (All-Union Geophysical Institute of Ministry of Geology).
- this institute deals exclusively with geophysics, and its main area of interest is in oil and gas exploration.

VITR (All-Union Institute of Techniques and Methods of Exploration).
- specializes in downhole methods and drilling techniques. VITR is part of Union Geotechnika, an industrial organisation. In 1973 VITR was combined with other organisations, and in January 1979 received powers of an All-Union Institute, with powers of a Department, and is now part of VPO All-Union Geotechnica.

NPO-Geofizika (Union Production Scientific Organisation-Geophysical).
- includes the manufacture of industrial equipment.

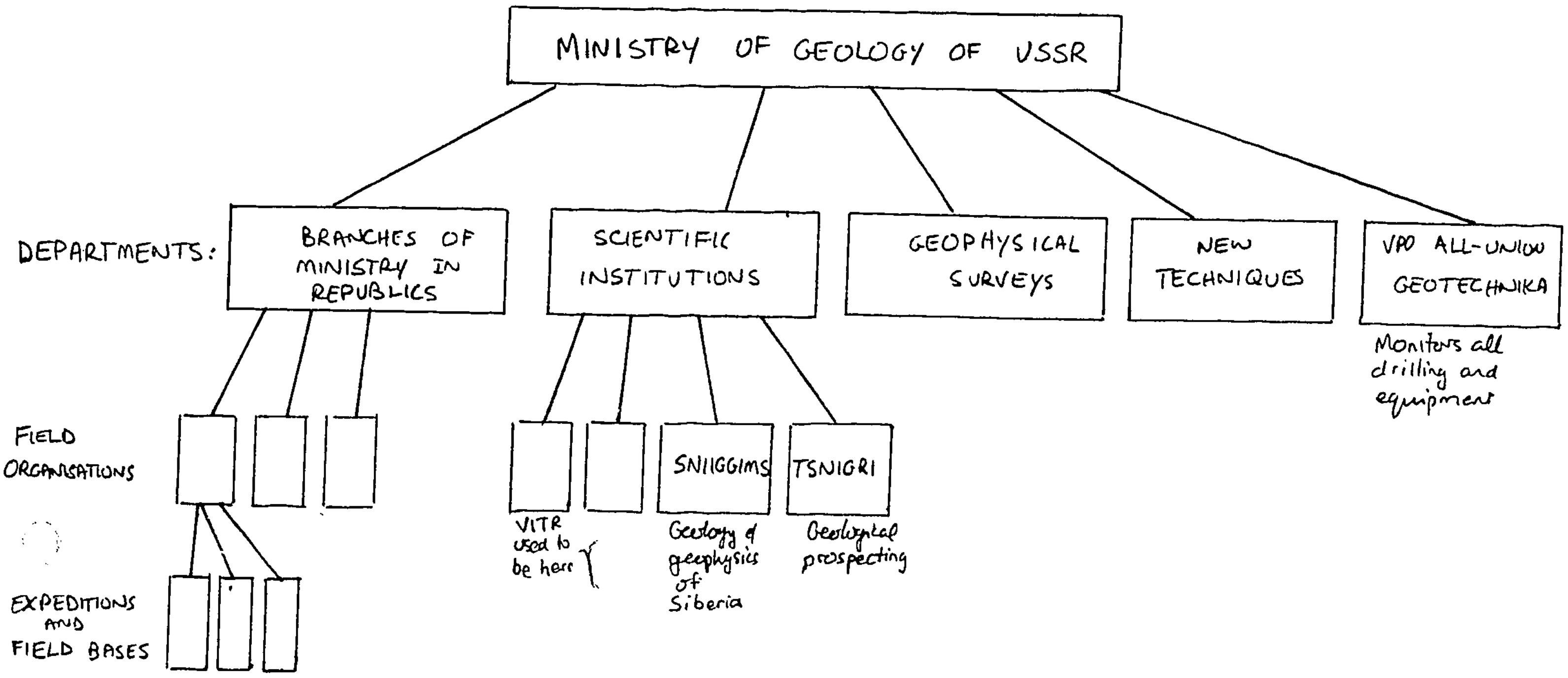

Figure 2.1 Structure of Ministry of Geology of USSR.

SNIIGGIMS (Siberian Research Institute of Geology, Geophysics and Mineral Resources) - specialises in the geology, geophysics and mineral resources of Siberia, including mapping, exploration and equipment development.

ACADEMY OF SCIENCES OF USSR

The Academy of Sciences is more research oriented than the Ministry of Geology, but does work in close conjunction with it. The branches include:

- IΦZ (Institute of Physics of the Earth)
- IZMIRAN (Institute of Earth Magnetism, Ionospheric and Space Physics).
- Institute of Oceanology.
- IGG (Institute of Geology and Geophysics, Siberian Division of Academy of Science).

MINISTRY OF HIGHER EDUCATION

- MGRI (Moscow Geological Research Institute). This is a teaching institute, and is more applied than Universities.

SUMMARY OF MAIN SCIENTIFIC DEVELOPMENTS

VNII GEOFIZIKA (ALL UNION GEOPHYSICAL INSTITUTE OF THE MINISTRY OF GEOLOGY)

This institute has a staff of over 1000. The Moscow branch is the largest, and deals exclusively in oil and gas.

Use of Electrical Methods in Oil and Gas Exploration

Electrical methods are widely used in the USSR for oil and gas exploration, and comprise magnetotelluric (MT), transient sounding and induced polarization (IP). The USSR has 100 MT crews and 30 electrical sounding crews. MT is routinely used as a reconnaissance method before seismic; annual expenditure being of the order of A$20-30 million.

Applications of electrical methods can be subdivided into regional, semi-regional and prospecting. Regional surveys study the tectonic framework and detect lateral changes, to a depth of 6000 m. The main method used is MT, with some transient sounding. Semi-regional surveys involve profiles up to 50 km long, using transient sounding as the main method with some MT and IP. The prospecting phase takes place after initial drilling, and transient sounding and IP are used to map the lateral extent of the oil and gas reservoir.

Models used to aid interpretation include 2D numerical and 3D scale models.

The equipment used for both MT and transient sounding is the Universal Digital Station (CES), which is capable of data acquisition in the 0.001 Hz to 10 Hz frequency range.

For IP measurements, the INFAZ-BPM equipment is used, which measures in the frequency range 0.03 to 312 Hz. Measurement of the fundamental frequency and 3rd and 5th harmonics allows automatic first-order removal of inductive coupling. Orthogonal arrays are usually employed to reduce inductive coupling.

Typical IP results over oilfields are two polarization maxima over the edges of the deposit, with a mimimum in the centre. The IP anomaly is attributed to pyritization which is formed in the reducing environment around the oil/gas deposit.

Computer processing uses an electrical prospecting package called EPAK, which is capable of handling MT, transient and electrical sounding, and IP. The first stage of processing is performed on mini-computers and comprises demultiplexing, checking and re-writing data on standard IBM tape. The IBM tape is then sent to regional or expedition processing centres for processing on larger computers of the ES 1020, 1030 and 1040 series, which are similar to the IBM 370 series. Processing involves 1D and 2D models, and limited 3D modelling using the finite element method. Inversion techniques are now being widely applied.

IZMIRAN (INSTITUTE OF TERRESTRIAL MAGNETISM, IONOSPHERIC AND SPACE PHYSICS)

This institute is mainly concerned with solid earth geophysics. The magnetic observatory uses proton precession and caesium vapour magnetometers with an accuracy of 1 nT. The magnetic variometers use quartz fibre suspensions which are manufactured on site, and have a low drift of 1 nT per 4 years.

Although most field work uses natural fields, one experiment used a magnetohydrodynamic generator (MHG) which can generate currents up to 10^6 amps. In a field experiment in the Kola Peninsula, fields were measured at distances of up to 750 km.

INSTITUTE OF MARINE GEOPHYSICS, ACADEMY OF SCIENCES, USSR

The main use of electrical methods in marine geophysics is marine MT, which is applied to deep structural problems at depths to 6000 m. The MT equipment is left to record for several days, and then recovered.

TSNIGRI (CENTRAL RESEARCH INSTITUTE OF GEOLOGICAL EXPLORATION)

TSNIGRI has two geophysical departments, one which deals with resource assessment on 1:500 000 and 1:50 000 scales (using gravity and magnetic methods), and the other which assesses new methods and interpretation techniques (especially EM).

Airborne FEM

The DUP-A (dipole inductive profiling-aerial) airborne system is used widely in western Siberia and Asia for exploration for highly conductive ore-bodies and geological mapping at shallow depths (less than 50 m). The system employs a large transmitter loop wound around the aircraft wings and a set of orthogonal receiving coils in a towed bird, and measures at frequencies between 78 Hz and 5000 Hz. The major and minor axes of the polarization ellipse are measured. Ten systems are presently in use.

Ground FEM

The EPP-2 system employs frequencies between 78 Hz and 20 kHz. The transmitter is a horizontal coil, and the receiver consists of two orthogonal ferrite coils, which enables measurement of the axes of the polarization ellipse. This system can also use a large transmitter loop or grounded wire, but is not widely used because of its limited depth of penetration.

EM sounding

A wide variety of loop-electrode configurations is used. Electrodes are used for both receiver and transmitter when the upper layer is resistive. A loop is used as a receiver when the target is highly conducting. For deep EM sounding, both E and H are measured to aid interpretation.

DUM (Two-loop inductive method)

This method is a frequency-domain analogue of the single-loop transient method, and is used in very noisy areas. Coincident transmitting/receiving wires are connected by means of an air-cored transformer which can compensate the received signal until it is exactly 90° out-of-phase with the primary (transmitter) coil. The frequency range is 20 to 20 000 Hz.

VLF and Radio Wave Methods

Work on the VLF method was started in the USSR in 1962. At present there are 15 airborne systems, which employ VLF, magnetic and radiometric methods. The main areas of use are in the Far East and Siberia, where there is favourable geology, i.e. highly resistive host rocks. The method is useful for mapping major tectonic units.

Ground measurements are used for detailed prospecting for bodies of high resistivity. The method is also used for well logging (see section on VITR).

The integral equation method has been used to obtain solutions for a horizontal and dipping plate in a halfspace, and for a truncated second layer in a two-layer earth, which are used for interpretation.

MGRI (MOSCOW GEOLOGICAL EXPLORATION INSTITUTE)

MGRI is a teaching institute and currently has fifty geophysics students in electrical/EM techniques. The main research aims are harmonic induction methods, TEM and IP.

Low Frequency Induction Method (LFIM or NP)

This method involves comparison of the measured magnetic field obtained using a low frequency inductive source and the earth's magnetic anomaly field. It is then possible to determine the relative amounts of residual (remanent) and induced magnetisation. The method has been used over all the major USSR iron ore deposits to aid in exploration and the estimation of reserves.

The equipment used is relatively simple, and consists of a standard IP transmitter and a special magnetic-cored receiver coil. With present technology the errors due to noise and topography limit the method to magnetic anomalies of about 1000 nT.

Methods of interpretation include a two-layer earth and a sphere in a two-layer ground.

Airborne TEM (AMPP)

Development of an airborne TEM system started in 1968. The present system is helicopter-borne and uses a large horizontal transmitter loop, wound around the helicopter, with a dipole moment of 6×10^4 Am. The receiver coil is towed in a bird. Because of the slow flying speed, the bird is located underneath the helicopter and it is possible to measure the vertical component since small changes in position will have little effect on the received signal.

The time range of measurement is 0.2 to 3 ms, which gives a greater depth of penetration than INPUT, but less than ground systems.

The system is used as a substitute for ground work, and the typical coverage is 200 km per day at 100 m line spacing.

SNIIGGIMS (SIBERIAN RESEARCH INSTITUTE OF GEOLOGY, GEOPHYSICS AND MINERAL RESOURCES)

SNIIGGIMS specialises in the geology, geophysics and mineral resources of Siberia. Since Western Siberia contains 1/3 of USSR oil reserves, and eastern Siberia appears prospective, much of the effort of SNIIGGIMS is directed towards oil and gas exploration.

Geophysics

The main minerals of interest are copper-nickel, diamonds, polymetallic lead-zinc and iron. The main methods used are magnetic, gravity, seismic, IP, TEM, S-P and misse-a-la-masse.

TEM Instruments

A major development of SNIIGGIMS is in new TEM instruments TSIKL (Cycle) and IMPULSE. TSIKL has many applications, such as sounding for oil and mineral prospecting, and can measure in the time range 0.1 ms to 44.8 ms. This range enables it to be used for deep sounding, either in a coincident loop mode, or using a central receiving coil.

IMPULSE is still in the prototype stage, and was developed for shallow sounding in ore prospecting. The time range is 10 μs to 80 ms, and the instrument uses integrated circuits and digital averaging to 10^4 cycles. Internal noise on short runs is 0.3 μV, and on 10^4 cycles is 0.1 μV.

Carborne TEM

A carborne TEM system has been developed which is useful in areas of tundra and steppe. The receiver and transmitter are mounted on trailers towed at least 3 m from the vehicles.

The transmitter consists of a 10-turn loop with a current up to 500A, resulting in a total moment of 2×10^5 Am. The transmitter-receiver separation is commonly 50 to 80 m, and the vehicles are stopped for readings.

Superconducting Magnetometers

Superconducting magnetometers (SQUIDS) have been in use for about 5 years, and are used in experimental IP, TEM and MT surveys. There are presently five in use, with a frequency range up to 25 kHz for oil prospecting, and 100 kHz for ore prospecting. The sensitivity is 10^{-5} nT.

TEM (MPP) - Method of Transient Processes

The main applications of TEM are in prospecting for copper-nickel, polymetallic deposits and magnetic rocks and kimberlites at depths up to 2 km, and determining the thickness of overburden for gravity corrections. In this field, SNIIGGIMS is linked closely to the Academy of Sciences for interpretation. A variety of loop configurations can be used, including single loop, electrode-loop and loop-loop. The magnetic field component can be either horizontal, vertical or time derivative.

One method of interpretation calculates the longitudinal conductance S, and depth H, of equivalent thin layers in a multilayered section. Results can be interpreted for models of a circular disk in a layered ground, and a 2D plate.

ZSB - Sounding by Establishment of the Near-Field

This is a TEM deep sounding technique developed at SNIIGGIMS ten years ago which uses small receiver-transmitter separations in comparison with the depth of investigation. TSIKL was developed for this purpose. Interpretation is by means of five-layer curves for loop-loop and loop-electrode configurations. Special arrays are sometimes used for detecting lateral resistivity changes. One of the configurations employs two horizontal-component SQUID magnetometers located on opposite sides of a large transmitting loop.

In the Siberian Platform, the combination of seismic and ZSB methods is very successful. About 1500 soundings are made annually, to a depth of about 3 km. The ZSB method is particularly useful in areas where high velocity volcanic layers render the seismic method ineffective.

Downward Continuation

A new interpretation technique being developed is that of downward continuation of frame-loop TEM data. This method enables separation of closely-spaced bodies and accurate estimation of their depth.

MTMPP

This method is a combination of MT and TEM and uses natural source EM fields, such as magnetic fields or Schumann resonances. The method is still in its infancy, but does offer the theoretical advantage of being much faster than MT, and not requiring a transmitter as with TEM.

IGG (INSTITUTE OF GEOLOGY AND GEOPHYSICS, ACADEMY OF SCIENCES)

Applications for deep sounding include detecting intercrustal conductive layers and mapping the top of the mantle. At IGG it is now considered that transient methods are superior to frequency domain methods for sounding applications. Theoretical curves exist for such models as horizontal layers, lateral inhomogeneities, and an on-axis vertical plug in a two-layer earth. Early theoretical derivations employed the integral equation method, but now the finite difference method is considered preferable.

Problems which are currently being studied include sounding for diamond pipes and quasi-3D profiling, i.e. an off-axis cylinder in a two-layer earth.

Logging

Downhole logging techniques are considered very important in areas prospective for oil and gas such as the Siberian Platform. Most are DC methods, but also include frequency, induction, and dielectric methods. The main direction of present research is to develop tools which can determine the coefficient of anisotropy and exclude the transition (invasion) zone by the use of a combination of geometric and frequency focusing.

VIK (high frequency induction logging) uses frequencies up to 70 kHz to allow the estimation of resistivities in the 0.3 to 150 ohm-m range. This led to a new technique called isoparametrical logging (VIKIZ) in which some parameters are automatically cancelled to reduce the effect of inhomogeneities. For example, as the sonde length is changed there is a corresponding change in frequency so that whole-space response remains unchanged.

Deep logging techniques have been developed which enable logging at depths of 5 to 6 km for 6 hours.

A new method, called magneto-electric logging (MEL) has been developed. This allows the determination of the coefficient of anisotropy, using a non-symmetrical array in which both E and H are measured. By means of geometrical focussing the same radius of investigation is achieved using a 1-metre 4-component MEL sonde as with a conventional 10 m lateral sounding sonde.

VITR (ALL-UNION SCIENTIFIC INSTITUTE FOR METHODS AND TECHNIQUE OF PROSPECTING)

VITR has a staff of 800 and deals exclusively in methods of drilling and down-hole techniques. The three main branches are techniques of diamond drilling, drilling rigs and installations, and borehole geophysics. The surface TEM methods were developed for siting drill targets.

VITR has developed several new inductive and geochemical methods.

Borehole Magnetometer

The TSMK-30 magnetometer is a 3-component, 30 mm diameter model, first developed in 1972.

Interborehole Radio-Wave Shadowing

Interborehole radio-wave shadowing techniques are used to determine t. continuity of ore deposits between drill holes, and to map the boundaries of the deposit. The application of this method is restricted to areas of moderately resistive host rocks. The equipment used is the CPP-30, which is 30 mm in diameter, and can also be used as a 1-borehole variant. Cver 200 sets of this equipment are now in use.

Borehole Induction Prospecting

Harmonic borehole induction methods are now widely used in the USSR. There are four basic variants: dipole-dipole (DEMPS), interborehole (MDEMP), method of field of currents (MPT), and a large transmitter loop.

The dipole-dipole (DEMPS) system ASMM-40M employs a 3 component receiving coil, 40 mm in diameter, and an axial-component transmitting coil separated by distances of 25, 50, 75 and 100 m. Frequencies employed range from 125 to 3375 Hz. DEMPS has now been used in 15,000 boreholes over 5 years, and the Ministry of Geology now requires that all boreholes be logged with DEMPS, because of the consequent reduction in drilling.

The interborehole (MDEMP) technique was developed three years ago. It has advantages in areas of sparse boreholes, and is capable of detecting orebodies up to 200 m beneath the bottom of boreholes. The maximum borehole separation is about 300 m. The method is also useful for determining the continuity of deposits.

The Method of Field of Currents (MPT or misse-a-la-masse) uses a transmitter grounded on the orebody or drill casing. The radius of investigation is increased to 150 to 250 m.

A large transmitter loop can be used in the one borehole variant (MPT-0) or two-borehole variant (MPT-2). Because of the stronger primary field, a smaller 30 mm diameter probe can be used. VITR does not consider the MPT-0 variant very useful because of the limitations caused by the large background field and limited depth of application.

For all of the variants listed above, the ASMM-40M equipment can be used. For MDEMP a special generator is employed. A new system, SINUS, has been developed, which uses frequencies in the range 125 to 22,000 Hz, and has a digital readout. It is more sensitive than the ASSM-40M system and can be used in holes whose deviation from vertical is greater than 2°.

Interpretation methods for down-hole methods are well developed. Scale model suites for the DEMPS variant are available for infinite, semi-infinite, thick and thin plates, thick and thin ribbons, and a disk. For MDEMPS, interpretation procedures are based on a dipping body being intersected by two, one or no drillholes.

MPP-4 TEM Equipment

TEM methods were developed at VITR for searching for non-intersected bodies and siting drillholes. The MPP-4 is in the development phase, and has three variants: one-loop, frame-loop and borehole. The transmitter supplies 20 A pulses 24 or 48 ms wide, and the receiver measures at times between 1 and 48 ms. The one-loop variant can employ loops up to 400 m in size. The one-loop variant is used in large areas in a reconnaissance node.

For the frame-loop variant, a three-component coil is located up to 1 km from the transmitter, and radio synchronisation is used. The frame-loop is better for detailing deposits. The detection limit is about 200 m for a highly conductive body of size 200-500 m. The borehole variant uses a 40 mm diameter ferrite-cored coil with three sets of orthogonal windings. The dipole moments of the axial and perpendicular coils are 200 m^2 and 800 m^2 respectively. The borehole variant is used at depth of up to 400 m.

Interpretation aids consist of model curves for finite and infinite thin sheets at different dips and depths, and also a sphere both inside and outside the loop.

Piezoelectric Methods

Piezoelectric methods are used for exploration for different types of quartz-veins, pegmatites and polymetallic deposits containing sphalerite. The piezoelectric effect depends on total volume, texture and grainsize, and can be used to differentiate between different genetic types of quartz veins.

The present equipment used is the KVARTS-1 of which 100 sets have been produced since 1973. It can be used in both surface and borehole variants. Another instrument, PAM3-8, has been developed at TSNIGRI for mine use.

The ground variant is used for depths less than 20 m. The source can either be explosive or non-explosive. The borehole variant can be used for two or more boreholes and has a range up to 100 m. The mine variant also has a range of about 100 m. The shots are located either in drill holes or the mine using directional explosives.

CHIM (Partial Extraction of Metals)

This is an electrochemical method in which water-soluble components are extracted from soil or rock by the passage of current through a porous electrode. The elements Cu, Pb and Fe are analysed to 0.01 μg/ml and Au to 0.003 μg/ml. In one example a polymetallic deposit was detected under 200 m of loose overburden.

The method can be used in a surface variant (halo CHIM), and as a logging method.

KSPK (Contact Technique of Polarisation Curves)

KSPK is an electrochemical technique developed at VITR for determination of the mineral composition, concentration of individual minerals and total reserves of an ore deposit, and has been widely used since 1972 in much of the USSR.

The transmitter uses one electrode in contact with the ore deposit and the current is gradually increased up to 200 amps. The potential difference is measured using surface electrodes, and plotted as a function of the current. The curve has a non-linear behaviour, due to the contact potentials of the various constituent minerals in the deposit, which can be identified by their characteristic potentials.

The method can also be used to determine whether intersected ore zones are connected, and whether minerals not intersected in the borehole are present elsewhere in the body.

The method is said to reduce drilling by a factor of ten, and is in wide demand. Only 3 to 5 units of the equipment, KSPK-1, are produced per year, and this is insufficient to meet demand. Each unit requires three trucks to mount the equipment, and 12 units have been built so far. There are several variants of the KSPK method, in which the receiver is located either on the surface or in another borehole.

A new development is a surface variant called SPK. Both the transmitting and receiving electrodes are located on the surface, and the method is used to locate the body and to outline areas of different mineralisation.

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APPENDIX 1. GLOSSARY OF TERMS AND ABBREVIATIONS

AB.	Transmitting grounded electrode pair
ab.	Receiving grounded electrode pair
ASMM-40 (ASMI-40)	Instrument developed at VITR for harmonic (FEM) borehole induction prospecting (40 mm diam.). (ASMM-40 M is the 1977 modified version).
AMPP.	Airborne MPP (TEM)
Axial array.	Dipole-dipole in-line array.
CES-2 (TSES-2)	Universal Digital station. Digital recording equipment developed at VNII-Geofizika for MT and transient sounding.
CDB.	Super-long radio waves. Equivalent to VLF.
CHIM.	Method of partial extraction of metals. An electrochemical method for extracting soluble ions, developed at VITR.
CPP-30.	Instrument for interborehole radio-wave shadowing, developed at VITR.
CYCLE	See TSIKL
DEMIS	Single hole borehole EM
DUP-A.	Dipole Inductive Profiling - Aerial. An airborne FEM system developed at TSNIGRI
DUM.	Two-loop transient method. A frequency domain analogue of single loop TEM.
DEMPS.	Borehole dipole-dipole induction prospecting
DHP-4.	Downhole FEM, large-Tx loop system developed by Scintrex Pty Ltd

EPP.	A ground FEM technique, developed at TSNIGRI, which measures parameters of the polarisation ellipse
EPP-2.	Equipment developed at TSNIGRI for EPP measurements.
ERS-67	General purpose generator/transmitter used at VNII-Geofizika for electrical sounding.
Far zone.	In EM methods, where spacing, R, and frequency ω are large (small T), such that $\sigma\mu\omega R^2 \gg 1$. The magnetic and electric field vectors are at right angles to each other, and the wave front can be thought of as a propagating plane wave. Also used for sounding where the depth of investigation is smaller than the receiver-transmitter separation (See ZSD).
FEM.	Frequency domain electromagnetic (harmonic)
Frame-loop.	TEM variant in which the Rx is a small coil.
Harmonic.	Frequency domain
H.	Depth
IZMIRAN.	Institute of Earth Magnetism, Ionospheric and Space Physics, Academgorodok, Moscow (part of Academy of Sciences)
IGG	Institute of Geology and Geophysics, Siberian Division of Academy of Sciences.
IK	Induction logging
IKT	Induction logging of Transverse (conductivity) - method developed at IGG to measure anisotropy in an arbitrary direction.
Im.	Imaginary component.
INPUT.	Airborne TEM system developed by Barringer Research Ltd, Canada.

IMPULSE.	A TEM system developed by SNIIGGIMS for shallow sounding
Isometric.	Equi-dimensional
KVARTS-1.	Piezoelectric field instrument designed at VITR. Replaces 8-SEV2m.
KSPK.	Contact technique of polarization curves, involving non-linear electrochemical reactions. Developed at VITR.
KSPK-1.	Equipment used for KSPK measurements.
K (Russian).	Used as subscript for "apparent"; equivalent to English "a"
Longitudinal conductance.	See S.
Lateral conductance.	See S.
MGRI.	Moscow Geological Research Institute, Ministry of Geology, Moscow.
MACHINOEXPORT.	Deals with all trade of mining and related equipment. Moscow.
MPP.	Method of transient processes. Same as TEM
MPPO-1	Single loop TEM equipment developed at VITR in the early 1960s. 140 units were produced until production ceased in 1972.
MPP-4.	Equipment developed at VITR for TEM surface & borehole measurements.
MEL.	Magneto-electric logging (MEK in Russian). A logging technique which measures anisotropy using a short sonde; developed at IGG.
MDEMP.	Inter-borehole dipole induction prospecting

MPT.	Method of field of currents (misse-a-la-masse)
MYSG.	2D analogue geophysical modelling system, developed at VITR.
MPT-0, MPT-2.	Single and two-borehole variants of harmonic (FEM) induction prospecting, developed at VITR
MTMPP.	Method developed at SNIIGGIMS which uses a combination of MPP and MT (natural fields)
MHD.	Magnetohydrodynamic. A MHD generator has been used by IGG and IZMIRAN
MTS.	Magnetotelluric sounding.
MPF.	Method of exploration according to the form of occurrence of minerals. An electrochemical/geochemical method, developed at VITR, which involves analysis of metallic organic compounds.
Near zone.	In EM methods, where spacing, R, or frequency, ω, is small, (large t), such that $\sigma\mu\omega R^2 \ll 1$. The distance R is small compared with the wavelength of radiation and the magnetic field is in-phase with the transmitted current and 90° out-of-phase with respect to the electric field. This region is also known as the quasi-static zone. Also used for sounding where the depth of investigation is larger than the receiver-transmitter separation (See ZSB).
nA, nIA.	Dipole moment of Tx and Tx coils (n = number of turns, I = current, A = loop area).
NP.	Low frequency induction method.
Non-stationary.	Harmonic or transient.
PEA.	Piezoelectric activity (expressed in C/N, coulumb/newton)
PAM3-8.	Underground piezoelectric equipment developed at TSNIGRI (also PAMZ-8).

Q.	Transmitting coil.
q.	Receiving coil.
Rx.	Receiver
Re.	Real component
RADVOKUP.	"Radio wave comparison and direction indicator" - an airborne radio wave EM system developed at TSNIGRI
R, r.	Separation of Tx and Rx
SNIIGGIMS.	Siberian Research Institute of Geology, Geophysics and Mineral Resources, Ministry of Geology, Novosibirsk.
SDBR-4.	New radio-wave EM system developed at TSNIGRI
SQUID.	Superconducting Quantum Interference Device.
SINUS.	Instrument developed at VITR for harmonic borehole (FEM) induction prospecting.
SPK.	Surface equipment being developed at VITR for KSPK (contact method of polarization curves) measurements.
S.	Conductivity - thickness product of thin plate or layer. Known as "longitudinal conductance", and often incorrectly translated as "lateral conductance".
Station.	English transliteration for "unit" or "equipment".
Self-process.	The transient decay induced in a receiver coil by a transmitted pulse in the absence of a conductor.
TSNIGRI.	Central Research Institute of Geological Exploration, Ministry of Geology, Moscow.

TEM.	Transient electromagnetic. Also called MPP (method of transient processes), or ZSB if used for deep sounding.
TSM-3 (TSM-Z), TSMK-40) TSMK-30)	Borehole magnetometers developed at VITR
Tx.	Transmitter.
TSIKL.	A deep-sounding TEM or ZSB instrument developed at SNIIGGIMS
Transient sounding.	Depth sounding, either electrical, EM or a combination, using transient fields
Thyristor.	SCR
T, t.	time
Trap.	Volcanic sill or lens, as a part of a sedimentary section.
VNII-Geofizika.	All Union Geophysical Institute of Ministry of Geology, Moscow.
VES, VEZ.	Vertical electrical sounding
VIEMS	All-Union Institute of Economic Mineral Deposits
VITR.	All-Union Scientific Institute for Methods and Technique of Prospecting.
VITR.	All-Union Institute of Techniques and Methods of Exploration, Ministry of Geology, Leningrad.
VIBROSEIS.	A seismic system with a controlled swept frequency source.
VIK.	High frequency induction logging, being developed at IGG.

VIKIZ. Isoparametrical logging, being developed at IGG. An EM logging technique which automatically adjusts one parameter (e.g. ω), as another is changed (e.g. z), so that the whole-space response remains constant.

VP IP

Z Tx-Rx separation in a logging tool.

ZSB (or ZSBZ) (Sondirovanie Stanovleniem polia v Blizhned Zone). Sounding by Establishment of Near-Field (see near-zone). A term used in Novosibirsk for deep sounding using TEM methods.

ZSD. Far-field sounding, in which the ratio of loop separation to depth, R/H, is usually greater than 5.

ZST Sounding buildup point

NON-ENGLISH SYMBOLS

η apparent polarization, %

Φ IP phase, degrees

ω angular frequency, radians/s

APPENDIX 2: RECORD OF CONVERSATIONS WITH SOVIET SCIENTISTS

1. VNII GEOFIZIKA - ALL-UNION GEOPHYSICAL INSTITUTE OF THE MINISTRY OF GEOLOGY

1.1 Introduction

I was met by the Vice-Director (Kozlov), who spoke briefly of the role of the institute. VNII Geofizika has over 1000 specialists and workers. The Moscow building is the main branch (oil and gas only). Other provinces have affiliates called VNII Geofizika with additions, e.g. in Leningrad it is mining. Fifty people work in electrical prospecting - making experimental equipment, studying theory, and doing field work (research) and data processing.

1.2 Program of Discussions

- method and techniques of electrical prospecting for oil and gas fields - I.A. Bezruk, G. Chernjavskiy; and M.N. Berdichevskiy (Moscow State University)
- the application of MT methods for geoelectric targets such as oil and gas fields
- artificial field EM - Yu. N. Popov.
- transient sounding for solving detailed problems in oil and gas prospecting - Yu. N. Popov.
- use of IP in electrical prospecting - A. Kulikov.
- electrical prospecting equipment for oil and gas - G. Chernjavskiy.
- mathematical algorithms and programs for computer processing of electrical data - S.A. Semenovich.

1.3 USE OF ELECTRICAL GEOPHYSICS FOR OIL AND GAS EXPLORATION

Electrical methods include frequency sounding (e.g. MT), transient sounding, and IP. Field equipment is used only for data acquisition. Processing is done in the laboratory at head office (except for IP and some frequency sounding). The USSR has 100 MT crews and 30 electrical sounding crews, with a ratio of 1 MT crew to 20 seismic crews. MT is useful when seismic is unfavourable, e.g. the velocity contrast of sand-shale may be 10-20%, but the resistivity contrast may be 10 to 100 if mineral waters are present. MT is always used first in a program, then seismic. Typical resistivities are:

Sand-oil 100 ohm-m,

Sand-water 1 ohm-m.

MT prospecting takes 75 percent of all electrical prospecting money (A$20-30 million per year is spent in the USSR).

1.3.1 Geological Problems

I. Regional. Depth 2000 - 6000 m. Aims are to study tectonic framework and direct lateral changes (Figure 1.1). Profiles are 100 km to 200 km long with stations every 5 to 10 km. MT and some transient sounding are used as an aid to seismic; MT is the main method. Detailed follow-up is carried out when lateral changes are detected. The regional stage of exploration in the USSR is nearly complete.

II. Semi-regional. Profiles are 10 to 50 km long, with stations every 1 to 2 km. Problems are the same as the regional problems (lateral changes and uplifts). Transient sounding is the main method; MT and IP are used as supplementary techniques. Semi-regional mapping is now widely in use. Computers are used a great deal in interpretation (e.g. inversion).

III. Prospecting. Following initial drilling, electrical methods are used to map the lateral extent of the oil (Figure 1.2).

1.3.2 Modelling

Modelling techniques include 2D numerical, and 3D scale models.

1.3.3 Equipment

MT & transient systems use a unit called a Universal Digital Station (system) CES (or TSES) for data acqusition. 150 units are in use operating in the frequency range 0.001 Hz to 10 Hz. The Ministry has 100 parties in the field, each having 1 or 2 systems. An MT station takes about 24 hours to record; transient method takes 1 hour per station.

The conductivity-thickness product of the sedimentary column, S, in these studies ranges from 100 to 2000.

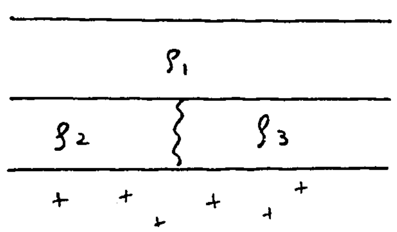


Figure 1.1 Geo-electric problem on regional scale.

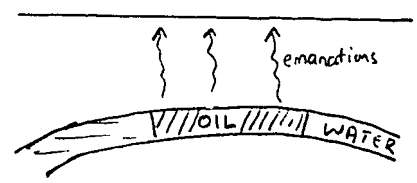


Figure 1.2 Geo-electric model on prospecting scale.

1.3.4 Processing

1) plot ρ_a versus f.
2) Interpretation - by qualified interpreters only.
   a) Inversion to horizontal homogeneous layers.
   b) Geophysical interpretation: combined interpretation with transient and seismic methods.

1.4 MAGNETOTELLURIC METHODS

1.4.1 Types: 1) MT sounding
2) simultaneous MT sounding (using a remote reference, very new)
3) TT - telluric current method - was popular in the early days but not used so much now. This technique measures the E field only.

1.4.2 History

TT & MT profiling in the early days used periods in the range 25-40 s (reliable field), giving qualitative data on the conductivity along the traverse. The MT work began in Western Siberia, which has now been covered with 10^6 km of TT and MT profiling. This area is characterised by very smooth lateral changes. When used in areas with sharp changes, these methods proved to be inadequate - there was a need for vertical and horizontal conductivity parameters, and so MT soundings were used. From 1961 to 1970 analogue systems were used with periods in range 10 s to 10^3 s; 3 to 7 days were required per station.

Because of the limited bandwidth of this equipment, a ρ_1 asymptote is not obtained on the frequency-time curves for areas where the lateral conductance, S, is less than 1000 siemens (Figure 1.3a). For S less than 100, a curve shown in Figure 1.3b is obtained.

In 1971 digital CS1 equipment was introduced; one station taking 24 hours. There are now 100 sets in use, and it takes 10 to 15 hours per station.

Later, CES-2 equipment was manufactured with a frequency range from 10 Hz to 0.001 Hz. There are now 50 sets in use; serial (large-scale) production started in 1978. It is now possible to get the complete sounding curve and hence, depth information. Since digital equipment has been introduced in this decade, mapping is done at a scale of:

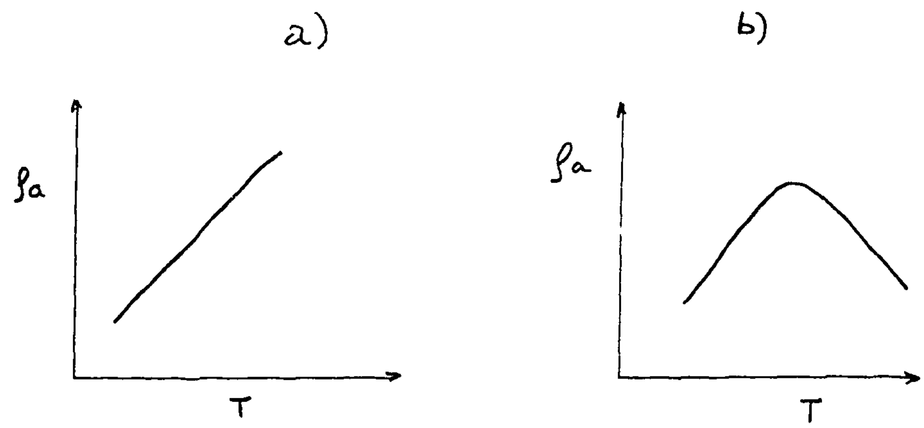


Figure 1.3 MT sounding curves.

regional 1:1 000 000 to 200 000
detailed 1:100 000 to 25 000 in well known regions

The transmitter uses the ERS-67 general purpose generator.

Early MT did not measure H or E simultaneously.

MVR magnetic variation prospecting measures only Hx, Hy or Hz.

Typical MT field results in the Bukalov Platform are given by Niketenko et al., in Brodovoiy (1974b).

Reference - a) Berdichevskiy, 1968,
b) "The effectiveness of MT prospecting for oil and gas surveys in the region of the Soviet Union", by M.N. Berdichevskiy - being translated by G.V. Keller at Colorado School of Mines.

1.4.3 Problems to be Solved by MT

1) Mapping of high-resistivity basement relief.
2) Study of deep fractures.
3) Lateral lithological changes
   a) regional
   b) local - study electrical properties over oil/gas deposits and away from them.

Berdichevskiy found a high conductivity layer at 20 km depth near the Conrad discontinuity, and found also that the asthenosphere is not uniform - if it is partially melted its resistivity is 5 to 10 ohm-m.

1.5 ARTIFICIAL FIELD EM AND ELECTRICAL METHODS

1.5.1 History

In the 1930s telluric current methods were widely used, together with Schlumberger soundings (VES). In the early 1950s, Al'pin worked on the dipole-dipole method, for both equatorial dipole and axial (in-line) arrays.

1.5.2 D.C. Sounding

In a horizontally layered medium, the equatorial dipole and Schlumberger arrays are equivalent, and the same master curves can be used.

- Schlumberger has low sensitivity for inhomogeneities
- Equatorial dipole array is sensitive to anisotropy
- Dipole Tx can measure in any direction, but in non-simple cases it is easier to interpret axial or perpendicular arrays.

As can be seen from Figure 1.4 a larger spacing is required for axial than for equatorial.

The axial dipole is $\partial/\partial R$ of equatorial dipole, and is even more sensitive to changes in dip, e.g. uplift.

Special Applications of Axial Dipole-Dipole Array

1) In forested areas.
2) Marine work e.g. Caspian Sea, Black Sea (shallow near parts of Crimea).

All the Azov Sea was surveyed 15 years ago for oil exploration. The maximum water depth is 50 m, and speeds up to 10 km/hr were employed. The spacing between Tx and Rx ships was 4-5 km. The electrodes were towed along the sea-bottom through mud to reduce the noise. AB spacings of 1 to 2 km were used, with a current of 200A with rectangular waveform. Interpretation assumed no contribution from the overlying layer (the sea), as shown in Figure 1.5. Soundings were done every 2 to 5 km for control, keeping the Rx ship anchored.

A marine survey has just been completed in the Bering Straits for tin, with 1 km spacing of profiles, with soundings, searching for old river channels.

Electrodes - Tx are steel, changed every 200 km
- Rx are $Cu-CuSO_4$ in wood. Can also use $AgCl_2$ in colloid like Agar Agar
- Pb electrodes not satisfactory because of polarisation

A good onshore Rx electrode can be constructed from Mg-Zn torch batteries, made by removing the Zn case and replacing with cotton. These are very good non-polarising electrodes, but require a high input impedance in the Rx. Usually, ten are made at a time and two are selected with the most similar characteristics.

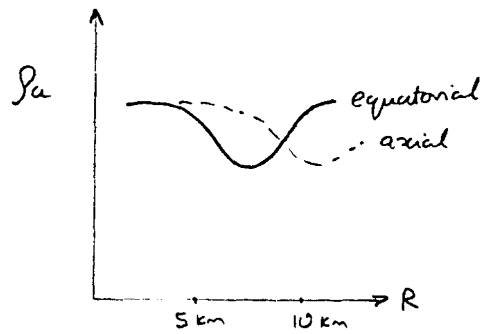


Figure 1.4 DC sounding curves.

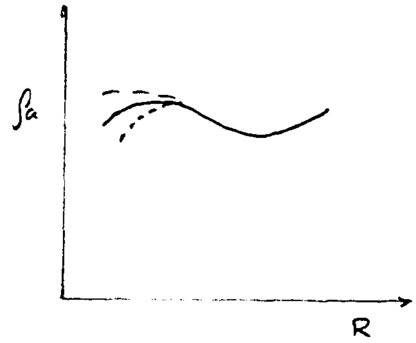


Figure 1.5 Typical DC sounding curves for marine work. The top layer is ignored.

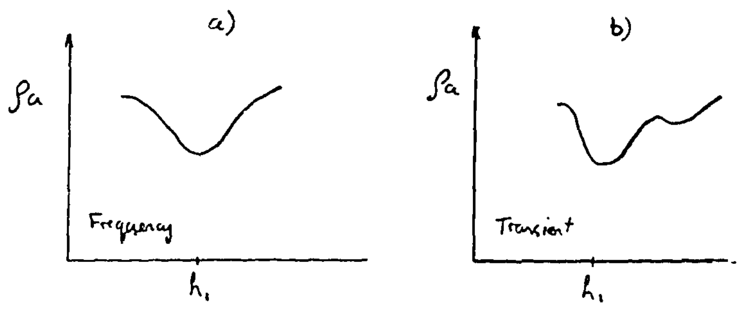


Figure 1.6 Frequency and transient sounding curves.

1.5.3 Choice of Sounding Method

DC soundings are mainly used for engineering, groundwater and ore prospecting. These methods have been superseded by frequency and transient soundings since 1960.

(In 1950s DC and Telluric methods were used with same equipment at same time. Telluric measured 20 s period of x and y components at both the base and moving station. This period usually gives information on basement relief (in north of USSR there is up to 700 m of permafrost).

Frequency, transient and DC methods are used for depths less than 4 km. For greater depths MT is used. A new development is MT with a reference base station. Differences between H_{xyz} and E_{xy} are measured and mapped.

1.6 FREQUENCY & TRANSIENT SOUNDING

Vanyan worked on the theory in the early 1950s. In the late 1950s VNII started field tests. They started with equatorial dipole array, then used a coil as Rx at the end of 1950s and start of 1960s. As field work proceeded, an interesting result was obtained:

- For frequency sounding using E field, spacings equivalent to DC are needed. Both are screened by a thin resistive bed.
- dBz/dt measurements see through the resistive screen, e.g. beds of limestone and carbonates. One method of interpretation was to look for differences between frequency and transient soundings, as shown in Figure 1.6.

Practically, frequency sounding is easier for high frequencies (above 1 Hz). Usually R is less than 5 km. Transient sounding is easier for large T (above 1 s). Usually R is less than 15 km. The Method of Continuous Approximation is used, which employs a Fourier transform to obtain the early time transient curve from the high frequency curve (Figure 1.7).

Methods of displaying data from field buildup (transient) methods are given by Popov, in Brodovoiy (1974a).

At SNIIGGIMS, Rabonovich has designed the TSIKL instrument to measure early times, 1 ms to 1 s; it is suitable for low values of S of about 100. This instrument was developed for east Siberia where the longitudinal conductance, S, of the sedimentary column is in the range 50 to 100. For oil and gas, transient sounding usually uses 0.05 s to 20 s time range, with radio connection between the Tx and Rx.

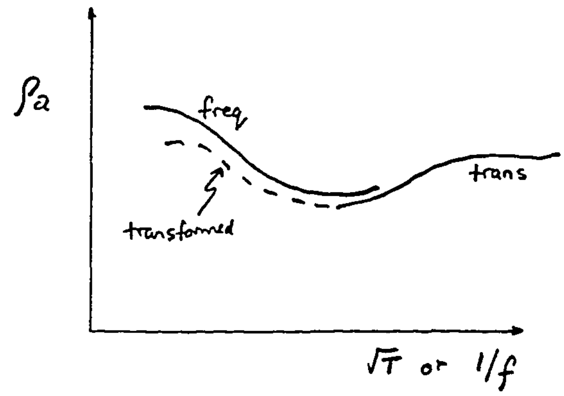


Figure 1.7 Sounding curves transformed by Method of Continuous Approximation.

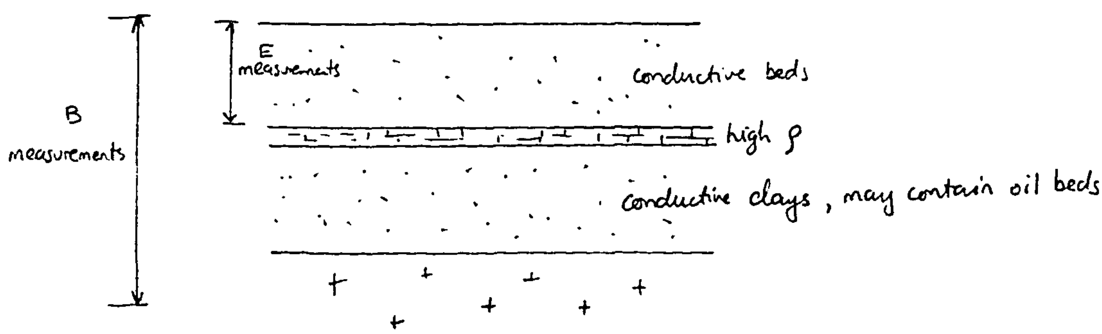


Figure 1.8 Geo-electric section showing application of methods.

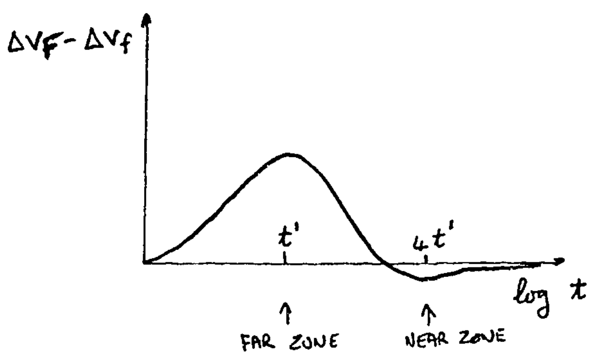


Figure 1.9 Plot of $V_F - V_f$ versus log t. The magnitude of $\Delta V_F - \Delta V_f$ may be 10^F times larger in the near zone than the far zone.

The last frequency soundings were done in 1967 or 1968. (Minor groundwater work with frequencies over 1 Hz using NChZ equipment is still being done).

1.7 TRANSIENT SOUNDING IN FAR ZONE (see also Chapter 3.5)

Vanyan worked on the theory in the 1960s. Definitions of the near-zone and far-zone are given in the glossary. It is possible to use combined MT and transient (or E and B Rx measurement) to enable a better interpretation. The range of application of methods is shown in Figure 1.8.

Popov has a theory about medium zone - can think of transient soundings as being "reflections". The "near zone" is defined as small spacing or late times: the "far zone" is large spacings or small times.

In a two-layer section, the top layer can be represented by a function $F(t/R^2)$ and the lower layer by another function $f(t/R^2)$. Popov prefers to use $V_F - V_f$ for interpretation rather than ratios, because the readings are larger (Fig. 1.9). Books by Kaufman et al. give curves for both electrical and magnetic components (Fig. 1.10). Note that if R/AB is greater than 3, then the system can be considered as a dipole. If AB = 2R and the receiver is in the centre of a loop, then a square loop is equivalent to four individual sides of a square terminated with grounded electrodes at the corners.

In the near zone, it is preferable to use one of the arrays shown in Figure 1.11. Array (d) is not advised because of large IP effects. This array may, however, be satisfactory for spacings of over 3 km.

Sidorov is working on new equipment to fill the time gap from microseconds to seconds necessary for small depths. The equipment will be tested on diamond deposits with high resistivity (exploration depth 100 m). A new method, state-of-the-art in transient sounding is to use very high currents of any waveform. These are known as impulse methods, and may have a waveform as shown in Figure 1.12. The transmitter is a magnetohydrodynamic generator, which uses a canon to move plasma (see Gorbunov, et al., 1979). Field tests are currently being done for comparison with other methods. The transmitter is large and kept stationary, and the receiver moves.

1.8 PHASE-FREQUENCY IP METHOD

A good reference for the phase-frequency IP method is Kulikov & Shemiakin, 1978.

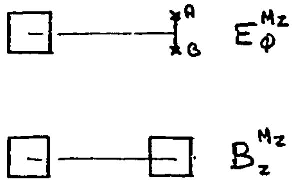


Figure 1.10 Configurations and nomenclature used in standard curves of Kaufman et al.

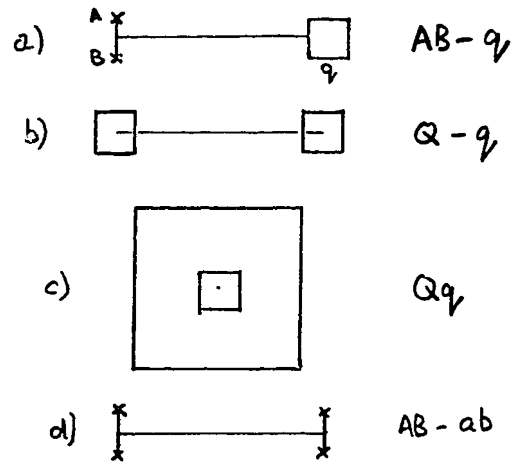


Figure 1.11 Configurations and nomenclature used for sounding in near zone.

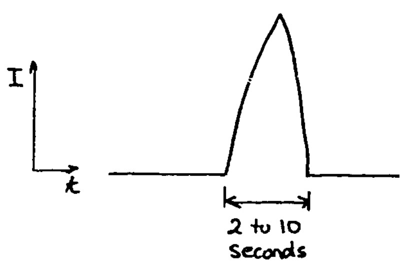


Figure 1.12 Waveform obtained with magnetohydrodynamic generator.

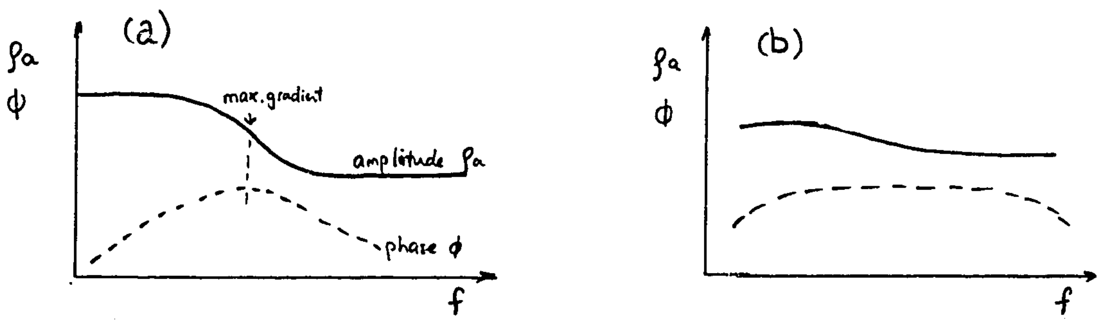


Figure 1.13 IP phase curves. (a) similar grainsizes, (b) different grainsizes.

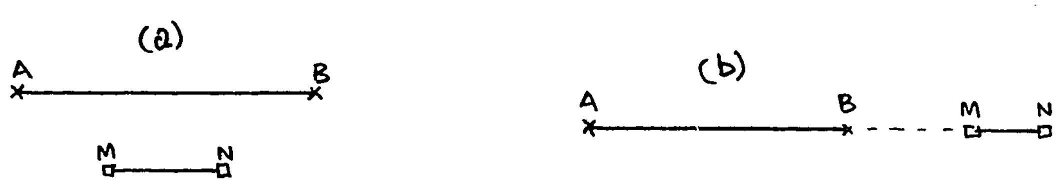


Figure 1.14 IP arrays. (a) equatorial, (b) axial.

1.8.1 Theory

Typical IP curves are shown in Figure 1.13. For assemblages of similar grainsize, two values of $\rho(\omega)$ are obtained, as in a). If two different grainsizes are present, the curve is much broader as in b). The flat part of the phase response is most interesting as in this region ϕ is independent of frequency.

EM Phase Response. Consider the arrays shown in Figure 1.14. Two current distributions are detected by MN: (1) inductive i_u and, (2) conductive i_k. At very low frequency, i_k is 90° out of phase with i_u:

i_k = A sin t (amplitude is independent of frequency)
i_u = B cos t (amplitude is proportional to frequency, as in Figure 1.15a).

The phase angle ϕ is given by $\tan\phi = i_\mu / i_k$.

This is proportional to B/A and hence to ω (see Figure 1.15).

1.8.2 Arrays

I. Equatorial (Fig. 1.16a). ϕ (IP) is negative, but ϕ (inductive) is positive.

II. Axial (in-line) (Figure 1.16b). ϕ (inductive) is negative.

At low frequencies, only ϕ_{IP} is measured. Another measurement is taken at a higher frequency, f_2.

$$\phi(f_1) = \phi_{IP} + Kf_1, \text{ and}$$
$$\phi(f_2) = \phi_{IP} + Kf_2$$

where K = coefficient of proportionality and K f = 0 (inductive).

Thus $$\phi_{IP} = \frac{f_2\phi(f_1) - f_1\phi(f_2)}{f_2 - f_1}$$

If $f_2 = 3 f_1$, then $\phi_{IP} = \frac{1}{2}(3\phi(f_1) - \phi(f_2))$

In this approach it is assumed that the change of ϕ_{IP} with f is much smaller than the change of ϕ (inductive), and can be neglected.

1.8.3 Equipment

The equipment INFA3 BP, mass produced in 1972, performs this operation automatically using the fundamental and third harmonic. It measures the time between zero crossings Δt, from which ϕ_{IP} can be determined. This equipment uses a 14 kW generator, is vehicle mounted, with frequencies 0.3, 0.6, 1.2, 2.4 ... 78 Hz.

Modern equipment BP-F is portable, with a frequency range of 0.03 Hz to 312 Hz. This uses 12 V batteries (50 W) or a 400 W motor generator at 400 Hz. The Tx weighs 15 kg and the Rx 6 kg. Amplitude is read on a meter; phase is a digital readout. A wide frequency range is used for oil prospecting, but frequencies less than 78 Hz are used for ore prospecting. For ore prospecting, a coil is used to measure H as well.

The same equipment is used for IP and frequency EM sounding. Measurement of E results in broad IP anomalies over disseminated zones. H_z gives anomalies over massive deposits (IP low). Measurement of amplitude and ΔT (and hence phase) gives similar response to MPP. Different frequencies are used for E and Hz, e.g. in the Ukranian shield frequencies used are 0.6 Hz for E and 19 Hz for H_z. A typical field profile arrangement is shown in Figure 1.17. A current of 20 A is typical for a 40 kW transmitter. (Kulikov expressed great interest in our MIP work and I gave him details of the Scintrex MFM-3 magnetometer. Kulikov didn't think they would be able to purchase one from the west).

1.8.4 Mineral Discrimination.

In general this has failed. Best results are by Komarov, who measures IP to hours, and can distinguish between a low and high grade ore, but not between graphite and sulphide.

1.8.5 Non-Linear IP - (usually downhole).

In some cases this has been done on surface for minerals at shallow depths (Komarov).

1.8.6 Removal of Inductive Coupling

Inductive coupling is a large problem in oil and gas prospecting. The equipment INFA3-BPM (EVA-203) is used to measure the 1st, 3rd and 5th harmonics.

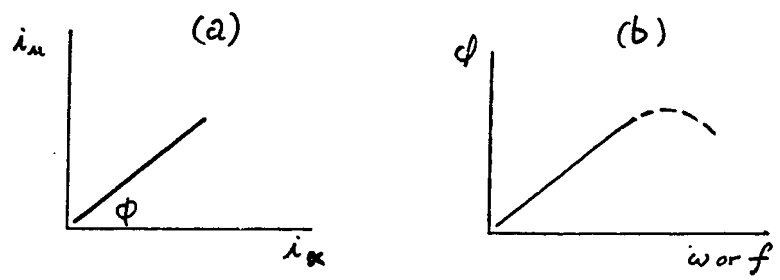


Figure 1.15 Types of phase response.

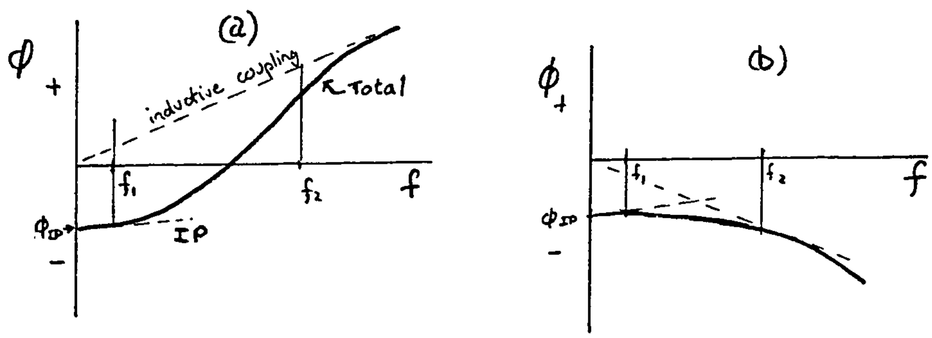


Figure 1.16 IP phase curves for a) equatorial array, b) axial array.

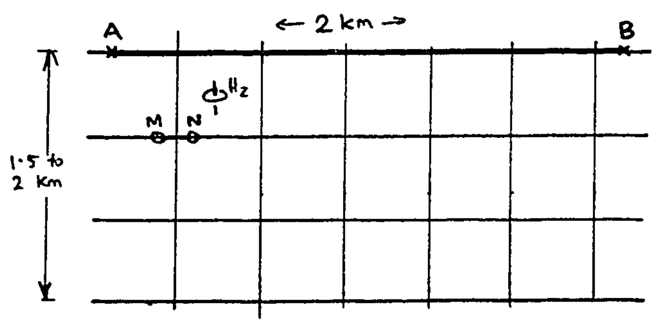


Figure 1.17 Field arrangement for reconnaissance survey. Both E and B are measured.

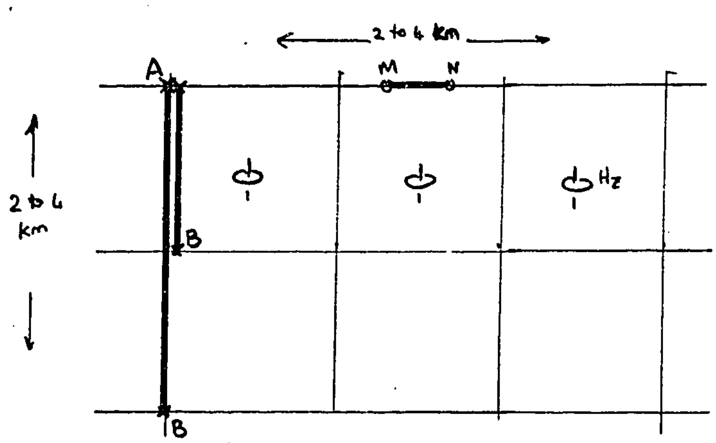


Figure 1.18 Field arrangement for oil and gas search.

By fitting the IP curve with a f^1 and $f^{3/2}$ curve, a first-order inductive coupling removal can be achieved.

The true IP phase, ϕ_{IP}, can be obtained by solving the equations:

$$\phi_1 = K_1 f_1 + K_2 f_1^{3/2} + \phi_{IP}.$$
$$\phi_2 = K_1 f_2 + K_2 f_2^{3/2} + \phi_{IP}.$$
$$\phi_3 = K_1 f_3 + {}_3 f_3^{3/2} + \phi_{IP}.$$

This equipment measures the time delay Δt between the 1st and 3rd, and the 1st and 5th harmonies. Note that the time delay is directly proportional to the phase difference.

To reduce EM coupling use orthogonal array (the coupling is zero for homogeneous ground).

A typical field setup is shown in Figure 1.18. At each point the entire frequency range is measured (total of 1½ hours). Soundings are made as well as profiles (every 5 or 8 stations). Frequency sounding is done in daylight, transient at night, when noise is less. The results are comparable. Kulikov likes frequency sounding and thinks it may regain popularity.

In heavily wooded country the array shown in Figure 1.19 is used since it is much easier to move the Rx wire. The two Rx halves average the results, and removes telluric noise. Typical results obtained with amplitude and time-delay measurements are shown in Figure 1.20. For amplitude measurements, pseudo-sections are drawn; for time delay measurements, profiles of ϕ_{IP} are obtained. The measurement of the phase difference between various frequencies, $\delta\phi$, removes the need for a radio link. Interpretation of EM mainly uses amplitude (maximum, minimum and inflection points), since it is too difficult to interpret $\delta\phi$. Standard curves are used for multilayers.

1.8.7 Applications of IP For Oil and Gas Exploration

Often a minimum IP or negative IP response is obtained over oil; a maximum may occur also on the flanks of the deposit.

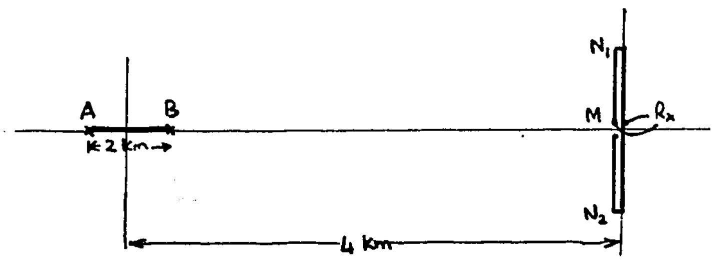


Figure 1.19 Field arrangement applicable in heavily wooded country.

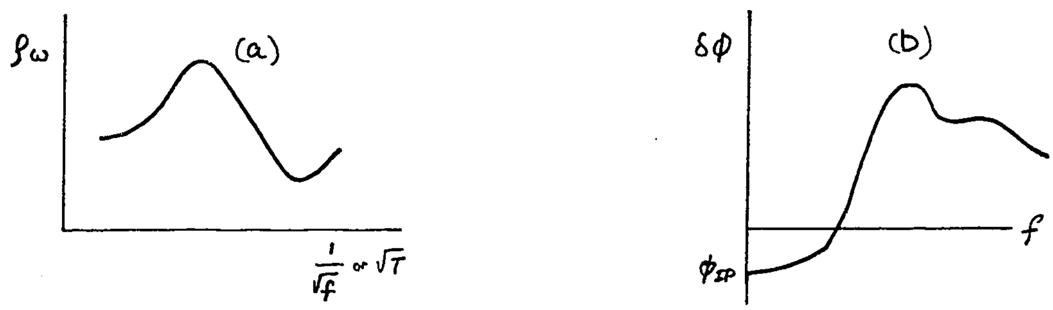


Figure 1.20 Apparent resistivity curves obtained with a) amplitude, b) time delay measurements.

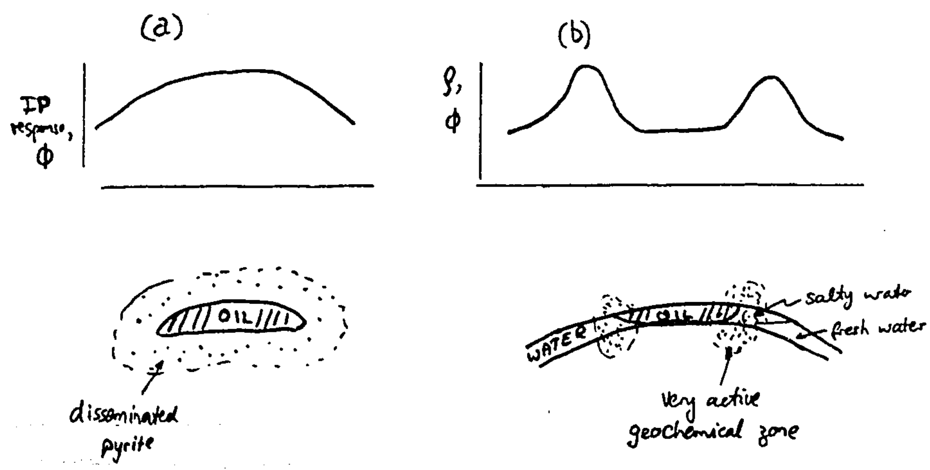


Figure 1.21 Geo-electric models of oil and gas fields showing regions of disseminated pyrite and associated IP anomaly.

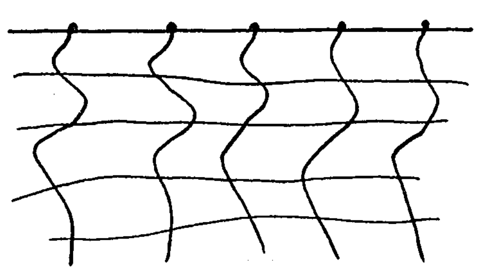
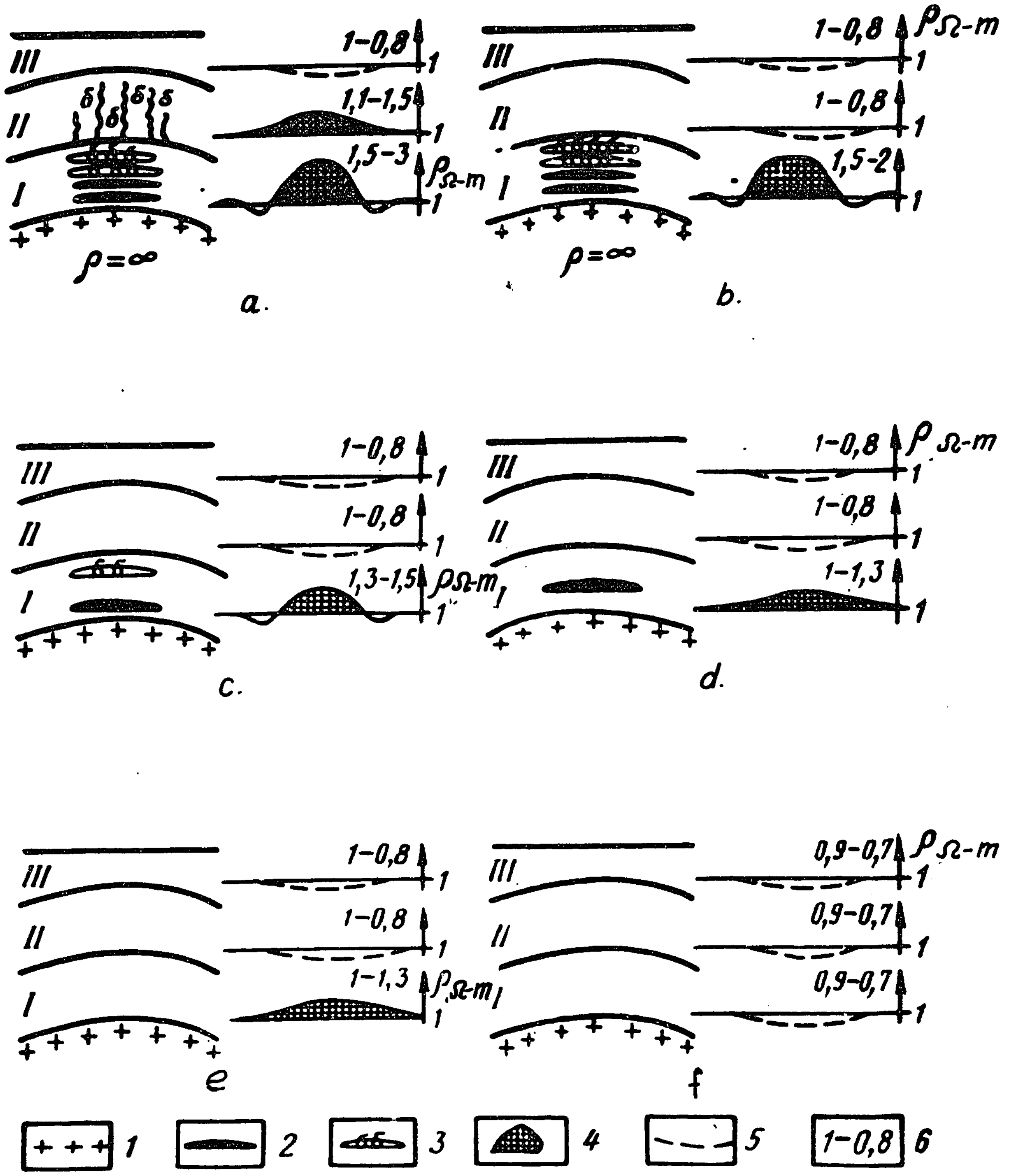


Figure 1.23 Pseudo-sections with correlations. The interpretation is based on horizontal layers.

Figure 1.22 Geo-electric models and resistivity profiles in oil and gas fields. a,b: "very large" deposits, c: "large" deposits, d: widely distributed deposits, e,f: non-prospective areas. 1: resistive basement ($\rho = \infty$), 2: oil deposit, 3: gas deposit (incl. non-economic gas), 4: anomalies with relative increased resistivity, 5: anomalies with relative decreased resistivity, 6: interval of relative change of resistivity. (after Kirichek et al., in Brodovoiy, 1947a).



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Mechanisms - Models

Two models are shown in Figure 1.21. Kulikov likes Pirson's (Oil & Gas Journal) model, involving the movement of oxides downwards. This creates regions of "cold burning" (reduction?) of hydrocarbons. This movement means the charges are directed in an eddy current pattern. In USSR the use of IP for oil and gas is quite new (5 years). Six crews are working full time on it now.

1.9 DIRECT DETECTION OF HYDROCARBONS

Methods used are transient sounding, MT and IP. The oil itself is a very small target and gives a small effect. However, logging has shown that the oil and gas are not inert, but geochemically active. This activity pushes fluids into and through surrounding rocks over a wide zone and changes the resistivity and generates some pyrite (see Figure 1.21).

1.9.1 Geoelectric Models

Geoelectric parameters of various models are given by Kirichek et al. in Brodovoiy (1974a), whose models are shown in Figure 1.22. Resistivity profiles are shown for each layer in the 4-layer section. Models (a) and (b) are classed as "very large" deposits, with a total effective thickness of oil/gas saturated rocks, h_{ef}, of greater than 100 m (h_{ef} probably refers to the total thickness of oil/gas in the reservoir after removing the rock and water). Model (b) is observed most often. Model (c) is a "large" deposit (h_{ef} = 50 to 100 m), model (d) is a widely distributed deposit (h_{ef} up to 50 m). In the case of "very large" deposits resistivity contrasts up to 3 are common.

1.9.2 Field Procedure

Field procedure involves VES or transient soundings at 1 or 2 km spacing. The smoothest curve is selected and compared with the rest for anomalies. The deposit is a local inhomogeneity in a lateral direction, as shown in Figure 1.23. Results are presented as contoured pseudo-sections of the difference between the smoothest curve and the others.

1.9.3 Field Examples

Field examples from various oil fields are shown in Figures 1.24 to 1.26 (from Kulikov & Shemiakin, 1978). Figure 1.24 shows profiles of IP phase, ϕ_{IP} , that approach the apparent polarisation, η_k, above oil deposits in the Kenkiak and Kokzhide fields (a), and Kumsai oil field (b). The anomaly of station-10 is associated with deposits of Kokzhide. Above the Kenkiak deposit (station 30 to 80) there is a complicated anomaly with two maxima, which extends outside the boundary of the deposit. Over the Kumsai deposit (b), a broad anomaly was observed.

Profiles obtained over the Kzyloi oil field are shown in Figure 1.25. This region has very low resistivities, in the range 1 to 30 ohm-m, so frequencies below 1 Hz were used. Orthogonal arrays were used for phase ϕ measurements, and a 4-electrode array for η_k measurement. Values of phase shown in Figure 1.25 were calculated at two frequencies (curve 1:, f = 0.076 and 0.15 Hz), three frequencies (2:, f = 0.076, 0.153 and 0.305 Hz), and four frequencies (3:, f = 0.076, 0.153, 0.305 and 0.61 Hz). Since the profiles obtained with 3 and 4 frequencies are in good agreement, inductive coupling removal was adequate.

The form of the anomaly consists of two polarisation maxima, one above each edge of the deposit, and a deep minimum in its centre. Similar results were obtained on the neighbouring Bazaisk oil field (Figure 1.26). In plan, the zone of the phase anomaly has a narrow range of negative values which follows the contour of the gas deposit.

Time-domain IP techniques are also used for oil prospecting. Figure 1.27 shows pseudo-sections of the rate-of-decay parameter, σ, where

$$\sigma = \frac{\Delta V_{IP} \text{ at } 0.5s}{\Delta V_{IP} \text{ at } 30s}$$ (from Brodovoiy, 1974a.)

The σ parameter is in effect a late-time IP parameter describing the rate of decay. Over each of the deposits there is a decrease in the value of σ.

1.10 COMPUTER PROCESSING

VNII Geofizika is the main organisation in the USSR for computer processing of electrical prospecting data, and is collecting a data base of all electrical, seismic, geodetic and logging data. They are developing automatic processing routines for:

Figure 1.24 IP profiles over (a) Kenkiak and Kokzhide oil fields and (b) the Kumsai oil field. For graphs of ϕ, AB = 500m. For graphs of η_k, AB/2 = 500m, t_2 = 2min and t_1 = 0.5s. 1: rock salt, 2: oil deposits, 3: tectonic disruption (from Kulikov & Shemiakin, 1978).

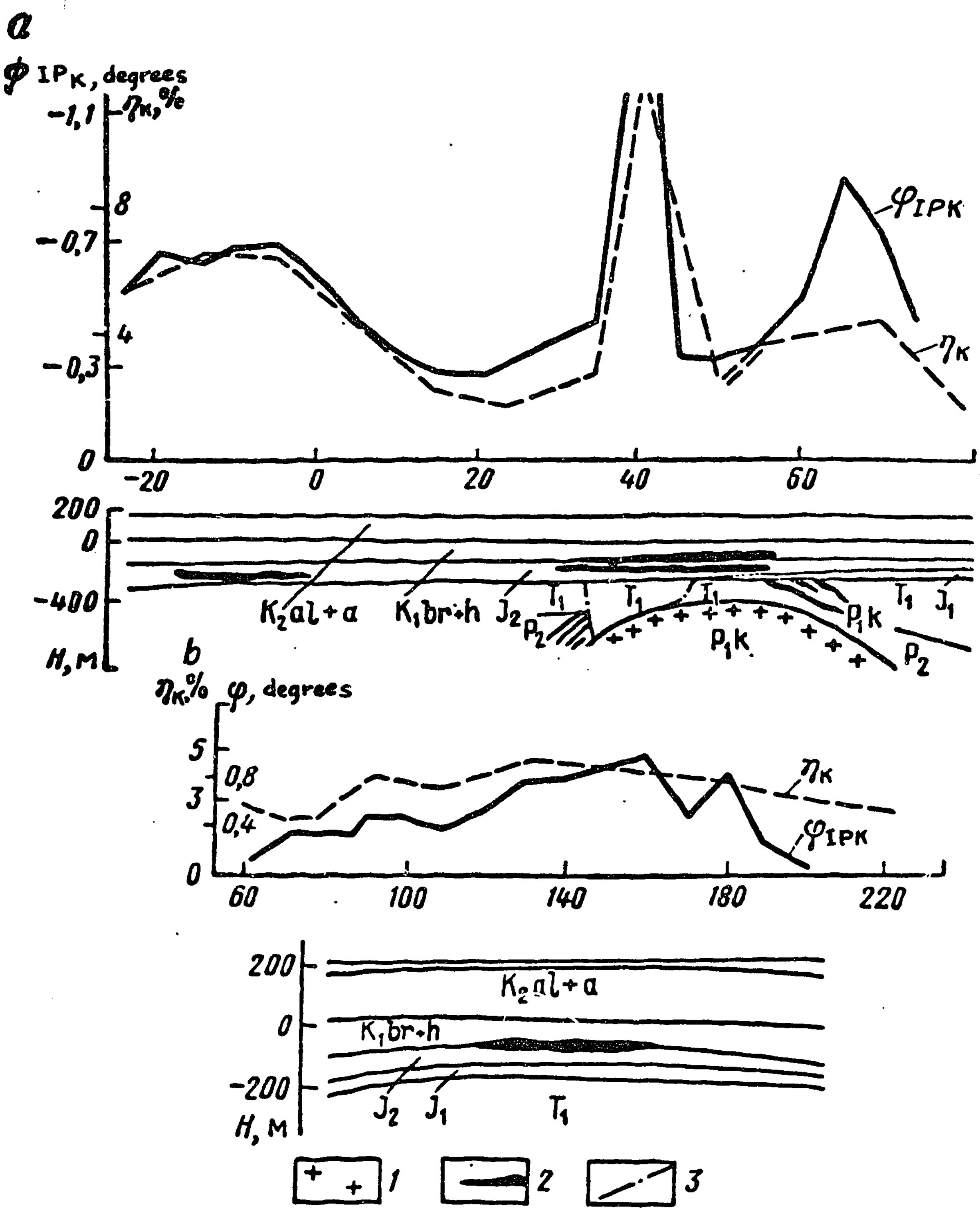

Figure 1.25 IP profiles over the Kzyloi oil field. 1,2,3: different frequencies (see text), 4: oil deposit (after Kulikov & Shemiakin, 1978).

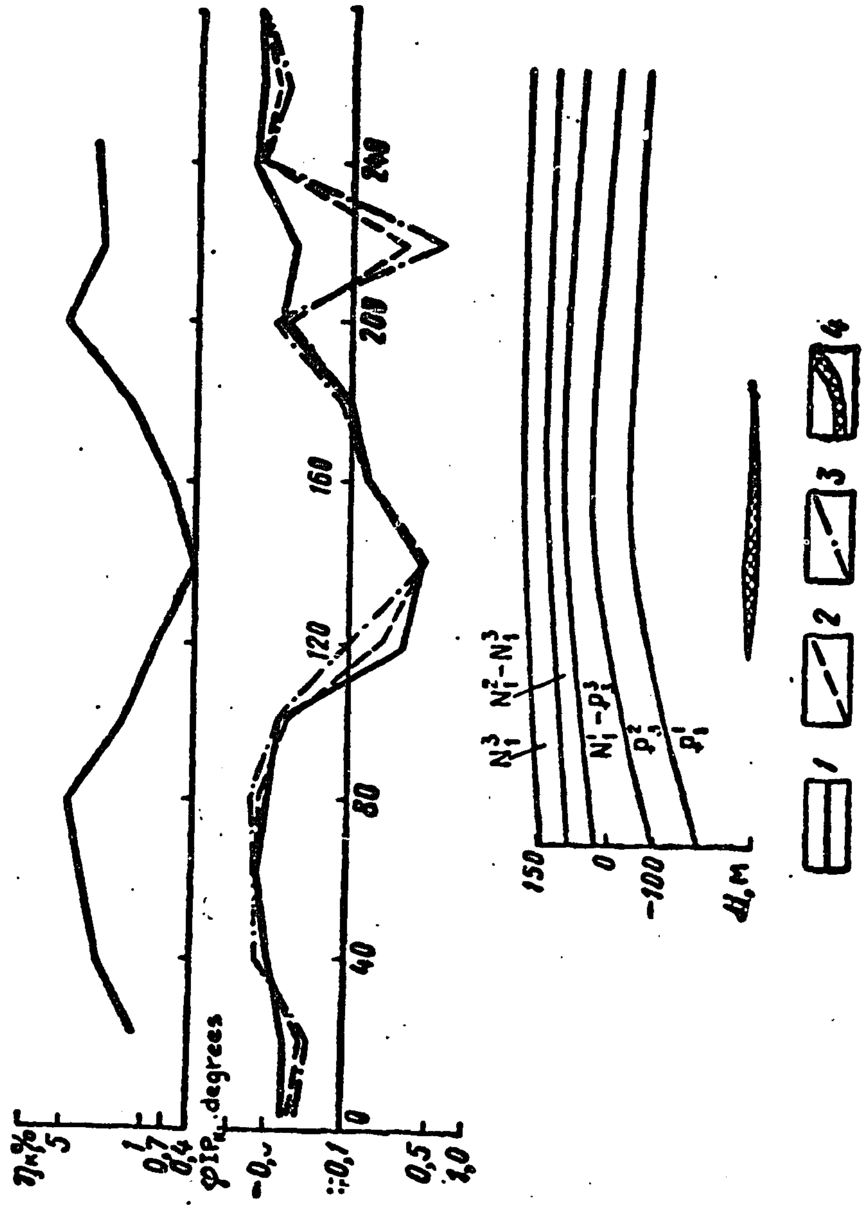

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Figure 1.26 Contour plan of phase Ø IP_K in degrees on the Bazaisk gas field. 1: profiles, 2: contour of gas field (after Kulikov & Shemiakin, 1978).

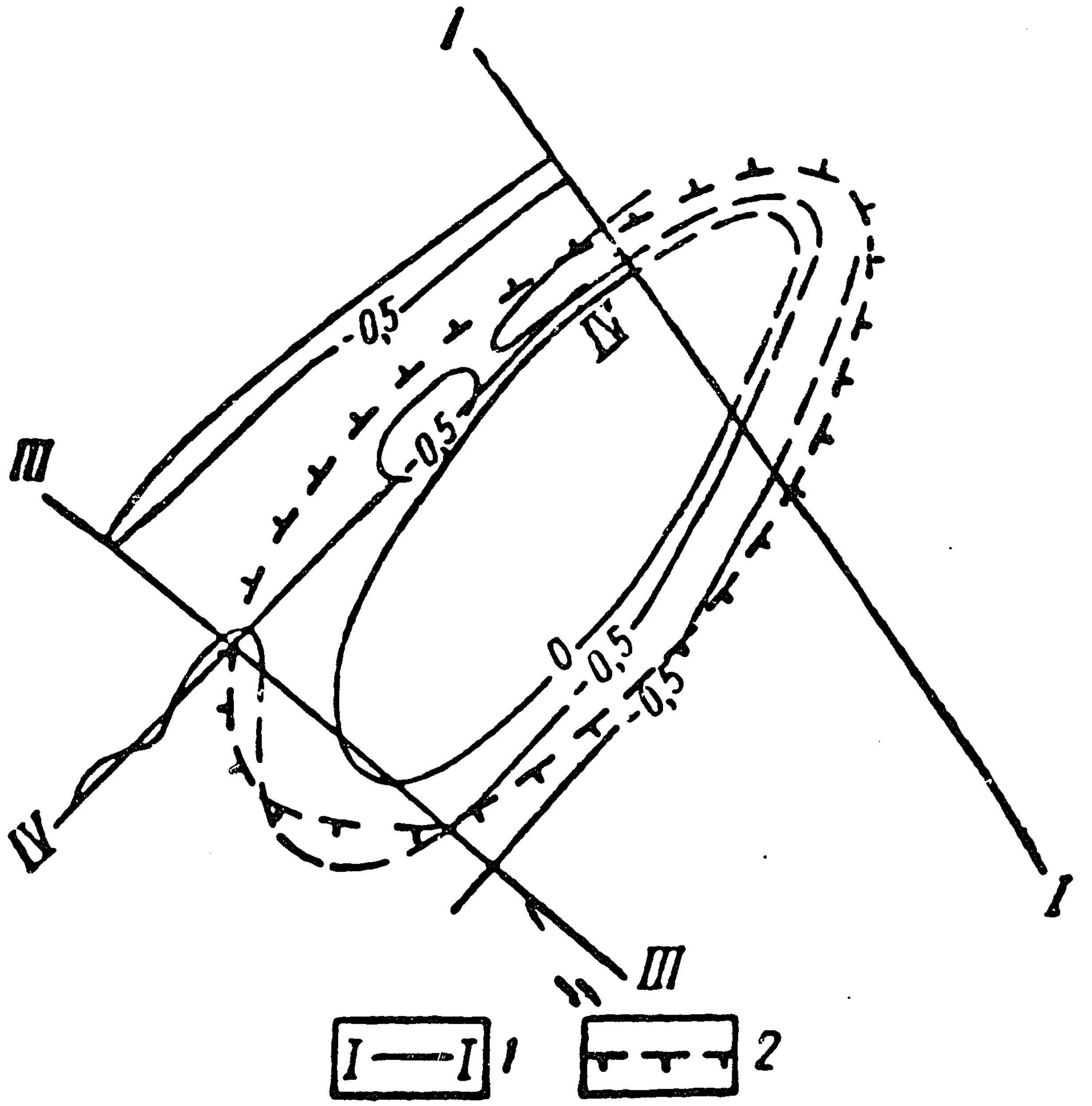

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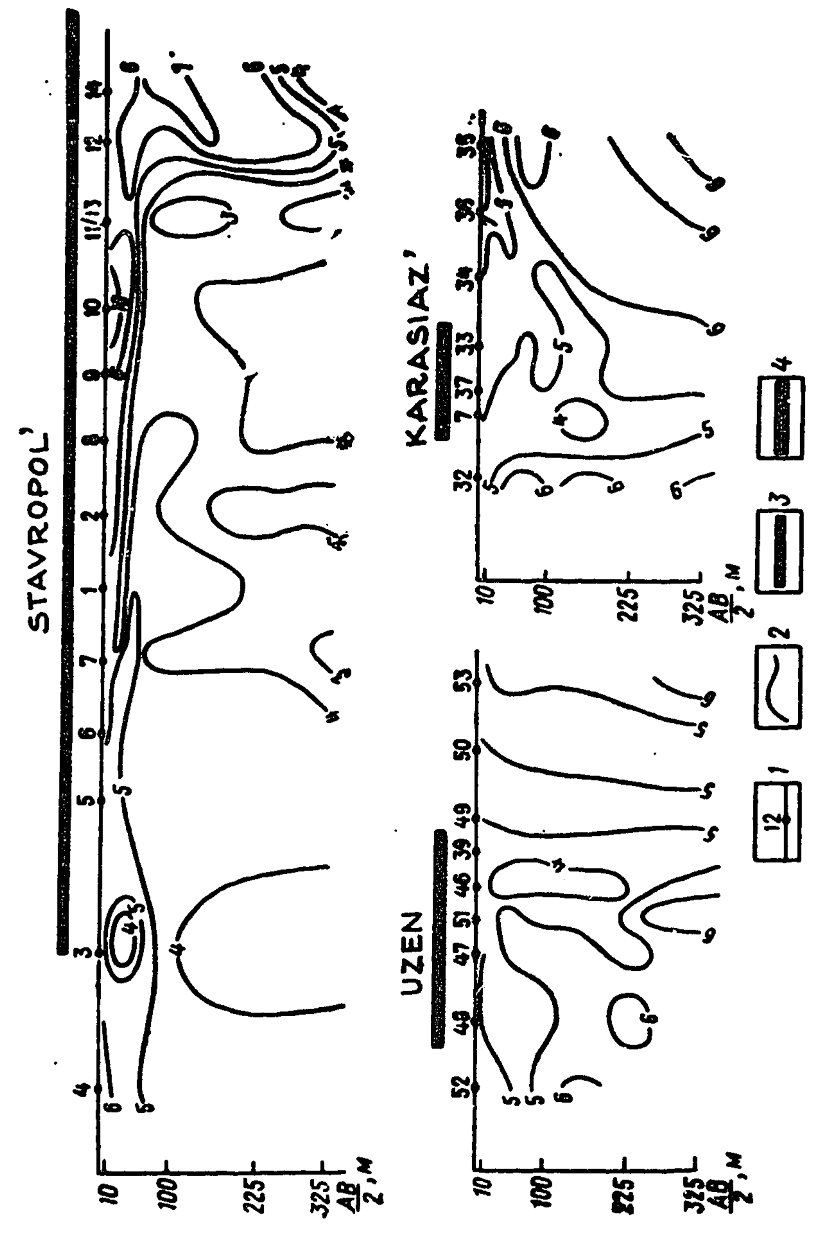
Figure 1.27 IP pseudosections of the rate-of-decay parameter, σ, over the Stavropol, Uzen' and Karasiaz deposits. 1: VEZ sounding positions, 2: countours of σ, 3: location of gas deposit outline, 4: location of surface oil (after Kruglova, in Brodovoiy, 1974a).



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1) primary processing,

2) interpretation,

in a complex computer package called EPAK (Electrical Prospecting Package) (analogous to SEISPAK for seismic) - this is believed to be the first of its kind in the world, and can handle all types of electrical and EM data:

MT (all types including magnetic variation and telluric),

transient sounding,

IP,

VES,

which are measured with the Universal Digital Station CES-1 & -2 (Digital Electrical Station) of which 300 have been manufactured. It records on magnetic tape which is non-standard for larger computers. Thus preliminary pre-processing and re-writing are required (Fig. 1.28).

Stage I. The M-6000 does the first stage of processing: de-multiplexing, data checking, etc. Simultaneously the data are re-written on standard format IBM tape. From 1979 to 1980 the number of M-6000 minicomputers will increase from 3 to 25.

Stage II. The IBM tape is sent to the expedition or regional processing centres for this stage of processing.

Processing Centres - Expeditions have small computer of type ES-1020 series, 1030 (similar to IBM 370), and 1040 series.

Regional centres - 12 centres, including Siberia 6, Europe 6: Moscow 2, Latvia 1, Middle Asia 3. The computers are ES-1050 & 1060, BASM-6, and AS-6 (30×10^6 operations/s).

(In Hungary they use a ES-1010 computer made by a local firm called Videotom. The ES family is equivalent to the IBM family).

Processing includes:

MTS - record impedance tensor $[z]$ - gives ρa and strike.

MT Synchronous - 2 sets of recordings.

$$\text{Telluric } E^F = \mu E^B \text{ (B = base, F = field).}$$
$$\text{Magnetic } H^F = V H^B ,$$

where μ and V are correlation parameters.

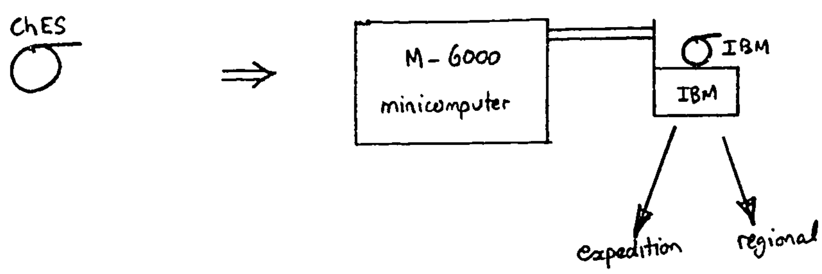

Figure 1.28 Block diagram of computer processing.

Transient sounding - signal coverted to ρa and other transformations.

IP - ηa induced apparent polarization, and ρa.

- all recorded on IBM tape <u>SOD</u> (System of Data Organisation) - identical for all methods.

<u>Stage III</u> - This is done mainly in regional centres. All data are combined to give resistivity, density, physical properties, depths.

Models: 1) Homogeneous horizontal layers
2) For MTS can use 2D models. The direct program works well and soon 3D models will be tried. The finite element method is used.

<u>Interpretation</u> uses two groups of algorithms. The first is <u>Regularisation</u> developed by Academician A.N. Tikhonov (father of MTS) and is used because the inverse has many solutions.

a) This involves finding the minimum of some function

$$\min f(\ldots) = \min \left\| \sum_{i=1}^{n} \left(\frac{\rho - \rho_T}{\rho_T} \right)^2 + \alpha\Omega \right\|$$

where ρ = apparent resistivity or tensor impedance
T = theoretical, ρ_T calculated from direct problem, and
α = parameter of regularisation (damping factor)

The $\alpha\Omega$ is used to limit the number of possible solutions. This can be built in different ways. Quantity limitation of the parameters can be used; also quality information and information on the errors.

Also use statistical methods based on the work of

F.M. Goltsman - Leningrad University

L.N. Porokhova - " " (Scientific Research Inst. of Physics)

on the maximum likelihood method. The method of maximum likelihood is not too dissimilar to regularisation because the functions look similar.

The function of maximum likelihood uses some conditional likelihood - the two approaches depend on whether the process is considered random or ordered. This is written in the publication of Leningrad University "Voprosm Geofizika" (Geophysical Problems). The whole algorithm is also given in the English translation Inzvestia Earth Physics, in the paper: "Simultaneous interpretation of amplitude curves of apparent resistivity of MT soundings for determining earth parameters", by L.N. Porokhova, 1975.

Another book is "Statistical models of interpretation", by F.M. Goldman, Nauka, 1971, Leningrad. Also, "MT sounding with the use of mathematical filter", Berdichevskiy, Bezruk et al. Izvestia No. 3, 1973, p. 76-92.

(Vozoff recently sent a preprint of a recent paper to Berdichevskiy, who sent it to Semenovich. They found it very stimulating and prompted further development. They thought the data were poor (large scatter of ρ_a). Semenovich says his program is better and gives very little scatter since it depends on mathematical filtering. This gives a 1% error in tensor impedance).

VNII-Geofizika is working with Control Data Corporation in the development of further programs.

2. IZMIRAN (INSTITUTE OF TERRESTRIAL MAGNETISM, IONOSPHERIC AND SPACE PHYSICS)

This institute is mainly concerned with solid earth geophysics. Akademgorodok is a city composed of five Institutes of the Academy of Sciences. Most of the EM work at IZMIRAN involves natural fields.

2.1 Magnetic Observatory

The magnetic observatory has proton precession and caesium-vapour magnetometers with an accuracy of 1 nT. The magnetic variometers have low drift (1 nT per 4 years) and are manufactured on site, using quartz fibre suspensions.

E.B. Fainberg has compiled data on the conductivity-thickness product of the earth's crust (Fainberg, et al., 1978).

2.2 Computer Centre

The computer centre at IZMIRAN had several disks (German), a minicomputer (Hungarian) and CRT terminals (German). They were very keen for me to try the moon rocket game, which is very backward by our standards - no graphics or time limits. Also a game called "pick the European country" - in German of course.

2.3 Use of Magnetohydrodynamic Generator

One field experiment which did not use natural fields was in the Kola Peninsula, using MHG, or magnetohydrodynamic generator (Gorbunov et al., 1979). The MHG, which is 4 to 5 m in size, was developed by one of the Atomic institutes and uses hot plasma which flows inside magnetic coils. With the MHG it is possible to generate currents up to 10^6 amps for an impulse (1 second base width), or to use it as a 4 MW power source for pulses of longer durations, such as 5 seconds on, with a 1 second turn-on and ½ second turn-off time. The transmitter current used in the Kola Peninsula was 2000 A at 2000 V, and electrodes were spaced 10 to 30 km apart. The received fields at a distance of 200 km were 0.7 nT to 20 nT, at 500 km were 50 pT, and at 750 km were 6 pT. The receiver is a coil or a high frequency caesium-vapour magnetometer (bandwidth up to 10 or 100 Hz).

3. INSTITUTE OF MARINE GEOPHYSICS, ACADEMY OF SCIENCES, USSR

3.1 MARINE MT

Marine MT is used for marine deep structural studies, and uses fields with periods 1 to 2 hours, for probing depths to 6000 m. The method can also be used on the continent for probing depths greater than 100 to 200 m for oil and gas exploration. E is measured with non-polarising Ag/Cl electrodes, and H with a proton precession magnetometer. The equipment is left to record for several days, then recovered.

3.2 AIRBORNE FEM

The transmitter loop is supported by the wings and tail of a fixed-wing aircraft. The receiver consists of two orthogonal coils in a towed bird, 50 to 150 m away and measures H_z and H_x.

H_z is phase shifted and amplified. The geometrical sum gives the major axis, and subtraction gives the minor axis of the polarisation ellipse. With this method, movement of the bird does not affect the results. The theory of the elliptically polarised field method is given by Svetov (1969).

The accuracy is 0.001% of the primary field. Possible frequencies are 78, 312, 1250, 5000 Hz, using two frequencies simultaneously. For orebody search 78 and 312 Hz are used and for geoelectrical mapping 1250 and 5000 Hz are used. There are 4 systems in use at present.

3.3 LOOP CONFIGURATIONS FOR GROUND TEM SYSTEMS

1) One-loop configuration uses sides of 100 m or 200 m.
2) Two-loop configuration is better for differentiation of strike, dip and shape.
3) Dual-loop (figure-of-eight) configuration is good for noise cancellation and in areas of uniform overburden.

In reconnaissance mode, 1) and 3) are used. In detailed mode, 4 loops are set up with the instrument at the centre and all configurations are used.

3.4 FREQUENCY EQUIVALENT OF TRANSIENT ONE-LOOP (DUM)

A method developed in TSNIGRI measures the quadrature component in a coincident loop configuration. The main advantage is that this can be used in noisy areas (industrial) where the transient method cannot be employed (further description given in chapter 4.6).

3.5 NEAR ZONE - FAR ZONE

Consider the normalised parameter

$$p^2 = \xi^2 = \sigma\mu\omega R^2, \qquad \ldots (1)$$

where σ, μ, ω and R refer to conductivity, magnetic permeability, angular frequencies and Tx-Rx separation, respectively. The dimensionless parameter can also be expressed as

$$\frac{\lambda}{R} = \frac{2\pi\sqrt{2}}{\sqrt{\sigma\mu\omega}\,R} \quad . \qquad \ldots (2)$$

For 'near zone', (1) <<1 and (2) >>1, i.e. the primary field is the same as in free space. The quadrature field is proportional to σ. For the in-phase component σ has little effect.

For 'far zone', the primary field propagates in the air and at the R_x has plane wave character, propagating in a vertical direction. The secondary field is proportional to resistivity.

These definitions are somewhat different to those used at SNIIGIMS in Novosibirsk, in which near zone and far zone relate soley to the ratio of depth of investigation to transmitter-receiver separation.

3.6 CURRENT TRANSIENT RESEARCH IN OTHER INSTITUTIONS

3.6.1 Waveforms. The conventional square wave is not optimum. The transient field can be expressed as a sum of exponentials $\sum_{k=1}^{\infty} a_k e^{-a_k t}$. We want to reduce coefficients with large exponents and define those with small exponents.

The input method has a better waveform (half-sinusoidal), but a better waveform is a bell shape. However, it is difficult to design a Tx, so another method is to use an active filter.

3.6.2 Active Filter. An active filter has been designed which makes coefficients a_k small when α_k is large. This has advantages, in that it is not necessary to have the same wide dynamic range of amplifier. This decreases signals from overburden, halfspace, and bodies with low conductivity.

3.6.3 Arrays (refer to Figure 1.11).

AB - ab. Results at low frequencies are equivalent to DC. Sensitive to inhomogeneities. Good for geological mapping but not orebody search.

Q - q. Best for orebody search. If very high accuracy then can also be used for geological mapping.

AB - q. Better differentiation for geological mapping, but very difficult to interpret.

3.6.4 EPP.

This ground method is similar to the airborne method described in section 3.2, recording the major and minor axes of the ellipse. For geological mapping low frequencies 78 to 100 Hz are used.

3.6.5 Oil Search.

The best method is transient prospecting in the near zone, using a 1 km Tx loop. Can 1) measure in the same loop, or 2) measure in the centre of the loop, or measure the E field not far from the loop. Measurements are made at very late times of 10 ms to 100 s, to search to large depths (structural mapping).

4. TSNIGRI (CENTRAL RESEARCH INSTITUTE OF GEOLOGICAL EXPLORATION)

4.1 GENERAL

Started with general round-table discussion, welcome, etc., by the Vice-Director, Prof. G.P. Volarovich.

TSNIGRI has two Geophysical Departments:

1) predictions (resource assessment on 1:500 000 and 1:50 000 scales - uses gravity, magnetics);
2) assessment of new methods and interpretation, especially EM.

"Russian geophysicists can work anywhere". Volarovich considers the area between geophysics and geochemistry is important, e.g. the use of nuclear methods for determination of Cu, etc., in ores.

EM methods are both airborne and ground. Frequency domain is better for geological and structural mapping.

4.2 PROGRAM

- Introduction - G.P. Volarovich.
- EM techniques - V.I. Piatnitskiy.
- VLF and Radio Wave Methods - Sedelnikov.

4.3 AIRBORNE EM

Uses: 1) Exploration for highly conductive orebodies
2) Geological mapping at shallow depths (<50 m)

Frequencies of 78, 312 and 5000 Hz can be used, with 2 frequencies measured simultaneously. The parameters H_a (major axis of polarisation ellipse), and H_b (minor axis of polarisation ellipse) are obtained by to give quadrature anomalies.

Measuring the parameter $(\Delta Hb/Ha) = \Delta V_{312Hz} - 4\Delta V_{78Hz}$, where ΔV is the induced voltage, excludes the influence of the swinging bird and overburden. In the presence of orebodies, this parameter is small (Figure 4.2).

The DUP-A (Dipole Inductive Profiling-Aerial) airborne system (Figure 4.1) is used on a large scale, at present in W. Siberia and Asia where the ground is moderately resistive. At present 10 systems are in use. The main application is structural mapping.

The aircraft's secondary field is bucked out by the use of a smaller coil on the aircraft, wound in opposition. The position of, and current in, this coil were determined from model studies, and tested at high altitudes. Different compensation is required at different frequencies.

TSNIGRI has a McPhar airborne system, but the swinging bird creates too much noise.

4.4 GROUND FEM PROFILING USING EPP-2

This system also measures ellipse of polarisation and the ratio H_b/H_a, at frequencies of 78, 312, 1250, 5 K and 20 K Hz.

The transmitter consists of a horizontal coil, about 120 m from the receiver. The receiver consists of two orthogonal ferrite-covered coils, mounted on a tripod. The parameters measured are H_a, proportional to the primary field, and H_b, which is insensitive to orientation errors. This system is considered better than loop-loop DEMP (Slingram) equipment.

EPP-2 can also use a large Tx loop or grounded wire. Profiles are read inside or outside the loop. There is no need to use a connecting cable, because the ratio H_b/H_a is measured. The data are presented as contours of ρ_a.

EPP-2 is not widely used because of the small depth of penetration. EM sounding methods are now being used for geological mapping in ore provinces. Since layered-ground interpretation is not appropriate, pseudosections of ρ_a are plotted.

4.5 EM SOUNDING

Various configurations are possible (see Figure 1.11).

AB-q gives anomalies from very good conductors, but is insensitive to structures with resistivity contrasts of less than 10 or 20.

AB-ab is used in areas where the resistivity of the top layer is greater than three times the resistivity of the lower layer.

Equatorial-dipole configuration is more sensitive to structure, and resistivity contrasts of 3 to 5.

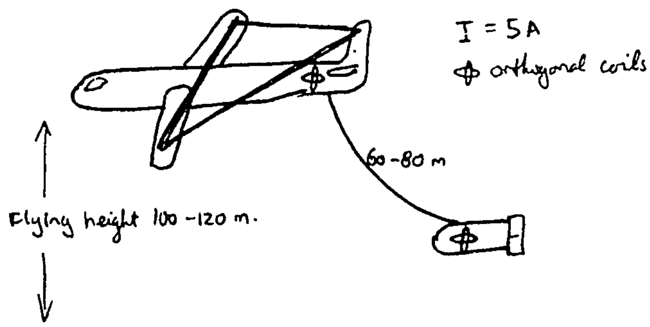

Figure 4.1 Diagram of DUP-A (Dipole Inductive Profiling-Aerial) System.

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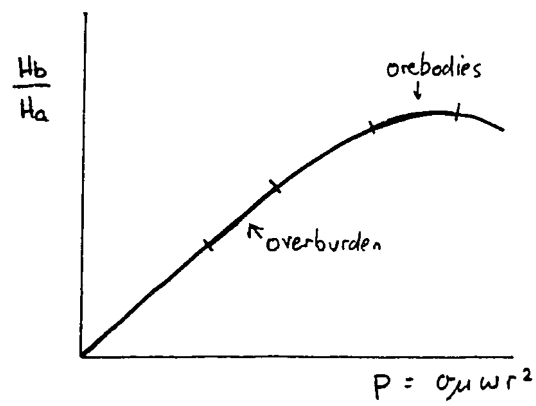


Figure 4.2 Airborne FEM response curve.

Frequencies used are 1, 2 ... 20 000 Hz in steps of 2 or $\sqrt{2}$. Typical parameters are AB = 500 m, separations = 2000 m, MN = 100 m, with radio link, giving a depth of penetration to 1000 m.

Both E and H are measured, and both are plotted as pseudosections, as a function of frequency, and also as functions of depth (skin depth approximation). In these plots,

P_x = dipole moment of Tx, and
E_x = received ΔV for various R/h
R = Rx-Tx separation
h = depth to layer

There are 2-layer theoretical curves for

$\rho\omega$ with electrodes (amplitude),
$\phi\omega$ with electrodes (phase),
$|H_y^x|$ magnetic field (amplitude) and ρ_ω^H
where $\rho_\omega^H = K \frac{\Delta V}{I}$, where $K = \pi R^4 / (AB \times \text{area of loop})$
ϕ^H magnetic field (phase)

In mountainous, low resistivity areas, a large Tx loop is often employed, with measurements both inside and outside the loop.

4.6 DUM (Two-loop Inductive Method)

This method is a competitor of transient methods, since it is much less sensitive to noise. The layout is shown in Figure 4.3. An air-cored transformer links two coincident Tx and Rx loops, which are normally about 400 m across. The secondary windings of the transformer are moved inside the primary windings (wound in opposition) until a minimum voltage is obtained in the Rx. At compensation the phase shift equals 90° and the resultant voltage is out of phase with the primary. Using a narrow-band filter and CRO or meter, compensation (cancellation of primary in-phase component) to better than 10^5 or 10^6 is possible (electronic devices could achieve only 10^3 or 10^4).

The Tx range is 20 to 20 000 Hz, but the frequencies normally used are 19, 78, 312, 1250 and 5000 Hz. Two frequencies are used, and the value

$$\Delta \xi = \xi_{19Hz} - 0.25 \; \xi_{78Hz}$$

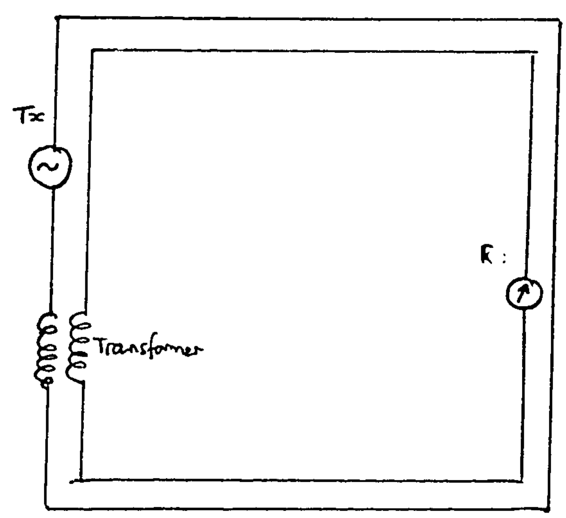


Figure 4.3 Loop arrangement for DUM method.

is calculated, where ξ is the measured voltage. If the field strength is proportional to frequency, then $\Delta\xi$ value will be zero. In the presence of an orebody, $\Delta\xi$ will be non-zero.

The system can be vehicle mounted with a 30W transmitter providing 2 to 3 amps. The system takes longer to use than transient methods, and results are very similar to MPP. In noisy areas there are examples where MPP did not give an anomaly, but DUM did. Also, the lower frequencies used in DUM offer better discrimination against surface conductors.

DUM is good for geological mapping since much higher resistivities can be measured. DUM can also be used to measure magnetic permeability, by compensating for the quadrature field, leaving only the in-phase. The quadrature component does not depend on μ, but the real component does. This compensation is quite difficult; each frequency needs to be compensated separately. This method is good for low frequencies, where there is little noise.

4.7 DOWN-HOLE EM

Down-hole EM was developed in 1960 (SAFI equipment). This uses a Pb weight on one side of the probe to orient x and y axes. This works well even in steeply dipping holes.

ASMI-40 is a dipole-dipole downhole method, with 40 m separation. Orebodies can be detected to distance of 80 m. The frequency range is 78 Hz to 5000 Hz.

Mise-a-la-Masse is used much by industry, especially in Urals.

4.8 FUTURE DIRECTIONS OF RESEARCH

1. Airborne development, so that greater areas can be covered more effectively.
2. Better definition of anomalies; combined geophysical-geochemical methods (e.g. nuclear for Cu content).
3. Better follow-up. More sophisticated downhole methods.

4.9 VLF & RADIO WAVE METHODS

4.9.1 History

1946/8 The first use of distant radio stations was by Prof. Tarkhov, using stations in range 150 - 500 kHz ("long waves" in Russia; "LF" in USA). Theory was not developed at that time. The method was not used very widely because the high frequency limited the depth of penetration. The best areas had high resistivity, such as W. Siberia and N. USSR, but there are very few radio stations in these regions.

Early 1960s Interest was renewed owing to CDB (super-long waves). Simultaneously, but unknown to USSR scientists, this method was being developed in Canada (VLF). At TSNIGRI work started in 1962. Experimental equipment was built using semiconductors, and field tests on non-ferrous and noble metal deposits were carried out. The theory was developed later, by Prof. Dimitriev at Moscow State University.

1972 First airborne use. At present the method is comprehensively developed and is used in conjunction with magnetics and radiometrics. There are 10 to 15 airborne systems, used mainly in the Far East and Siberia where there is favourable geology. Each airborne party has one follow-up ground party. Also, ground CDB methods are used independently by other organisations, but not as widely as other methods, such as IP, EM profiling.

1980 Book will be published by Nedra: "Electrical Prospecting by the Radio Wave Method", by Sedelnikov.

1980 TSNIGRI will be producing serially a portable ground RX called SDBR-4. (cost $1,500).

1981 TSNIGRI will be producing serially an airborne version. The Russian name for this equipment is RADVOKUP "Radio Wave Comparison and Direction Locator".

4.9.2 Theory

Use either orthogonal cartesian or cylindrical coordinates for survey axes.

In air, $E_z \approx$ 10 to 100 E_x or E_y. In the ground, this is vice versa; the wave travels almost vertically downwards and decreases exponentially. The practical limit in measuring E is 100 μV/m. VLF waves travel in the earth/ionosphere wave-guide, and can be used at distances of 10 000 to 12 000 km.

The intensity of long waves can be mapped to detect large features, such as the land/ocean interface (Figure 4.4). The attenuation increases with the conductivity of the ground.

Typical diurnal variations are shown in Figure 4.5. If the variations are slow they are not considered important.

The impedance $Z = E_r/H_\phi$ can also be studied. Both E & H fields are elliptically polarised. Master curves exist for E_y/H_x and phase shift $\phi_E - \phi_H$, as shown in Figure 4.6. There are three distinct regions on these curves:

1) Z and ϕ only depend on ρ; this is seen at low frequencies where $Z \propto \sqrt{\rho}$.
2) Z and ϕ depend on ρ and ϵ.
3) asymptotic region.

Measurement of Z

Ground - all 3 components are measured using electrodes and antenna.

Airborne - because E_z is large, the quadrature E component (E_b) is measured; this is equivalent to the minor axis of the polarisation ellipse. The vector E_r is not measured.

Arrays

Four different arrays are possible, as shown in Figure 4.7. In array (a), the receiver is asymmetric. In (b) the receiver is symmetrical. (c) uses shielded cable to reduce noise. Array (d) is used for separations greater than 10 m and can only use symmetrical receiver. Note that since this is an open electrical dipole E_r is twice as large as measured with the other arrays. The capacitance of the wire must be much greater than the capacitance of the receiving device. The Rx array is tested by mapping the symmetrical radiation pattern.

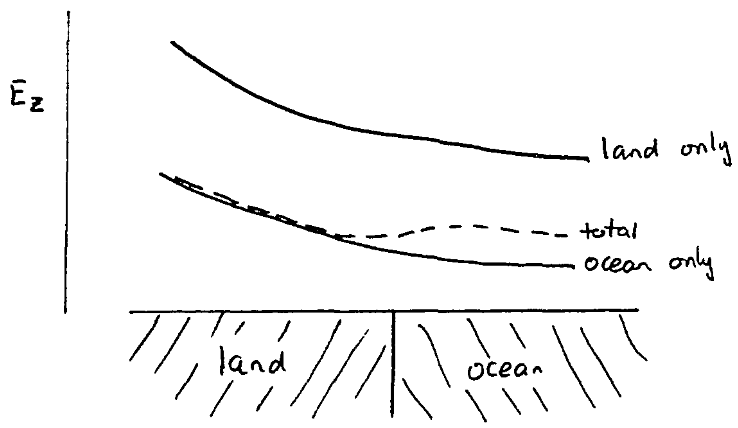


Figure 4.4 VLF intensity profiles.

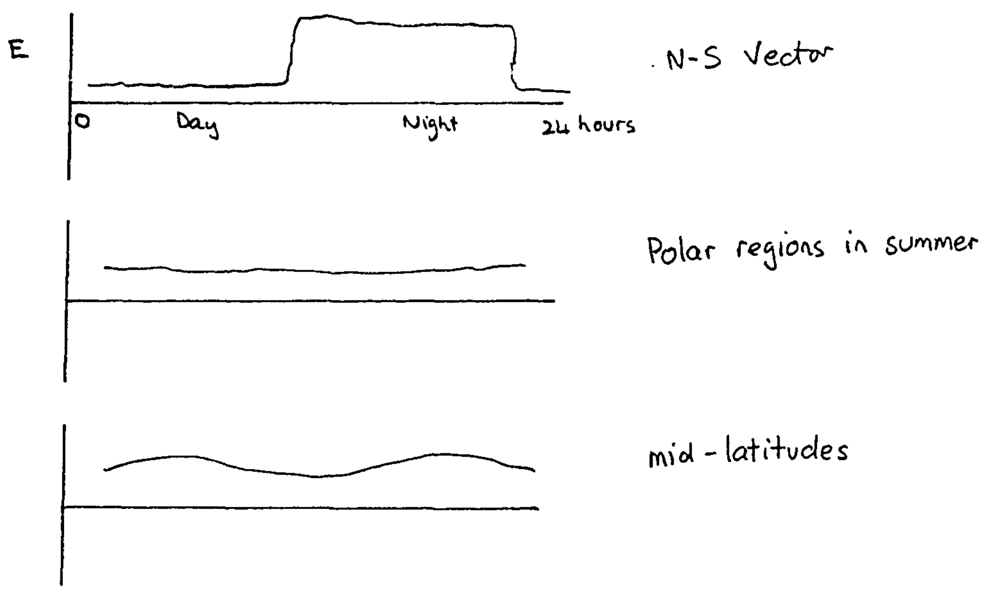


Figure 4.5 Typical VLF diurnal variations.

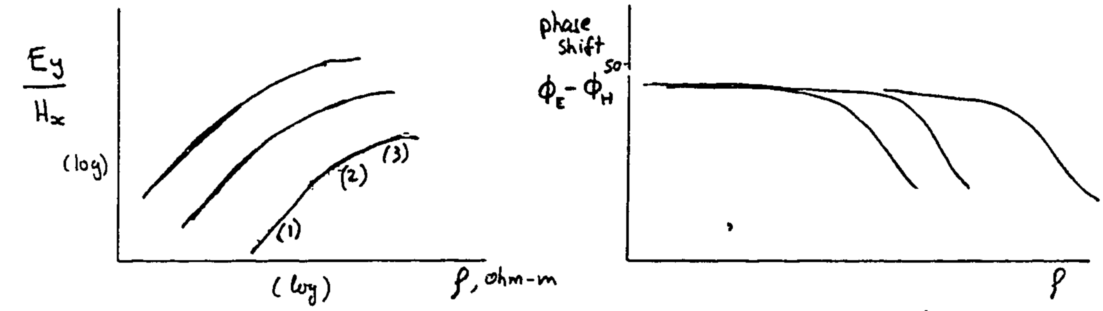


Figure 4.6 Master curves produced for use in radio wave methods.

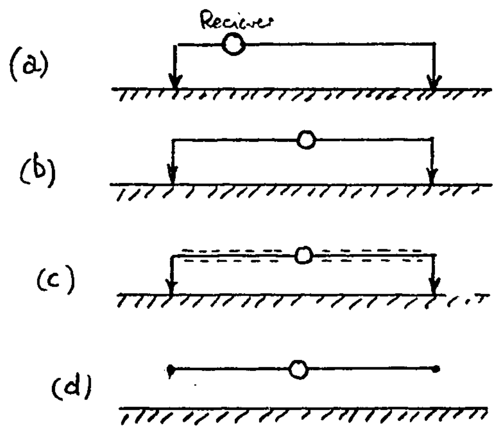


Figure 4.7 Arrays used for radio wave measurement. a: asymmetric, b: symmetric, c: shielded symmetric, d: for large separations.

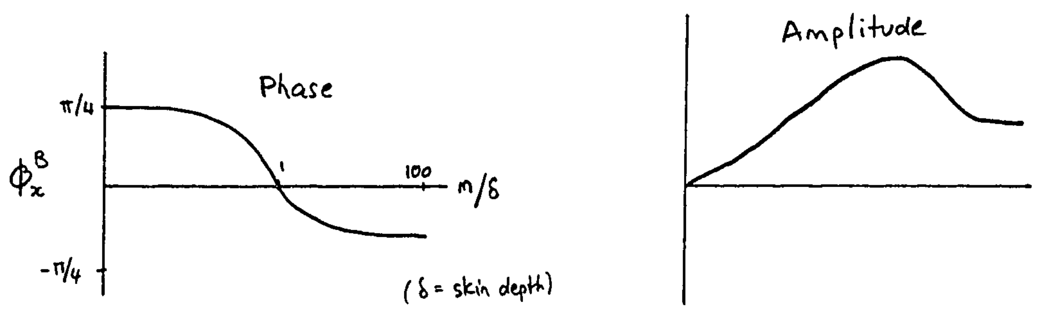


Figure 4.8 Secondary field response.

NB In contrast to inductive methods, this method responds only to resistivity contrasts.

The intensity of the primary field is given by:

$$A_H = K \frac{Z_1}{R + i\omega L}$$

where Z_1 = Z of host rock,
R = active resistance/unit length, and
L = inductance/unit length.
K = constant

At low frequency, or small depth, the secondary electric field E_s. leads E_p. As σ, f or thickness is increased, the phase decreases until it equals zero. For larger σ, f or thickness, E_s lags E_p, resulting in negative phase.

The secondary field has a response shown in Figure 4.8. Solutions for 2D bodies have been obtained using the Integral Equation method e.g.

a) horizontal plate in a halfspace,
b) truncated second layer in a 2-layer earth,
c) dipping plate in a halfspace.

If the plate is 3 skin depths long, it may be considered infinite. The depth of investigation is 0.3 to 0.7 skin depths. Model study results are given by Piatnitskii & Malashev in Postelnikov et al. (1978).

4.9.3. Applications

(1) Detailed prospecting for bodies of high conductivity - measure H (e.g. fracture zones and sulphides).
(2) Detailed prospecting for bodies of high resistivity - measure E (horizontal) perpendicular to strike (H polarisation).
(3) Well Logging. Examples of the use of radio-wave methods in well logging for buried kimberlite pipes are given by Bekhtereva in Postelnikov et al. (1978).

4.9.4. Instruments

1) Amplitude Measurements - Portable instrument with 7 frequencies from 11 to 23 kHz, using integrated circuits. Both horizontal and vertical components (major and minor axes), and dip of H are measured. Electrodes are used for E to give impedance.
2) Phase Measurements - equipment is not yet in serial production. Measure Z and E to give resistivity, and also phase difference between components; can also use a coil to measure H.
3) Measure Im and Re components Only a few instruments made; restricted to aerial work.

The depth of investigation is 10 m in moderately resistive areas, 100 m in very high resistivity areas.

4.9.5. Airborne Version

The airborne version is very useful for mapping tectonic units, e.g. granites of different ages have different fracture patterns, and hence signature. The main problem is the occurrence of anomalies due to terrain. The anomalies which coincide with terrain changes are rejected by hand.

The Rx is located in a 1.5 m boom behind the wings or out of the side of the fuselage. Compared with conventional airborne EM this method is less affected by changes in flying height. Anomalies have been recorded over Cu lenses.

Future - developing a portable VLF Tx to use at distances of 300 km.

5. MGRI (MOSCOW GEOLOGICAL EXPLORATION INSTITUTE)

5.1 GENERAL

MGRI is a teaching institute and currently has 50 geophysics students in electrical/EM techniques. MGRI has three main research aims

a) Harmonic induction methods - separation of induced and remanent magnetisation. This has application to magnetic permeability studies.
b) TEM - ground and airborne
c) IP - frequency domain, especially non-linear effects.

5.2 PROGRAM:

- Low Frequency Induction Method - I. Yakobovskiy
- Airborne TEM - F.M. Kamenetskii
- Ground TEM - F.M. Kamenetskii, V. Timofeev

5.3 LOW FREQUENCY INDUCTION METHOD (LFIM or NP)

Early theoretical work was carried out by Wait and Ward in the USA on the response of a permeable sphere, etc. Theory continued at MGRI on oblate and prolate spheroids, and plates (scale model studies were used for plates).

5.3.1. Theory

At low frequencies, the phase angle does not depend on μ, but the magnitude does. (For a non-conductive, permeable body the phase does not give any information; neither does magnitude in transient measurements). If a magnetic anomaly is obtained from conventional magnetics, with low frequency EM it is possible to determine the relative amounts of residual (remanent) magnetisation, and induced magnetisation.
NB similar information can be obtained from magnetic variometer method.

5.3.2. Background

The influence of remanent magnetisation is a big problem in the USSR for interpretation, especially in prospecting for iron ore. The field procedure described below has been carried out on all the major iron ore deposits of the USSR. Special Rx coils were supplied to regular IP crews all over the country. Since they use standard IP equipment this is very cheap.

5.3.3. Methodology

It is best to use as low a frequency as possible, to reduce the effect of conductivity. Practically, conventional IP equipment is used, with a lowest frequency of 22.5 Hz. It would be preferable to use more modern equipment with a lower frequency range. If the body is conductive, there is a need to measure over a wide range of frequencies up to 2 to 3 kHz.

A very large Tx loop is used to create a uniform field (e.g. Kurst is 200-300 m deep), usually 1 km square to 3 km square, with a 50 W Tx providing 0.5A of current. The Rx is a specially built coil, with a dipole moment of 5000 turns m^2 and a magnetic core. This is tuned to a lowest frequency if using 22.5 Hz, or left wideband if other frequencies are used. Usually, the vertical component is measured. The quadrature component may be used to estimate conductivity.

5.3.4. Accuracy

The main errors arise from topography and the effect of conductivity. Other sources of error are instrumental when measuring amplitude. An accuracy of 0.1% is required, but at present it is only possible to achieve 0.5%. e.g., if the magnetic anomaly from a body is 1000 nT, and the Earth's field is 40000 nT, then the anomaly is only 2.5% of the primary field.

For the large loop induction method, a uniform field of about 8,000 nT is possible, and an anomaly of 2.5% of primary field will be obtained, i.e. 200 nT. If the accuracy of the Rx is 0.5%, then the 200 nT anomaly is just within our measurement capabilities. That is, the current limitation for this method is for a 1000 nT magnetic anomaly. The main problem is subtracting an anomaly in a large primary field, and eliminating the effect of conductivity.

5.3.5. Loop Configurations

Various types of loop configurations are shown in Figure 5.1.

a) Profiling within a large loop.

b) Vertical sounding. Curves of apparent susceptibility versus L are plotted. Interpretation uses:
   - 2-layer master curves,
   - sphere in halfspace,
   - sphere in 2nd layer.

c) Large grounded cable. This is used in areas of high resistivity. In other areas this configuration results in many false anomalies owing to conductivity changes.

d) Dipole-dipole (not shown). This array is more sensitive to geometrical errors such as spacing.

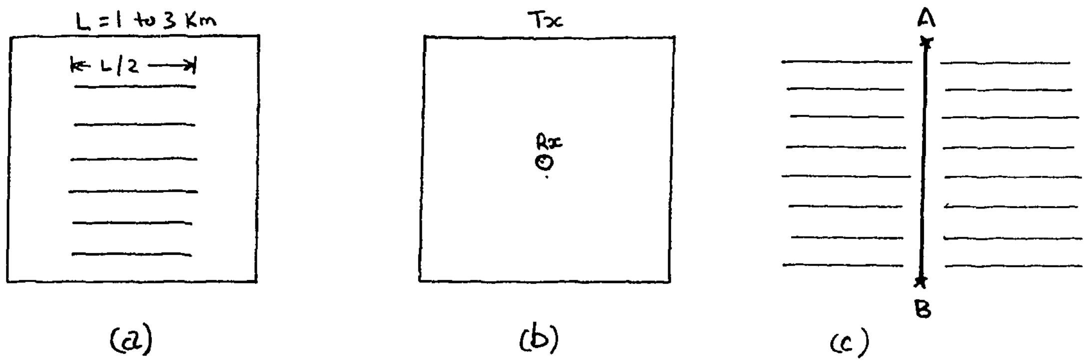


Figure 5.1 LFIM loop configurations. a) profiling, b) vertical sounding, c) large grounded cable.

Figure 5.2 Results of investigations using LFIM method on magnetic deposit in Samara I-II in Gornoi Shorii. 1: unconsolidated sediments, 2: diorite, 3: oxidized magnetic sediments, 4: massive magnetite (after Garanskiy et al, 1976).

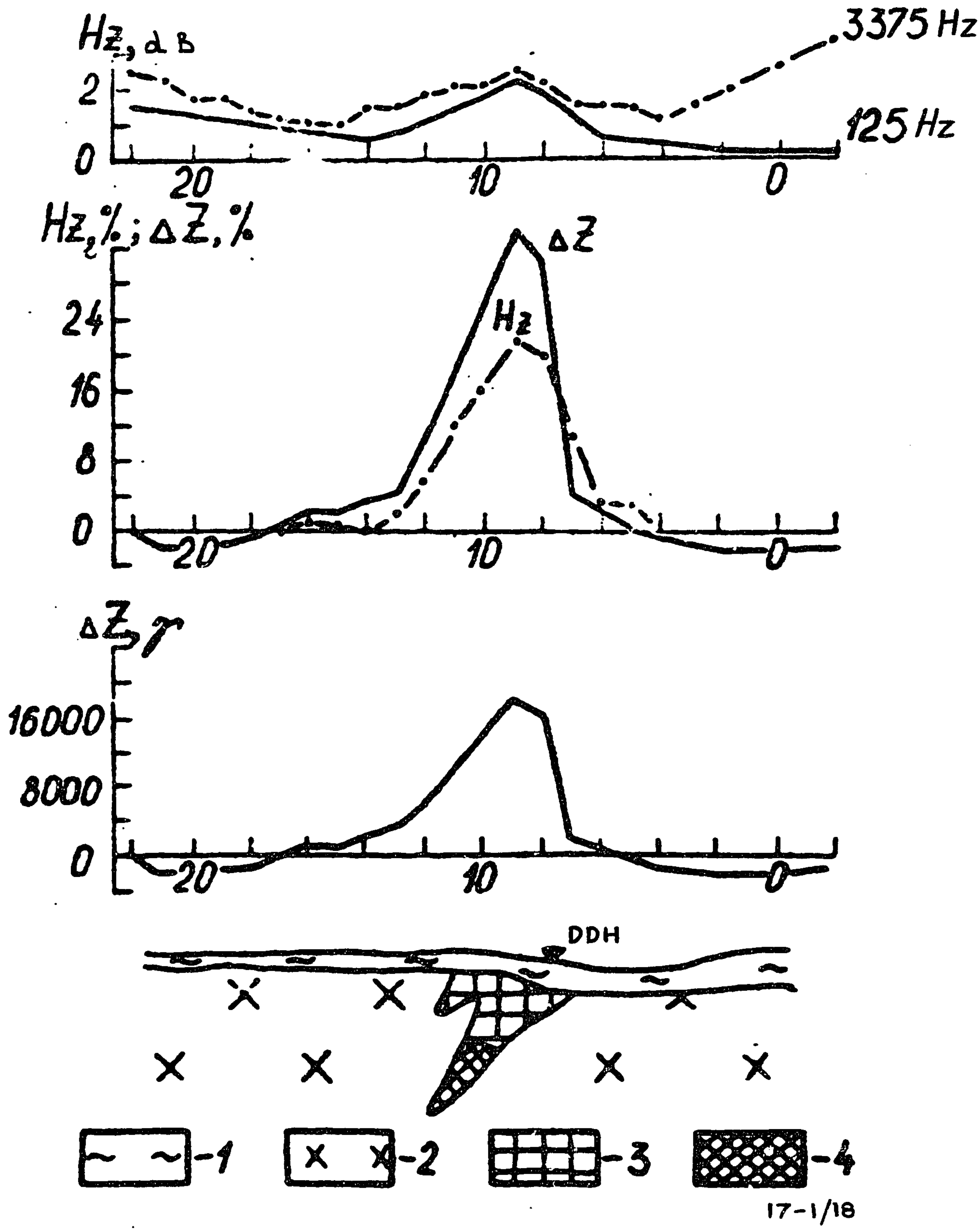
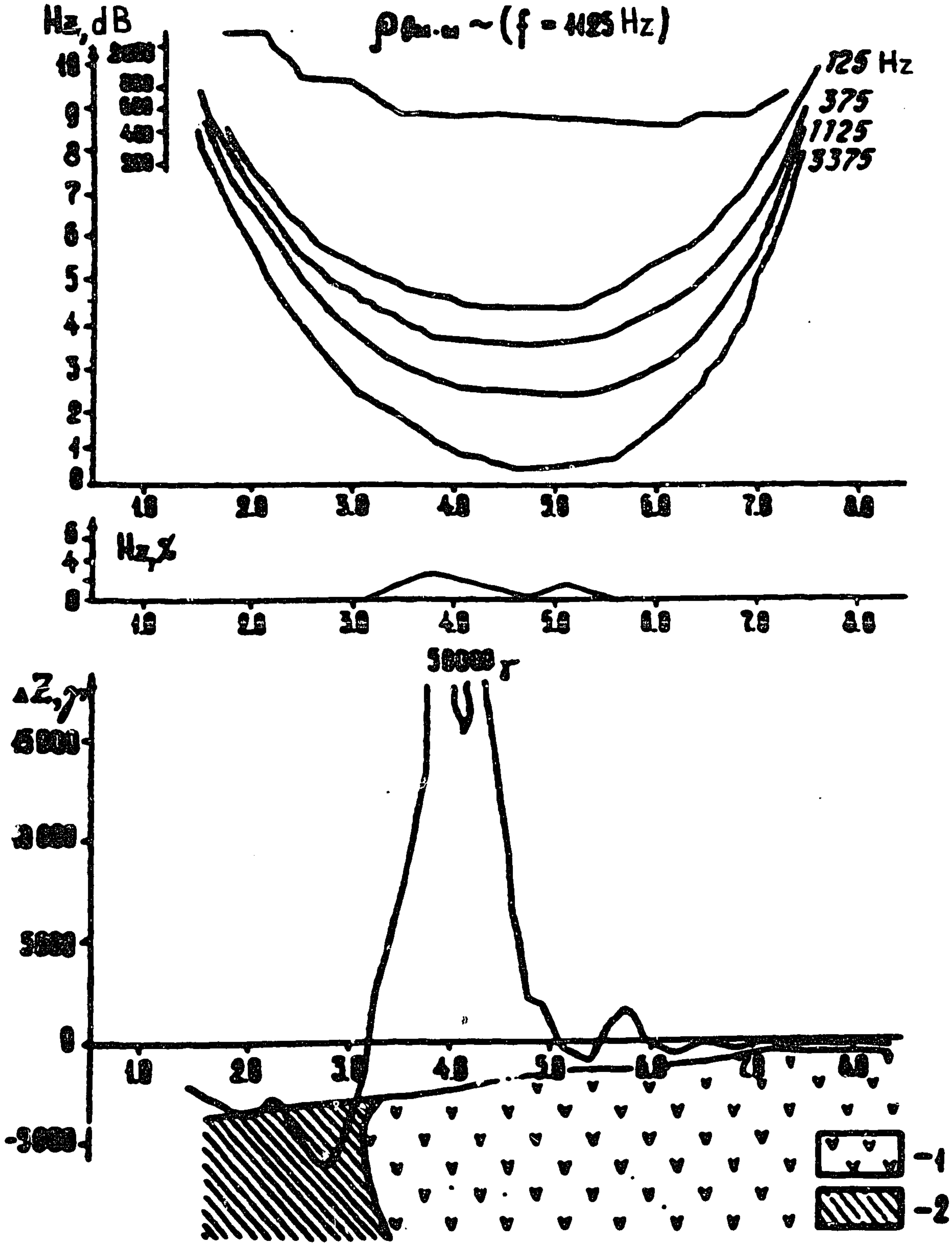


Figure 5.3 LFIM results in the Shurskii site in Middle Priangar. 1: dolerites, 2: calcareous sandstone (after Garanskiy et al, 1976).



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5.3.6. Field Procedure

1) Carry out magnetic survey.
2) Repeat, with LFIM.
3) Compare anomalies and interpret.

A field example, from Garanskiy et al. (1976) is shown in Figure 5.2. The top profile is the LFIM results, Hz, at 2 frequencies, in dB. The bottom profile is the magnetic results, ΔZ, in nT. In the centre profile, both H_z and ΔZ are expressed as percentages of the primary field, and compared. The difference is interpreted by assuming a model, e.g. sphere. The use of different components is often useful in interpretation.

5.3.7. Applications - areas with remanent cover, e.g. "trap" (basalt) over deposits. An example of this type of response from Middle Priangar is shown in Figure 5.3. A large magnetic anomaly is obtained (lower profile), but no anomaly is obtained with LFIM (top profile). Thus most of the magnetisation is remanent.

5.3.8. Future Developments - MGRI will soon be trying a SQUID receiver. It should be very sensitive, but will not reduce geometrical problems.

5.4 AIRBORNE TEM (AMPP)

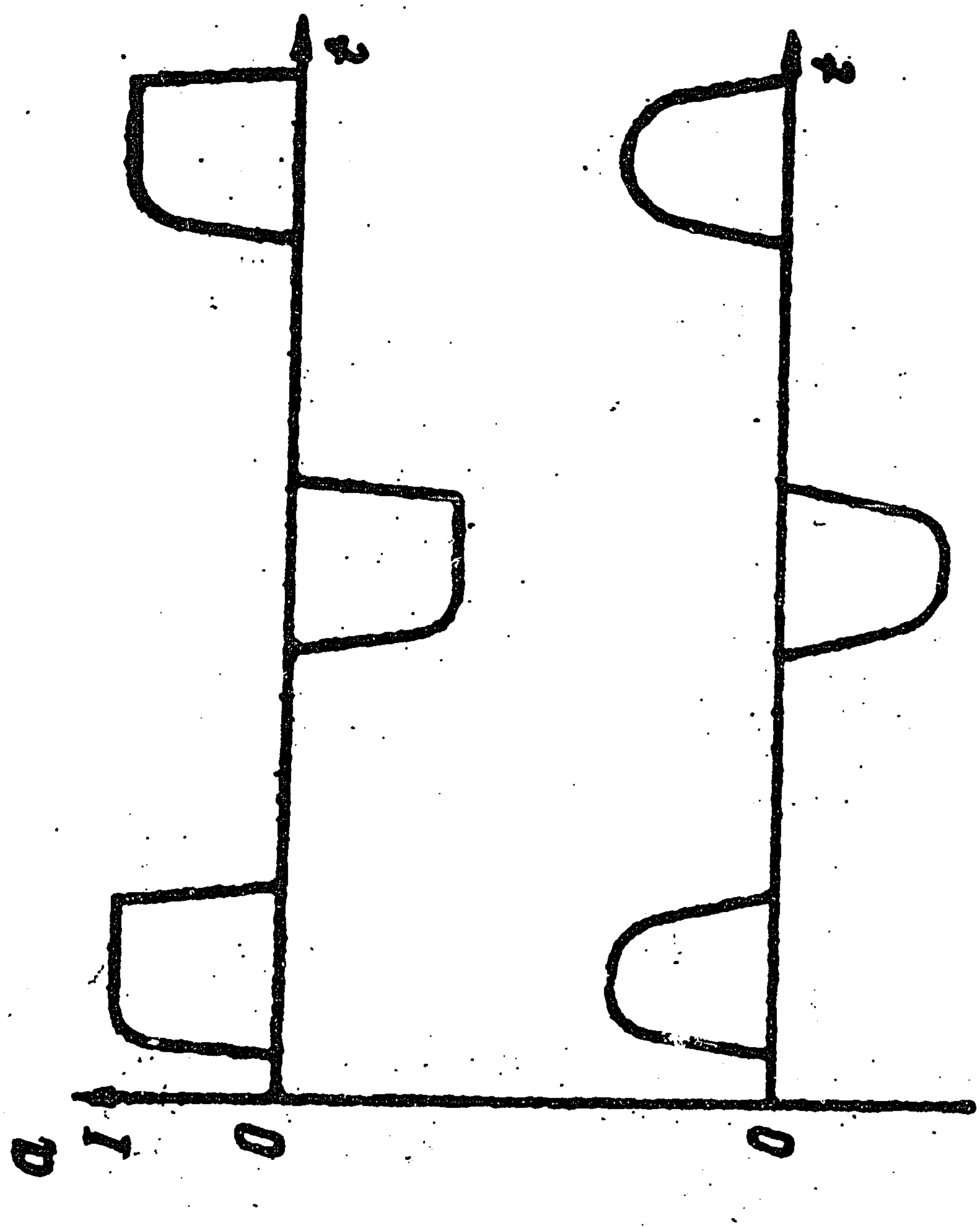
5.4.1. History

Development of the airborne TEM system started in 1968. Originally, MGRI tried a simple conversion of the ground technique to an airborne version, but difficulties were discovered, e.g. they tried to use much later times than the Canadians (INPUT), but the noise was too large. The noise spectrum was very close to that of the signals. Sample times used now are between ground and Canadian (INPUT) systems. Coverage to date is 4000 square km with a 100 m line spacing.

5.4.2. Waveforms

The transmitted waveform is shown in Figure 5.4b. The on-time is 4 ms which is longer than with INPUT (1 to 1.5 ms). A half-sine waveform is used because it is not possible to obtain a square wave with the multiturn coil. The receiver measures times of 0.2 to 3 ms. There are 5 channels, of which 2 are used for noise measurement. The selection of channels depends on the area being surveyed. The readings are averaged with a 1.5 s time constant.

Figure 5.4 Transmitted waveforms used in airborne TEM. (a) quasi-rectangular, (b) half sinusoidal (after Kamenetskii, 1978).



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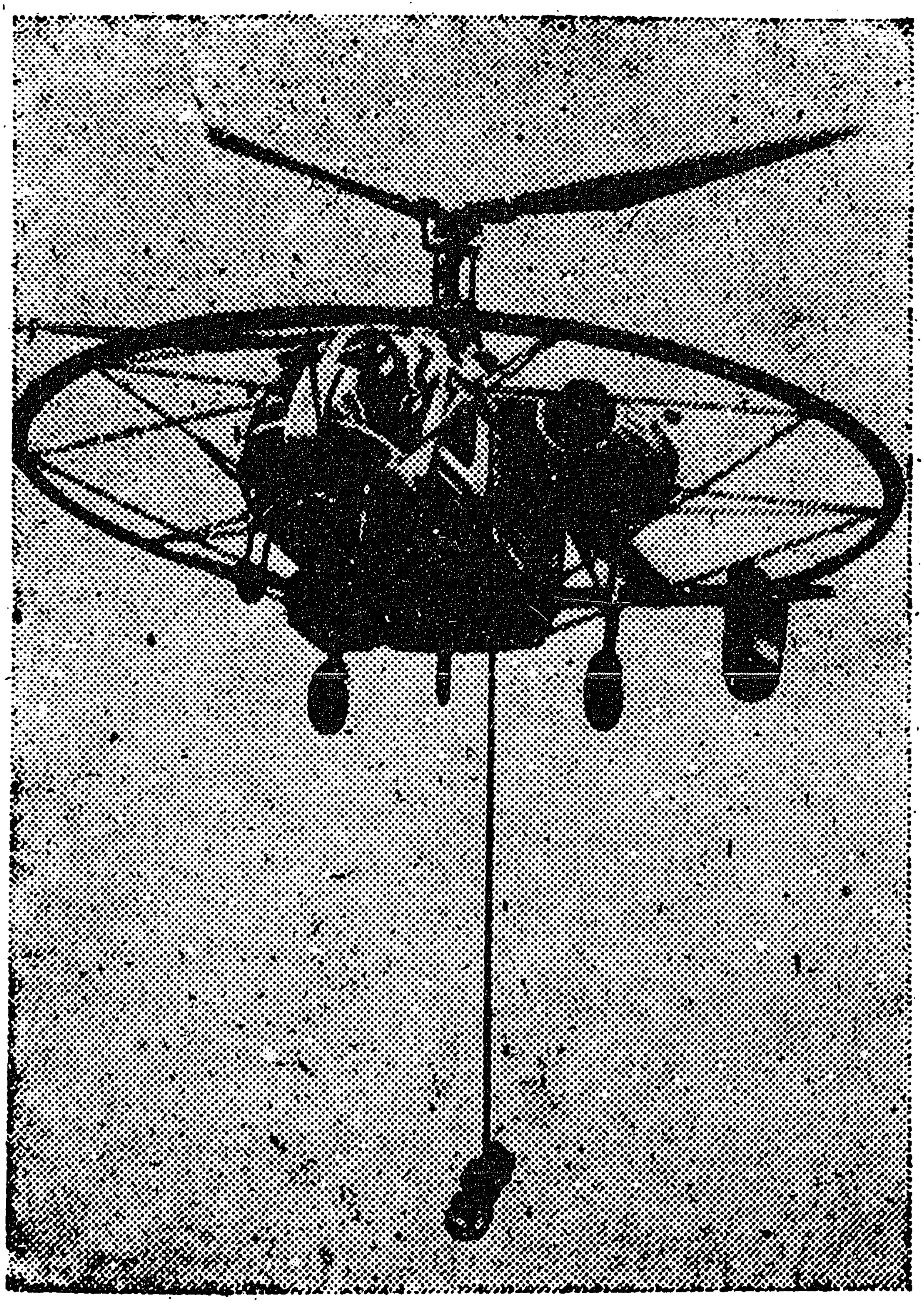

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Figure 5.5 General view of AMPP–2 System using KA–26 helicopter (after Kamenetskii, 1978).

5.4.3. Helicopter and Transmitter

The helicopter, shown in Figure 5.5, is a 7 seater type KA-26. This has no tail rotor and 2 opposing main rotors, and was originally designed for agricultural use and has a 3kW 28 V generator which is used for the Tx. The helicopter has many plastic parts.

The transmitter loop consists of a 7 m diameter 10-turn aluminium tubing, with cross-section 40 mm^2, insulated and epoxyed, with a weight of 50 kg. This is much better than using wires, which need a mechanical support and would weigh 150 kg.

The transmitted current is 150 A, operating at 4.5 kW peak.

5.4.4. Components Measured - Input measures the horizontal component because of the long cable (150 m) and the high speed of the aircraft. The angle between the cable at the aircraft and vertical is about 53°. At the position of the bird the primary field is nearly horizontal. For a helicopter, the angle of the cable is less than 5°, so it is better to measure the vertical component to reduce noise and increase the signal.

5.4.5. Noise Sources

1) Electrical interference from helicopter, especially radio transmissions (need to report every 1/2 hr).
2) Vibration of Rx in the earth's field.
3) Eddy currents induced in the helicopter body. These are large, and have a slow decay at about 10 mV level, and require 10 µV sensitivity.
4) Self-process of coil, designed to be less than 200 µs.

The noise sources are reduced as follows:

1) The radio is used only at the end of flight lines.
2) Two schemes are used to reduce the noise carried by movement of the bird in the earth's field.
    a) The coil has a large mass of 10 kg, and is pivoted at the centre of gravity (Figure 5.6). The resonant frequency due to coil movement is very low. The dipole moment of the coil is 300 turns m^2. In addition, a preamplifier with a gain of 10 is used, giving a total moment of 3000 turns m^2. The noise using this scheme is reduced to 3 or 4 µV.

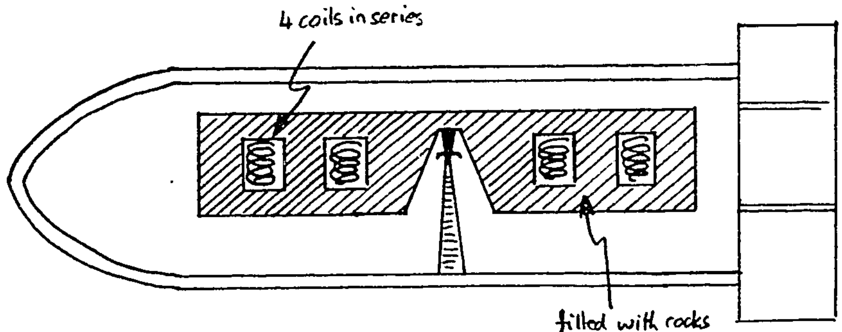
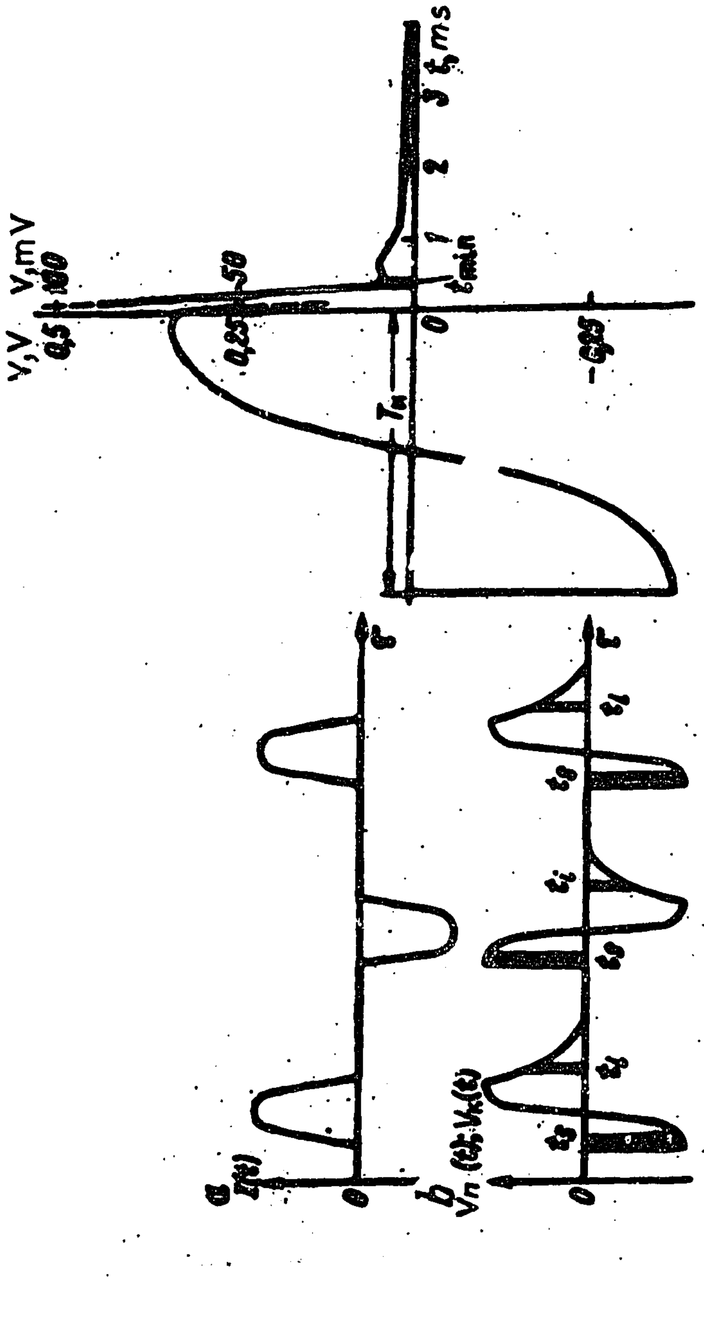


Figure 5.6 Diagram of receiving bird used in helicopter TEM.

Figure 5.7   Sampled TEM waveform (after Kamenetskii, 1978).



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b) The bipolar Tx current reduces the low frequency noise to a large extent.

3) Eddy currents in the body of the helicopter produce noise by:

a) change in mutual geometrical position of bird and helicopter. The method used here is the same as INPUT - a sample of the primary field is measured during the on-time. At MGRI this is done for 2 components, because of the shorter cable distance (50 m). The Tx loop may be considered as a dipole, with the same centre as eddies in the body of the helicopter. There is also a small horizontal component, which is compensated by using a vertical transmitter coil around the helicopter body and transmitting just before the main Tx pulse. The current in this coil is varied to reduce the noise.

The sampled waveform is shown in Figure 5.7. t_s is the received primary signal, which is used to normalise the gain of each of the three transient measuring channels t_1, t_2 and t_3.

Adjustments are made on the ground in a resistive area, with the Rx 40 m ahead of the helicopter on the ground. In this position the field is similar to that 50 m underneath the helicopter. The Rx is held vertically, then horizontally, and compensated. This is repeated 3 or 4 times to obtain a null. In this position there should be no signal received as the bird is rotated. In addition, the system is flown to a height of 300-400 m and the main dipole normalisation is readjusted.

b) the non-rigid helicopter body causes movements which alter the electrical contact, and hence the eddy currents. This effect is worse for older helicopters, but not bad in new ones. Geophysicists suggested during early flights that they should tell the pilot when it is not safe to fly.

The effect is overcome by attaching a coincident loop with a moment of 40 to the main loop. This response is overwhelmingly that of the helicopter body, and not the ground. This response is measured in a special channel and monitors changes in the eddy currents in the helicopter body, e.g. as shown in the example in Figure 5.8. Curve 2 is the coincident loop, or compensating channel response. Curve 3 is the received transient. Curve 1 is the compensated response - note the

Figure 5.8 Appearance of fake anomaly due to movement of helicopter body in normal flight (t = 0.5 ms). Channel 1: compensated response, 2: compensating signal, 3 received transient (after Kamenetskii, 1978).

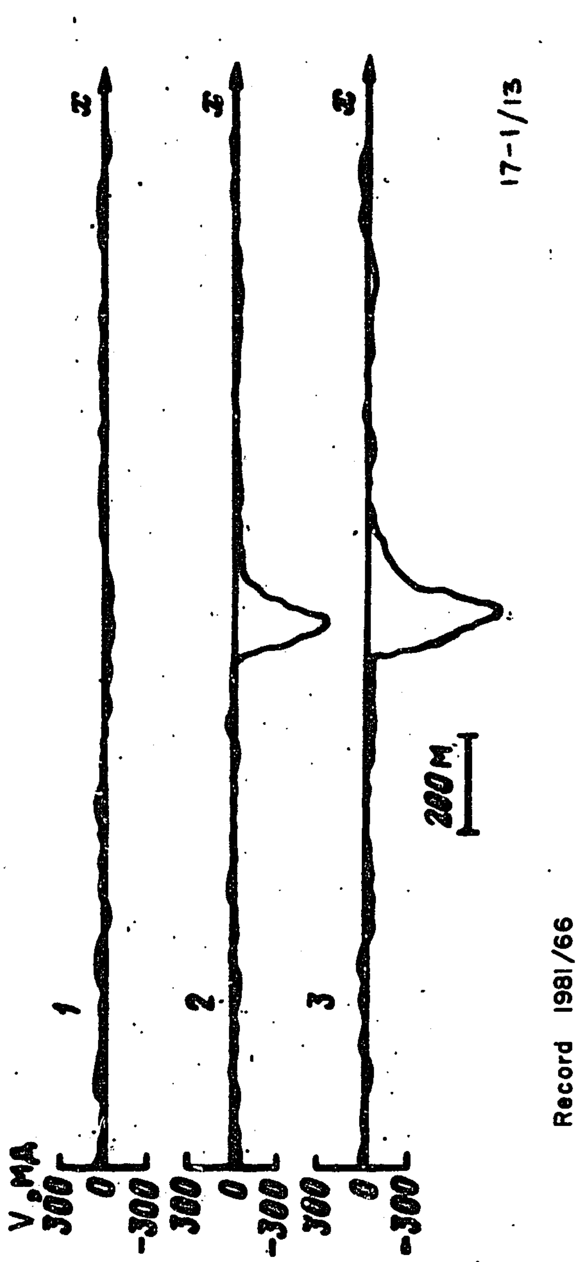
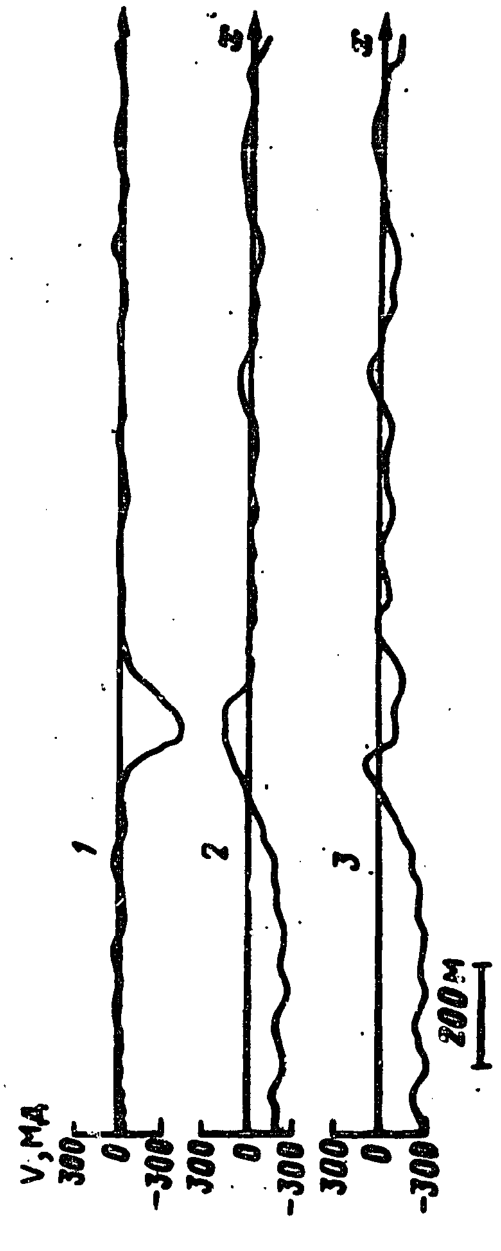


Figure 5.9 Elimination of genuine anomaly caused by appearance of false (helicopter movement) anomaly on flight path over a known orebody (t = 0.5 ms). 1: compensated response, 2: compensating signal, 3: received transient (after Kamenetskii, 1978.



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absence of the false anomaly. The noise is reduced to less than 10 μV. Figure 5.9 shows results over a genuine anomaly, which is clearly seen in Channel 1. In the uncompensated channel (3) the anomaly is obscured by noise.

5.4.6. Data Reduction

For noisy surveys, the ratio of channel 1 (Tx measurement) and channel t_1, t_2 or t_3 is calculated. The ratio is plotted with a wide spatial window (greater than the width of expected anomalies) and a simple correlation analysis is performed between residual signal and the primary field. Different weighting functions are used to reduce the correlation. The primary signal t_s. is plotted to check for variations (normally less than 10%). For each of the transient channels t_1, t_2, t_3 the primary signal is used for normalisation.

5.4.7. Field Procedure

Two systems are in use. The threshold for anomalies is normally chosen at 20 μV, even though this is close to the noise level. Anomalies are obtained over aout 1% of the survey area, the ground follow-up is used to eliminate false anomalies due to noise. The system is meant to be a substitute for ground work. The line spacing is 100 m (very detailed), and normal coverage is about 200 km per day (25 sq km equal to 1000 sq km during a 4 month field season). Navigation is by airphotos; the pilot's job is to keep a constant flying height. Extra control is by flight path recovery, with a photo every 1 km. Recording is analogue, with some punch tape. Flying height regulations state that the bird must be at least 25 m above trees. Usually the helicopter is flown at 100 m, or 80 m if there are no trees.

5.4.8. Comparison with Input

The two systems have about same total sensitivity, with 50 ppm noise. The MGRI system has a lower absolute sensitivity, but is compensated by a lower flying height. The MGRI system is better for detailed work since it flies lower and more slowly. In addition it is better in conductive areas because of later sample times.

5.4.9. Comparison with FEM Airborne

FEM probably has a better depth of penetration, but more anomalies are obtained. The equivalent frequency range of the MGRI TEM system is lower than the harmonic method, and thus is better for massive sulphides.

5.4.10 Comparison with Ground TEM

- not as sensitive but still worthwhile

5.4.11 Field Examples

1. AMPP profiles at 3 ms and three different flying heights over a shallow sulphide ore lode in the Veski-Iavr area are shown in Figure 5.10. A clear anomaly is obtained even at 100 m.

2. A contour map of AMPP response at the 20 μV level from an area in the Urals is shown in Figure 5.11. In the total area of 200 sq km there are four regional anomalies and 16 local anomalies which cover 1% of the survey area. Ground follow-up showed 13 of these anomalies to be due to noise. Anomaly 8 is a known orebody. Anomaly 20 was drilled, and found to be a 40 m wide body containing chalcopyrite, pyrite and pyrrhotite, at a depth of 40 m.

5.4.12 Present research - MGRI is trying to adapt a caesium-vapour magnetometer. Input uses a proton magnetometer which is time-shared with TEM. MGRI is designing a continuously recording one, with the head mounted in the non-ferrous bird. However, there are various noise frequencies in the magnetometer which adversely affect the TEM:

a) 200 MHz, used to energise the caesium bulb. This is a very strong noise, which is somehow modulated by movement of the bird or parts thereof.

b) 1.5 MHz frequency which depends on the earth's magnetic field, but does not affect the TEM.

c) 300 Hz modulation. To overcome this problem, this frequency is synchronised with the repetition rate of TEM pulses. The solution is to mount all parts on the rigid coil platform. A master frequency generator with frequency multipliers is used to synchronise the waveforms.

The main problem is that it is difficult to purchase non-ferrous cable. Those available are copper alloys and very thick and heavy, so they shift the bird further back and therefore introduce noise.

Figure 5.10 AMPP profiles at t = 3 ms in the Veski-Iavr ore province, at helicopter flying heights of 70, 85 and 100 m. 1: gneiss, 2: amphibolite, 3: pegmatite, 4: sulphide ore, 5: unconsolidated sediments (after Kamenetskii, 1978).

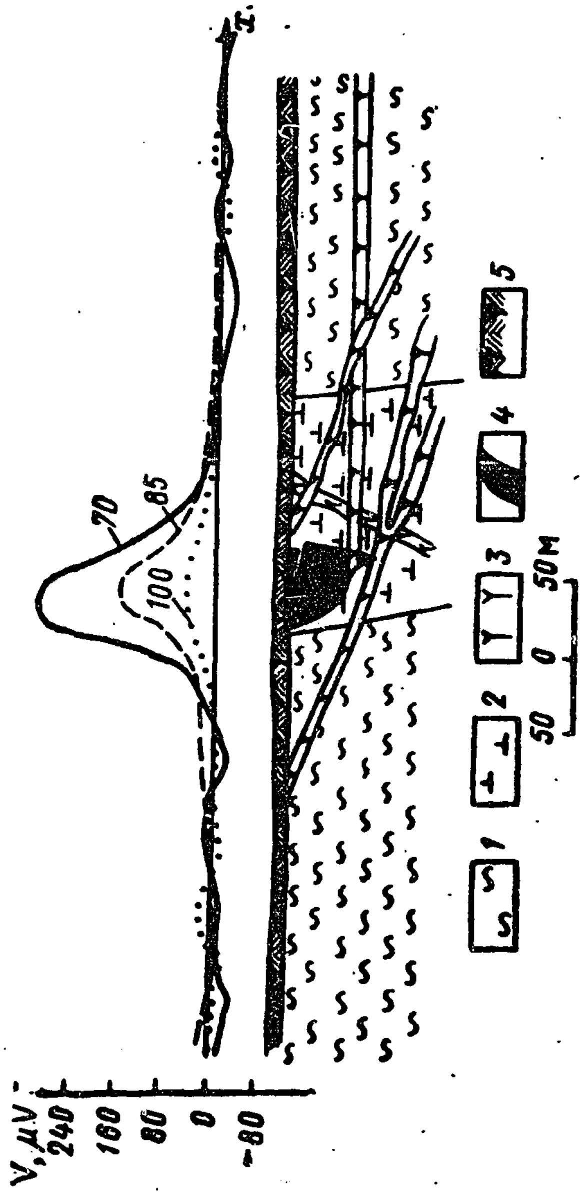
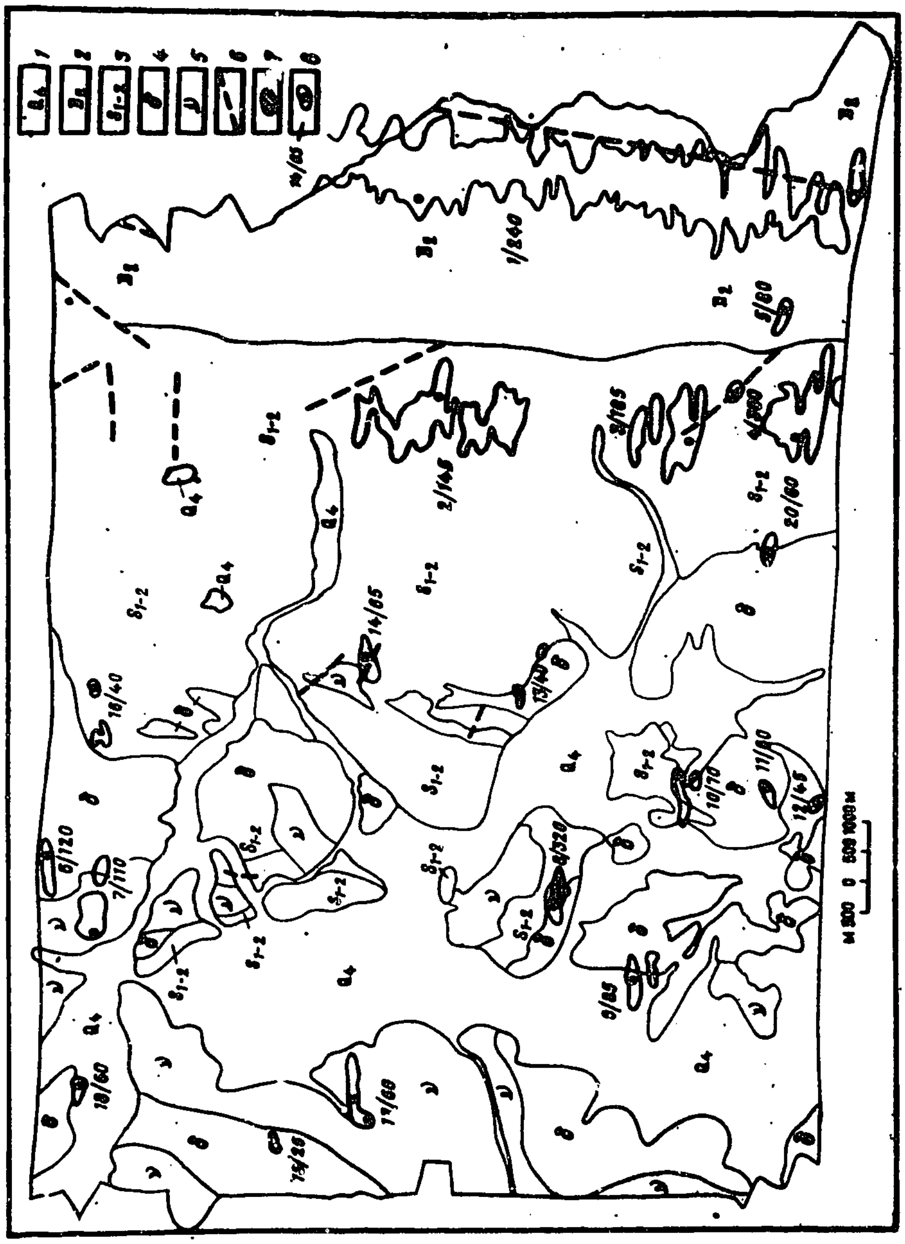


Figure 5.11 Contour map of AMPP anomalies from the North Urals ($t = 0.5$ ms) 1: quaternary deposits, 2: calcareous sandy deposits, 3: volcanic rocks, 4: diorite, 5: gabbro amphibolite, 6: fault, 7: outline of ore deposit, 8: AMPP anomaly at 20 μV level (numerator: anomaly number, denominator: maximum signal in μV).



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5.5. DEVELOPMENTS IN GROUND TEM

5.5.1. Interpretation of Transient Curves - This method was suggested by Sidorov (in Urals) together with Isaev & Rabinovich (SNIIGGIMS), and although the procedure is based on master curves for layered media, it does not use them. Consider:

a) Homogeneous halfspace. At any given time the response can be thought of as being solely due to a layer extending to depth d. Since the response is unaffected by material at greater depths we may assume it to be an insulator. The top layer can be replaced by a thin layer of conductance S_i at depth d_i at time t_i. For a halfspace the best value for d is the half-thickness of the layer.

b) Layered ground. v(t) is replaced by apparent S at an effective depth H_{eff}. A typical curve obtained using this technique is shown in Figure 5.12. This method works best for thick resistive layers, and thin conductive layers, with dips less than 30°, and is ideal for qualitative interpretation. Kamenetskii has solved the forward and inverse problem for a homogenous ground.

5.5.2. Volume of Investigation

(Based on a paper, in prep., by Kamenetskii, to appear in Prikladnaya Geofizika in 1979).

Both Makaganov and Kamenetskii have worked on a time domain analogue of skin depth. The normal explanation of skin depth was originally derived classically as the power (energy) dissipated by DC in a thin shell on the outside of a cylindrical conductor. Makaganov did the same for time domain and found that

$$\delta t = \sqrt{\frac{2\pi t}{\sigma\mu}}$$

Thus ω the frequency domain can be thought of as $1/\pi t$ in the time domain. Kamanetskii has examined the area of influence of the eddy currents flowing in the ground. The calculations first integrate a thin horizontal sheet from zero to infinity in the vertical (z) direction, then a cylindral sheet outwards from zero to infinity in the radial (r) direction. A response curve similar to that in Figure 5.13 is obtained. This implies that lateral sensitivity is twice the depth sensitivity.

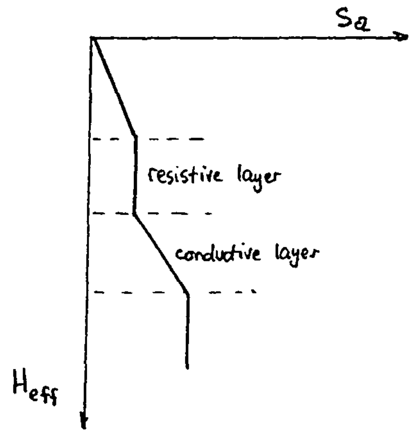

Figure 5.12 Plot of apparent conductance versus effective depth.

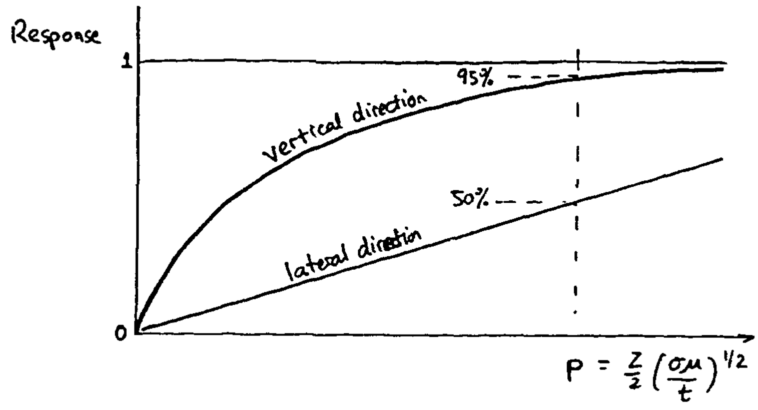

Figure 5.13 Distribution of eddy currents in the ground.

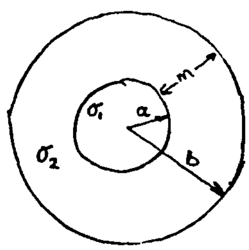

Figure 5.14 Model of two concentric spheres used by Negi.

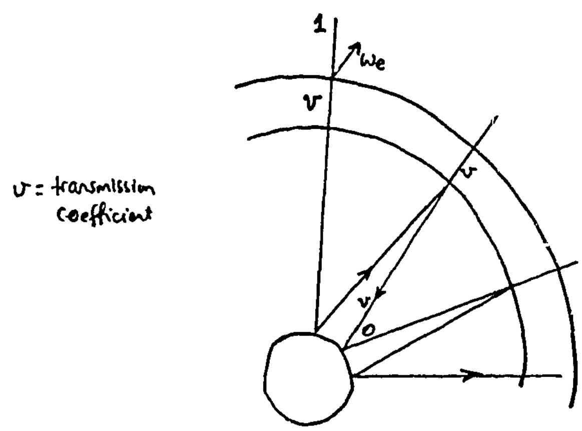

Figure 5.15 Reflections in concentric shell model.

5.5.3. Superposition

Negi considered two concentric spheres, as shown in Figure 5.14, and calculated (Hab-Hb)/Ha, where Hab is the total response, and Ha and Hb and are the individual responses. For superposition this parameter will equal 1. Negi found that sometimes the parameter was greater or less than 1, and called the phenomenon negative screening. Kamenetskii considers that Negi is wrong, and screening cannot be negative. At MGRI this effect is called 'NEGItive screening'. It is better to use

$$(Hab - Hm)/Ha \qquad \ldots.(2)$$

where Hm is the difference in response between the two shells.

Kaden wrote a German EM text in which he solved this problem by considering reflections, as shown in Figure 5.15.

Total waves out=

$$W_e + V^2W_a + V^2W_a{}^2W_i + V^2W_a{}^3W_i{}^2 + \ldots$$

$$= W_e + V^2W_a\left(1 + \sum_{K=1}^{\infty}(W_a W_i)^K\right) \qquad \ldots.(3)$$

The solution comes out the same as (2)

For superposition only the first two terms in (3) are used. They are usually the dominant terms.

5.5.4. Large Loop Methods

Large loops are preferable because:

a) inductance is proportional to L,

b) area is proportional to L^2,

c) interwinding capacitance increases if a multiturn loop is used.

Consider the loop shown in Figure 5.16. Inside the loop the E field is small compared with the magnetic field; therefore anomalies are produced by induction only. Outsidside the loop the strength of the E field is high and anomalies from concentration of the E field can also be obtained. These are known as "electric anomalies", and include such effects as current gathering and IP effects. If the ground is highly resistive, electric anomalies are uncommon. This work was studied years ago by Kaufman et al., who concluded that measurements inside the loop were preferable.

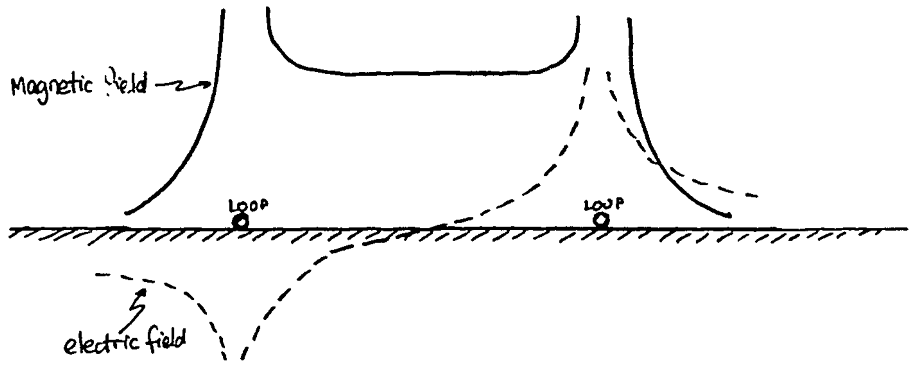

Figure 5.16 Magnetic and electric field distribution of a large loop.

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5.5.5. Sign Reversals sometimes occur in areas of high resistivity and polarisable ground. To check their validity, the polarity of the transmitter should be changed. This should change the sign of the received transient.

6. SNIIGGIMS - SIBERIAN RESEARCH INSTITUTE OF GEOLOGY, GEOPHYSICS, AND MINERAL RESOURCES, MINISTRY OF GEOLOGY.

6.1 PROGRAM

- Introduction to SNIIGGIMS by Assistant Director (Science), Prof. V.I. Bgatov
- Seismic - V.I. Bgatov
- Geodesy - A.G. Prikhoda
- Ore geophysics - H.H. Rempel
- TEM instruments - D.I. Kunin
- Carborne TEM
- Squid magnetometers - Y. Gitarts
- TEM theory - G.A. Isaev, N. Poletaella, G. Itskovich, V. Filatov, M. Noppe
- ZSB theory - B.I. Rabinovich

6.2 INTRODUCTION

SNIIGGIMS specialises in the geology, geophysics and mineral resources of Siberia, and includes areas such as the Urals and Khazakstan. An outline of the departments in SNIIGGIMS is shown in Figure 6.1

There are also two other institutes which share the work:

a) located in Tyumen - deals with oil and gas on Siberian Platform (Mesozoic & Cainozoic) - 3 million sq km.

b) located in Irkutsk - deals with mineral resources of this region.

There are 3 main branches of SNIIGGIMS (also 2 small branches located in Krasnoyarsk and Tomsk, and a few field bases):

1) Evaluation of oil and gas in Siberia, especially Palaeozoic (except areas covered in a)).

The work of SNIIGGIMS results in recommendations to the regional survey each year where to carry out detailed geological work.

2) Evaluation of mineral resources in Siberia; Fe, Al, P, Au, Cu, also others, e.g. engineering.

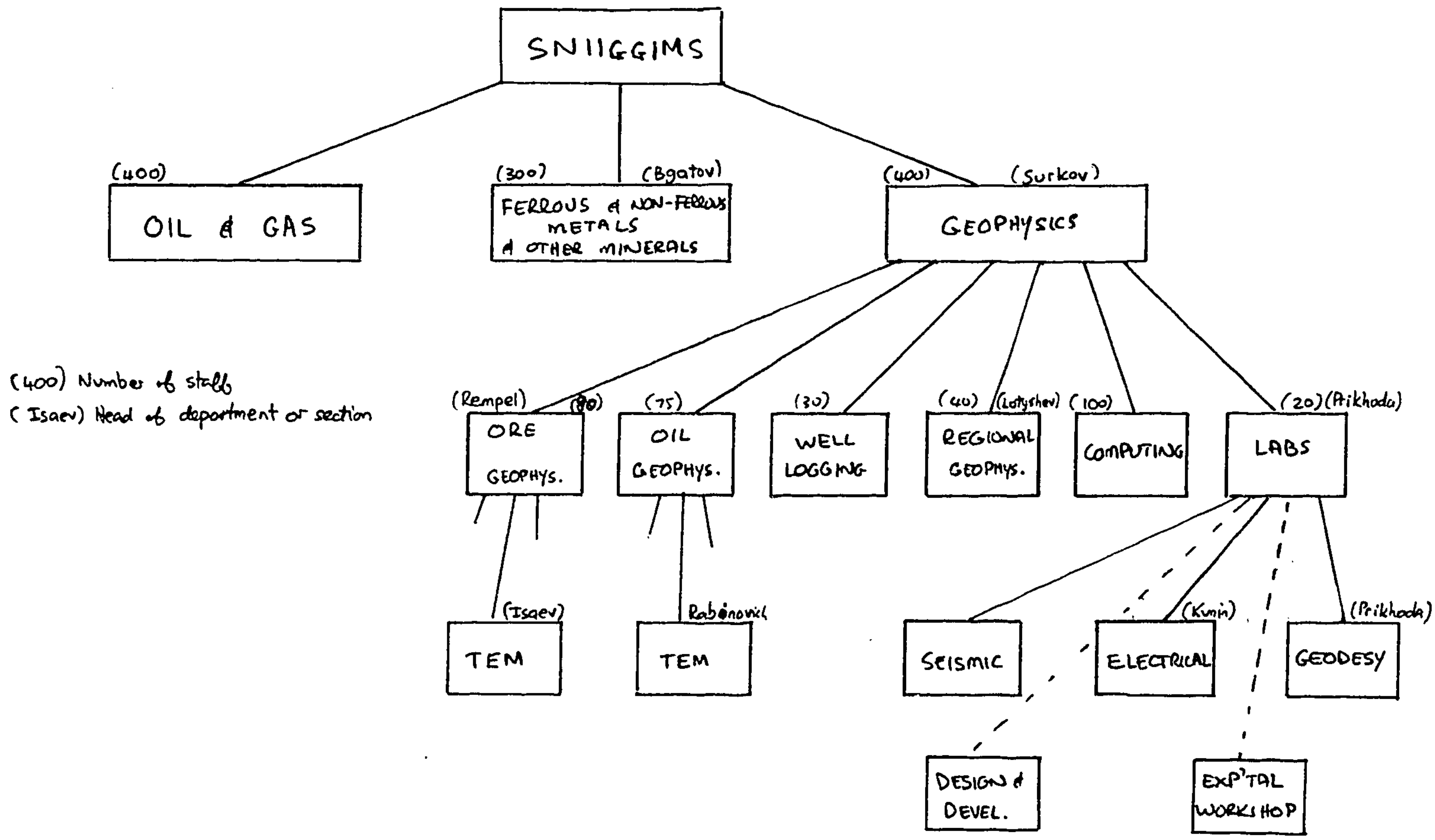

Figure 6.1   Structure of SNIIGGIMS.

3) Technical Geophysics - service to 1) and 2) - R & D applied to Siberian conditions.

SNIIGGIMS also carried out fundamental research - e.g. stratigraphy of the Pre-Cambrian.

Since Siberia contains much dense forest ("Taiga"), 60% of all transport is by air. Western Siberia is a young platform which produces 1/3 of USSR oil. Exploration is now taking place in eastern Siberia, which is very prospective. Siberia contains 60% of the world's coal. There is a shortage of bauxite, but alunite deposits have been developed to obtain aluminium. There are two leucitite deposits which are unique as they do not have a leucite crystallography. These are developed to produce 22% Al_2O_3 for Al and 20% Ca_2O for fertilizer. There are enough reserves for 3000 years.

6.3 SEISMIC

1) VIBROSEIS. SNIIGGIMS works on design, development and theory. Their system is simpler than the Americans', and uses electro-magnetic vibrators. These have the advantage that they can produce compressional as well as shear waves (P and S). USSR bought 10 sets of U.S. equipment, but are finding it difficult to use because of its complexity.
2) SPECIAL SEISMIC EQUIPMENT FOR SIBERIA. SNIIGGIMS are developing airborne techniques. They use radio telemetry (10 kHz) from the data acquisition system (geophones) to helicopters where the data are stored on digital magnetic tape.

6.4. GEODESY

1) Design and development is concentrated on aerial navigation, using a triangulation technique with three base stations. 180 MHz impulses are used. The aircraft has a translator (repeater). This system is used for surveys fifty to seventy metres above ground.
2) Ground Work - Barometric
   - Hydrostatic - accuracy is four centimetres per station (for n stations accuracy is $4/\sqrt{n}$ cm).
   - Optical laser equipment, accuracy 1:10 000

Reference: Prikhoda, 1972 and 1973; Prikhoda & Rabinovich, 1979.

6.5 ORE GEOPHYSICS

This area employs eighty people They study electrical applications, methods, theory, direct and inverse modelling and resource assessment. Mineral resources of interest are Cu-Ni, diamonds, polymetallic Pb-Zn, Fe, aggregates.

6.5.1. Cu-Ni - started this work in Norilsk in northern Siberia. The deposits are flat-lying and located at depths of 400 m. The main methods are magnetic (airborne & ground), and gravity.

6.5.2. Diamonds - The methods used are gravity; seismic (to locate faults); and MPP techniques.

6.5.3. Airborne magnetics has been surveyed on several hundred thousand sq km, and is still continuing.

6.5.4. Electrical Methods - IP
- MPP
- SP
- Miss-a-la-masse ("Zaryad" = Charge)

IP

Time domain only with a time range of 0.1 ms to several tens of seconds. Inductive coupling is removed by subtracting 2-layer models. There has been no success at mineral discrimination. A typical problem to be solved by IP is shown in Figure 6.2.

The array used is usually Schlumberger, and not dipole-dipole.

New Methods - using natural electrical fields (new MPP technique developed by Noppe).

6.6. TEM INSTRUMENTS

In the electrical laboratory there are 10 engineers working on 3 projects, including down-hole seismic. The main development is in new TEM instruments, TSIKL and IMPULSE, photographs of which are shown in Figure 6.3.

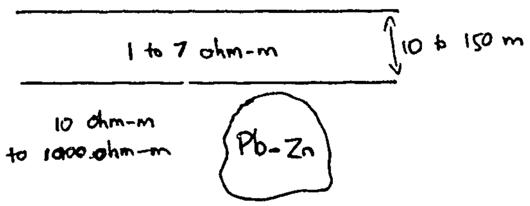

Figure 6.2 Typical Siberian IP target.

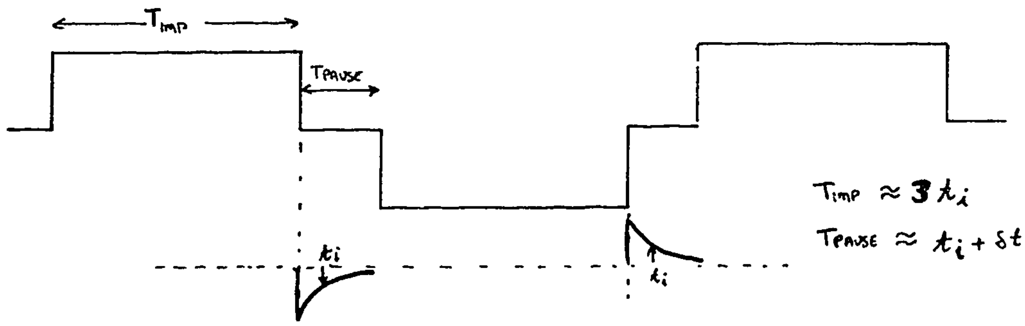

Figure 6.4 IMPULSE and TSIKL waveforms.

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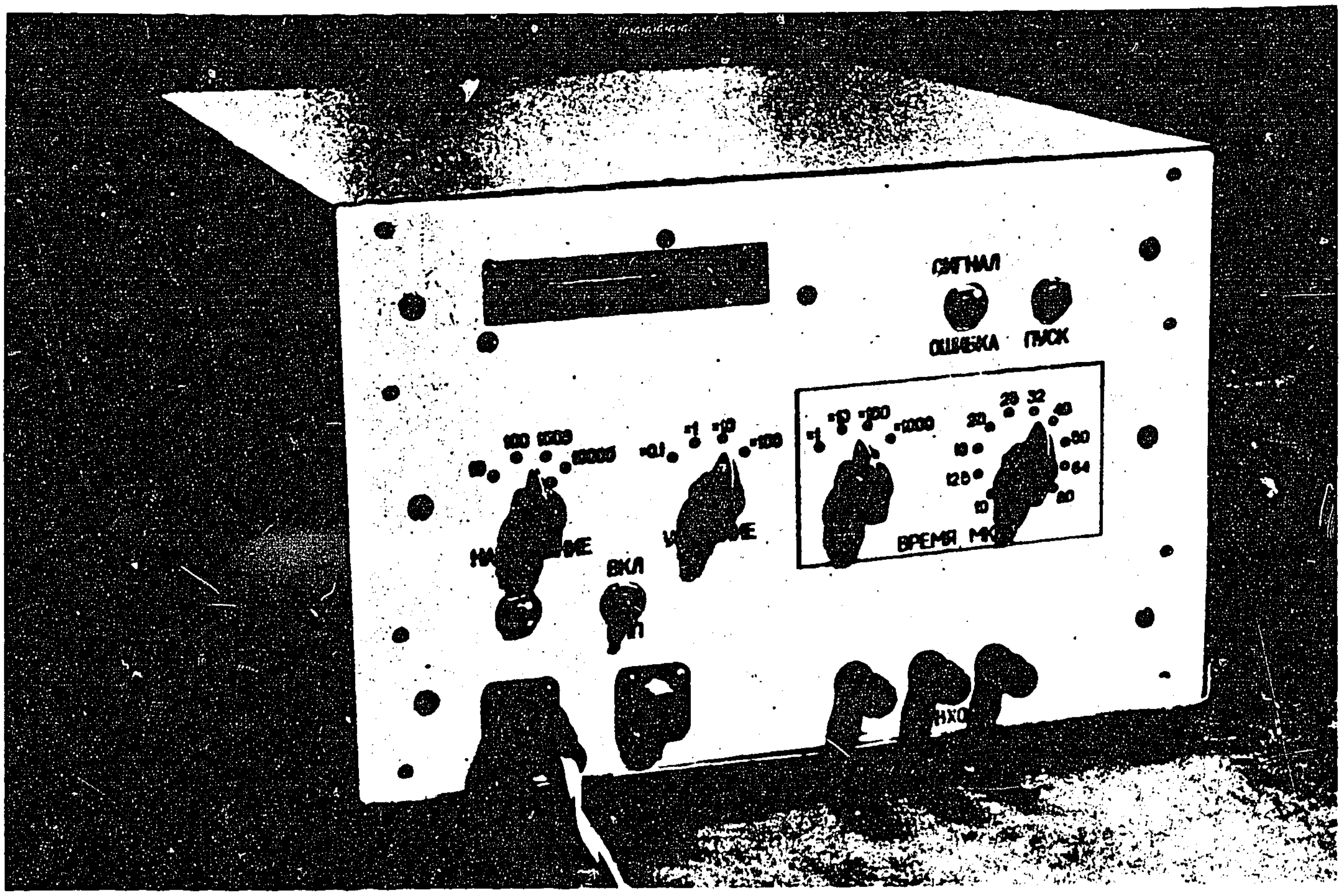

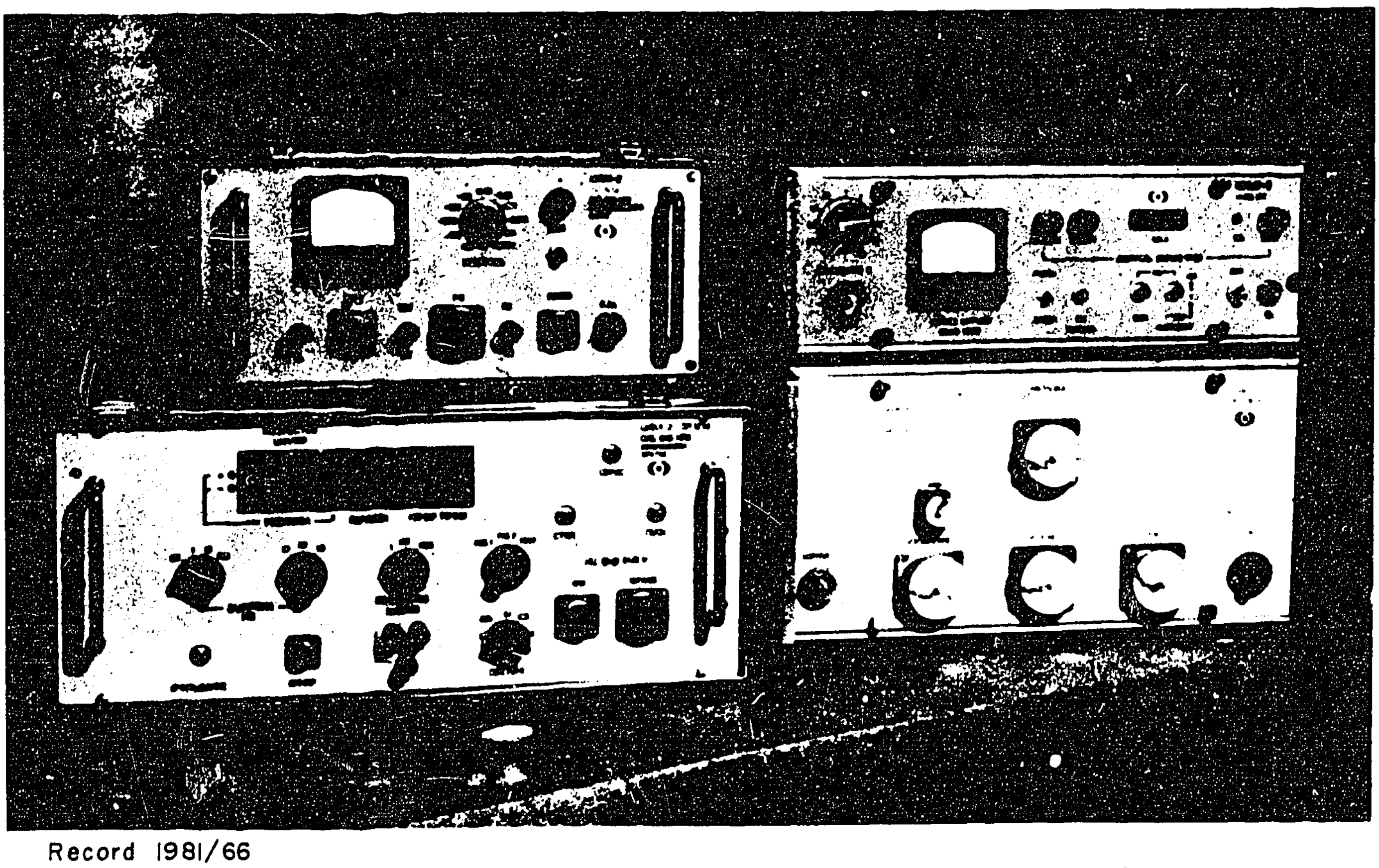

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Fig. 6.3. Photographs of IMPULSE and TSIKL system. The top photograph shows the IMPULSE receiver; the bottom photograph shows the TSIKL-2 receiver and transmitter.

6.6.1. IMPULSE

Impulse is in the prototype stage. It should be serially manufactured in a portable version with a harness in 1981. IMPULSE is developed for shallow sounding (ore prospecting), using a portable low-power generator (20A).

Tx square loop 100 m to 200 m

Rx a) coincident mode

b) smaller one-turn loop in centre

c) separated loops

The timing and waveforms used in the IMPULSE system are shown in Figure 6.4. Note that the bandwidth of the amplifier changes with time range, such that fo=10/t. Analysis is still being carried out as to whether 10 is the optimum factor.

Time Range 10 µs to 80ms (4 decades). Width of samples t=1/fo. 9 steps plus 4 ranges (1, 10, 100, 1000) = 36 sample times

Average from 10 to 10 000 cycles. Noise rejection by choosing appropriate fundamental frequency.

Circuits are now ICs, serial production will use micropressor.

Internal noise in short runs is 0.3 µV; on 10 000 averages is 0.1 µV (input shorted)

Dynamic range 120 dB, 0.2 µV to 2V

NB ZOND was an earlier instrument and is not now used. A description of the IMPULSE - Ts (digital) system is given by Gol'dort et al. in Prikhoda and Rabinovich, 1979.

6.6.2. TSIKL

TSIKL is an earlier version of Impulse and costs R 15 000 (A$22 000) in USSR. It has wider applications and can solve different geological problems and depths (used for sounding in near zone for oil as well as prospecting).

Tx - automobile motor generator 500 V, 100 A (power of 50 kW), or batteries supplying 2A for model studies. Uses thyristors (SCRs).

The Tx has 12 ranges of time corresponding to Rx range.

<u>Waveforms</u> - same as Impulse. 12 time ranges, bipolar.

<u>Rx</u> - 6 decades 0.1 ms to 44.8 s, 20 samples per decade (2 decades measured simultaneously).

12 ranges of time (each with 2 decades), overlapping

0.1, 0.2, 0.5 ms

1, 2, 5 ms

10, 20, 50 ms...

There is a combination of analogue and digital filtering.

<u>Width</u> of sample = 1, 10, 100 or 1000 units

<u>Average</u> 100 or 1000 cycles

<u>Range</u> 1 µV to 0.4 V

<u>Readout</u> digital nixi-tubes

<u>Noise</u> internal 0.5 µV

<u>Synch</u> - cable or radio

<u>Tx Loop</u> up to 1500 m for 3 km depth investigations. For a loop size of 1000 m the current is 40A (turn-off takes 400 µs). For loop sizes of 50 and 100 m the current is 100A (turn-off takes 50 to 100 µs)

<u>Loop Configurations</u>

a) 1500 m Tx loop with central 100 m Rx loop with 1,10 or 20 turns.

b) 800 m square coincident loop.

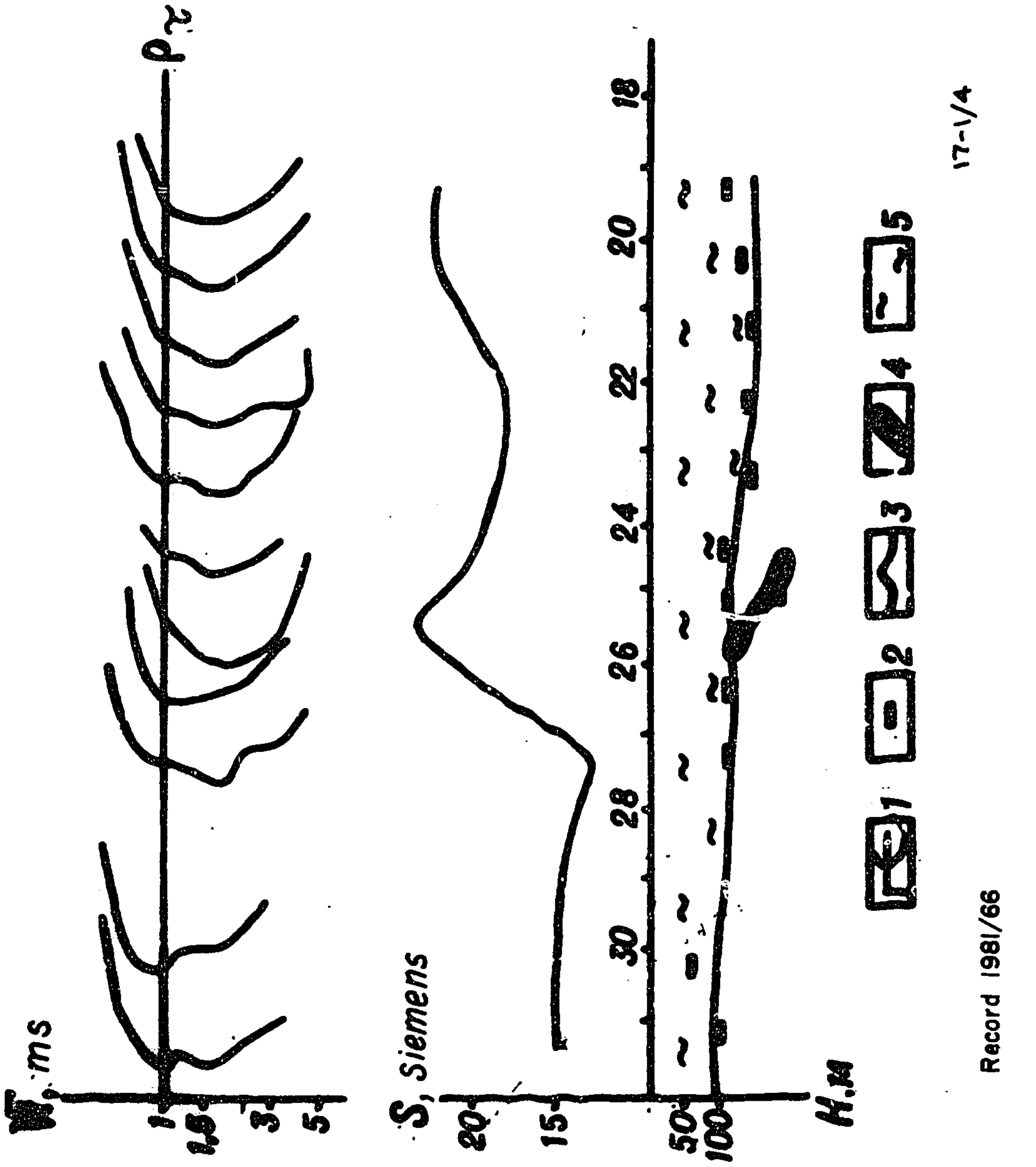
<u>Input Impedance</u> 5 kohm for TSKIL & IMPULSE. This is considered high enough. A description of the TSIKL - 2 system is given by Kunin et al., and Sachenko et al., <u>in</u> Prikhoda & Rabinovich, 1979, and in SNIIGGIMS (1976).

6.7 <u>CARBORNE TEM</u>

A carborne TEM system, developed at SNIIGGIMS is reported by Tsypliashehuk et al., <u>in</u> Prikhoda & Rabinovich (1979) and is useful in areas of tundra and steppe. The transmitter and receiver loops are mounted on trailers towed by vehicles at least 3 m away.

The transmitter consists of a 10-turn loop with a current up to 500A, and a total moment of 2×10^5 Am^2. The loop diameter is 7 m. The switch-off time is 1.5 ms. The Tx - Rx separation is commonly 50 to 80 m, and the vehicles are stopped for readings.

Figure 6.5 Results of TEM survey with "Tsikl-auto" apparatus over the Rubtsovkoe orebody. 1: apparent resistivity curves, 2: estimation of depth H obtained from MPP interpretation, 3: profile of longitudinal conductance S, 4: contours of orebody, 5: unconsolidated sediments (from Tsypliashehuk in Prikhoda & Rabinovich, 1979).



Typical field results are shown in Figure 6.5 for an area in the Altai region. The area is covered by 70 to 130 m of low-resistivity unconsolidated material (3 to 50 ohm-m), resulting in values of longitudinal conductance, S, of 14 to 20 S as shown in the figure. S increases to 26 over the pyrite deposit.

Apparent resistivity sounding curves are shown at the top of the figure. The interpreted depth to the bottom of the conductive layer, H, is shown on the cross-section as horizontal bars.

6.8 SQUIDS

Squid magnometers have been in use for 4 to 5 years, and are used for IP, MPP and MT. These are point contact devices which are stable for about 1 year. The Squid device is 100% Nb with screens of NbTi. The RF drive frequency is 25 MHz. The dewar is blown glass with a 1 l capacity, which holds helium for 72 hours. (Iurtov, in Prikhoda & Rabinovich, 1979).

For field work a 100 l dewar is used. This lasts a month. There are a total of 5 in use and usually 2 components are measured. The sensitivity is 10^{-5} nT. The frequency range is up to 25 kHz (for oil), and 100 kHz (for ore), sampling at 100 μs. Liquid He is transported by aircraft.

General USSR has plenty of He. Gitarts wanted to know why SQUIDS were not used more often in the USA - he said that the only problems are psychological. He has written a paper on the use of SQUIDS for MPP which has been published in Geologia i Geofizika in 1979.

References: Gitarts in Prikhoda & Rabinovich (1979) and Gitarts & Zavaritskiy (1979) give a detailed description of the Squid magnometer. Other geophysical applications of superconducting devices are given by Surkov & Matizen (1977).

6.9 MPP (METHOD OF TRANSIENT PROCESSES)

6.9.1. Applications

The main applications for MPP at SNIIGGIMS are;

a) prospecting for Cu-Ni, Fe, polymetallic deposits, magnetic rocks and kimberlites at depths up to 2 km;

b) finding thickness of overburden for gravity corrections and interpretation.

In this field SNIIGGIMS is linked closely to the Academy of Sciences for theory (Lavrentyev, Tabarovsky). Results of recent work in this field are published in Isaev et al., 1974 and 1977.

6.9.2 Square loop TEM

Both for coincident loops, AB-q and Qq configurations (Fig. 1.11). The magnetic field components can either be B_z or dB_z/dt, and the x-component. Two-layer curves have been derived for both one-loop and two-loop systems. There is also an inversion program which requires only the early part of the apparent resistivity curve to obtain ρ_1 and d. (Note Rabinovich has a 5-layer program).

6.9.3. Method of Interpretation of MPP curves to give S and H

Formulae are given in Isaev et al. (1974) for calculation of longitudinal conductance S for dipole Rx and Tx loops. Isaev et al. (1977) give large loop correction nomograms. For the case of coincident loops the calculations have to be worked out on a computer.

An idealised three-layer section and S & H curves are given in Figure 6.6. The procudure works best for

a) small loops where $L < H$,

b) large conductivity contrasts,

c) conductive layers.

For cases where the sheet is of limited lateral extent (radius R) and at a depth h, correct values of S are obtained when $R > 3h$, and correct values of h for cases where $R > h$. This also applies to 2D horizontal plates of width R.

Current problems being solved are the theoretical expression for

a) Sheet of radius R_d located under an infinite sheet

b) Sheet of radius R_d located under a sheet of radius R_1.

c) Permeable conductive sheet and cylinder located under an infinite sheet.

Example - 2D plate

Results of S & H interpretation over a thin horizontal 2D plate are given in Figure 6.7. Good estimates are obtained for H and S, for the conditions where the loop separation is less than the width of the plate.

Figure 6.6   Idealized 3-layer section and form of S & H versus t curves.

Figure 6.7 Curves of S, apparent resistivity and H over a 2D thin plate. A coaxial configuration with loop separation r_2, oriented perpendicular to the strike of the plate, was used. The symbols h_p, h_1, ρ_p and L stand for the thickness, depth, resistivity and width of the plate, respectively (after Isaev et al, 1974).

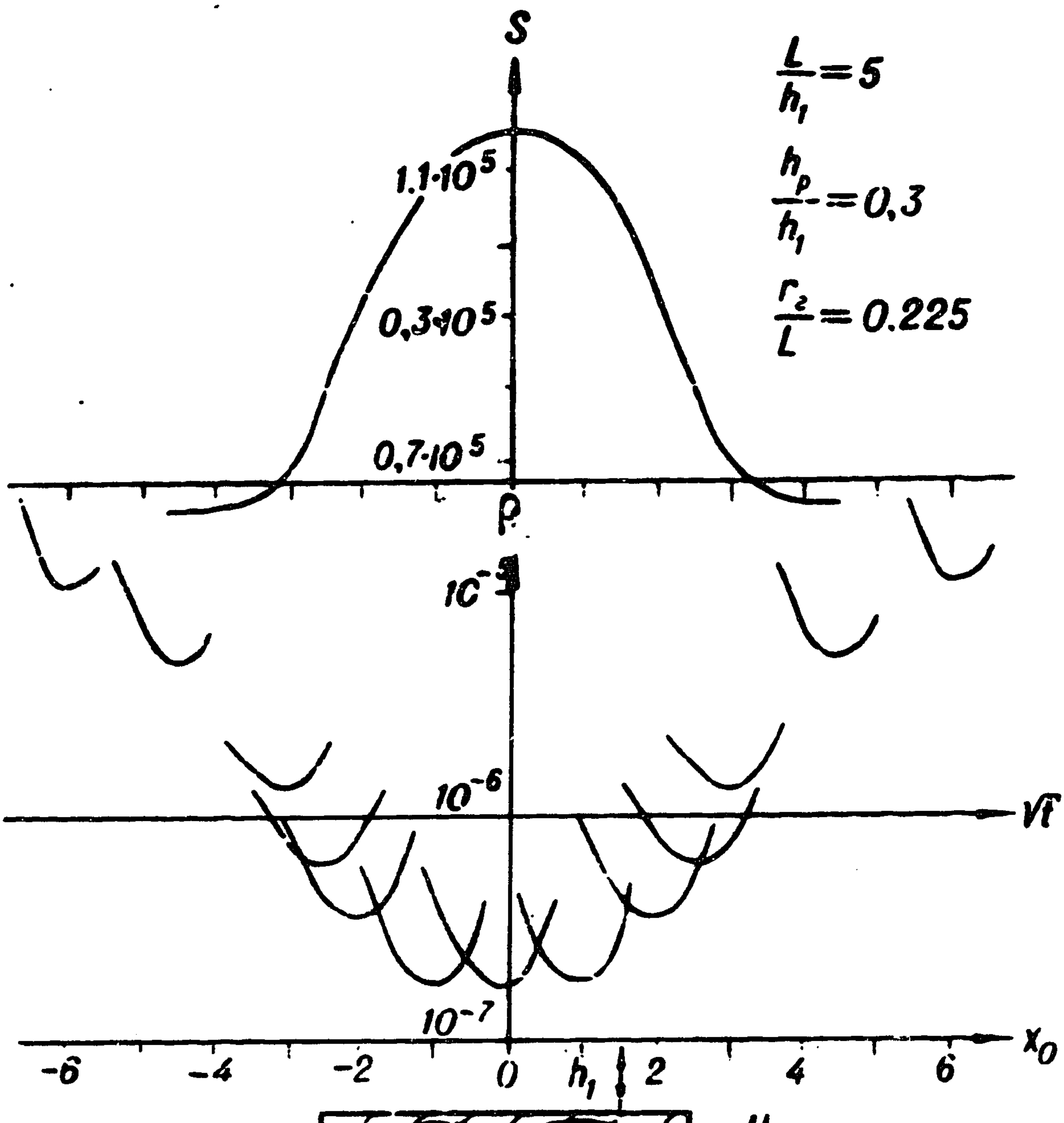
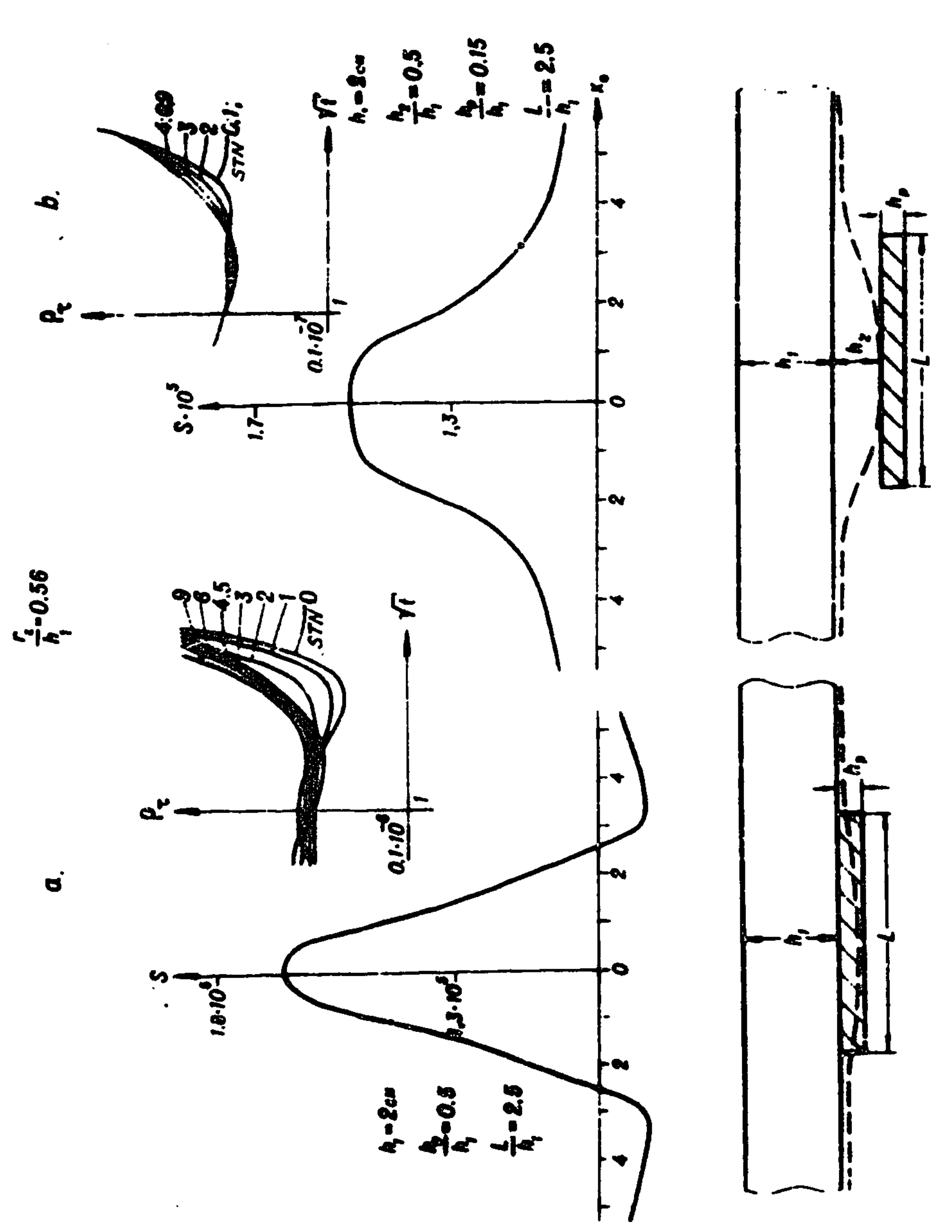


Figure 6.8 Curves of S, H and ρ_a over a 2D plate covered by conducting overburden (after Isaev et al, 1974).



Another example is given in Figure 6.8, where the plate is located underneath a thick conductive overburden (the model is constructed of Cu and Pb). Again good results are obtained.

Theoretical Derivations for a Disc

Numerical solutions for a thin circular disc of radius R_g in air, as well as under an infinite plate have been derived by Itskovich in Isaev et al. (1977). For a thin circular disc in air, the parameter used is

$$\alpha = (\mu S R_g)^{-1}.$$

and at late stages the time constant is

$$\tau_o = (5.56\ \alpha)^{-1}.$$

For cases where $R_g/H > 2.5$ and $t < 0.45/\alpha$, the disc looks like an infinite plate.

Calculations for a disc (S_2) under an infinite plate (S_1), have shown that the anomaly due to the disc will be 30% higher than that due to the overburden if

$$R_g S_2 / H S_1 > 3.5.$$

For later stages the loop acts as a dipole. At both early and late times the main response is due to S_1, and the disc (S_2) is seen over an intermediate time range.

6.10 ZSB (SOUNDING BY ESTABLISHMENT OF NEAR - FIELD)

Ten years ago SNIIGGIMS began development of a method of MPP called ZSB (Sounding by Establishment of Near - Field). The near - field is defined by $R/H \leq 0.7$, where R = separation of Tx and Rx, and H = depth of target.

Up to that time, the usual method was ZSD (Far - Field) where $R/H \geq 5$. The Tx in ZSB and ZSD is usually a loop, and the Rx can be either a loop or grounded electrodes. The early history of sounding involved DC sounding where large separations are necessary. When frequency sounding was first used it was assumed that large separations would also be necessary so these were used for traditional reasons. ZSB was developed as a joint project with Siberian Division, Academy of Sciences. TSIKL was developed for this purpose. Interpretation is by use of:

a) 5-layer curves for type Q - q and Q - ab. Note that electrode dipole ab is equivalent to a loop q, except for a factor of 2π.

b) 3-layer curves for $\rho_1 > \rho_2 > \rho_3$ and various h_2/h_1.

In practice, for high resistivity layers it is better to use a loop because of the small signal level. In some cases, it may be preferable to use a non-symmetrical array, such as AB - q - AB to detect lateral changes such as step faults.

6.10.1. Methods and Field Examples

Traditionally, the problems to be solved by sounding were structural. A problem which arose was that of volcanic "traps" (magnetic, resistive basalt sills). They interfere with seismic, gravity and magnetic methods.

Example 1

One area had a resistivity section as shown in Figure 6.9a. Estimates from ZSB of depth to basement (2300 m) had errors of between 0.3 and 4%.

Example 2

In the oil/gas section shown in Figure 6.9b the third layer is very conductive owing to saline water (300 g/l salt = 0.1 ohm-m). The resistivity of this bed is commonly 1 ohm-m. When oil or gas displaces the water the layer is resistive. A successful technique for exploration in these areas involves obtaining the lateral conductance of the 3rd layer, $S_3 = h_3/\rho_3$.

In the Siberian Platform, the combination of seismic and electrical methods is very successful. Typical seismic and electrical profiles are shown in Figure 6.10.

The combined interpretation is on a regional basis determining depth to basement with seismic and electrical techniques.

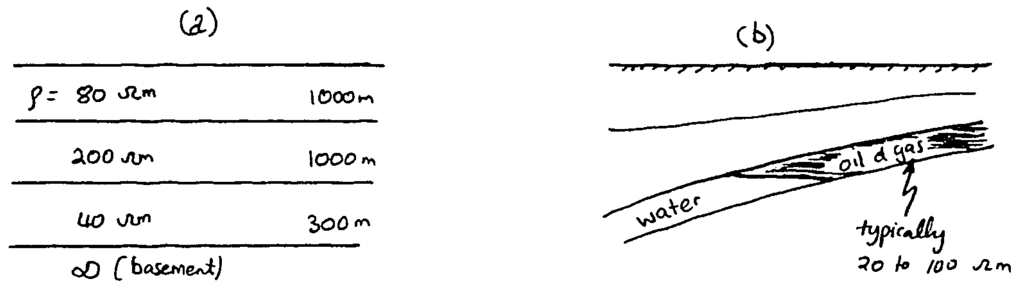


Figure 6.9 a) Geoelectric section of an area where ZSB was successful.
b) Application of ZSB for oil and gas search.

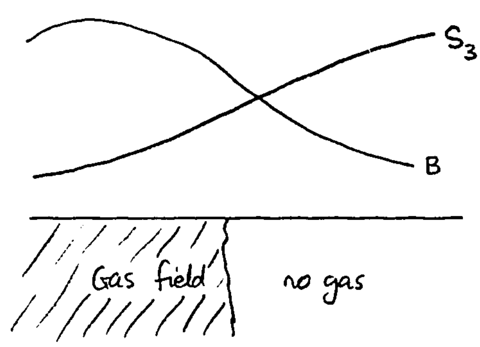


Figure 6.10 Typical seismic and electrical profiles in the Siberian Platform. S_3 is the longitudinal conductance of the 3rd layer; B is the absorption coefficient for seismic waves.

A special difficulty is that conductive layers close together tend to be indistinguishable. If the layer thickness or porosity is small, S is small, and thus is difficult to detect.

6.10.2 Use in USSR

In the Siberian Platform area (about 1/2 of total Soviet Union), about 1500 soundings are made annually. The depth of investigation is 3 to 3 1/2 km. There would be many more but there is a great demand for, and a shortage of TSIKL instruments, which are also used in the Volga River area and in Azerraijan (near the Caspian Sea).

6.10.3 Field Procedures

A large Tx loop (side L = 0.5 km to 1 km) is used with a smaller central Rx loop (l = 100 m). Twenty to thirty soundings per day are sometimes possible.

The one-loop configuration is not used because of the large self-transient. With the present setup, the self-transient is less than 1 ms. In early days AB - q configurations were used, but Qq is preferable.

6.10.4 New Improvements

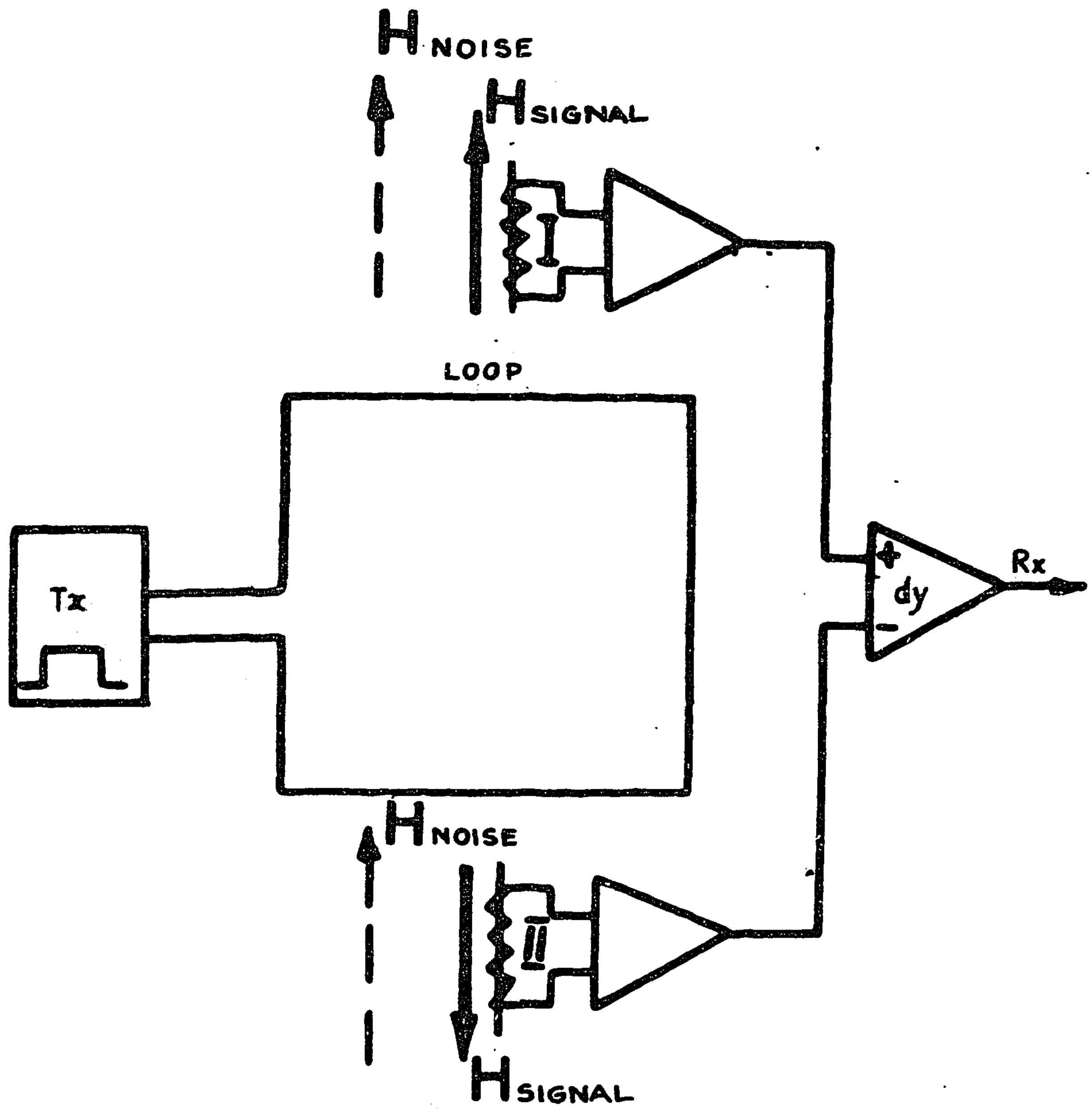
To detect lateral changes an ideal system is to use two Squids (horizontal component) as shown in Figure 6.11. This allows reduction of MT noise by a factor of 15 to 30. The loop size is the same as the Rx separation, and usually is of the order of 500 m. However, for experimental work this can vary from 100 m to 1 km.

6.10.5 Advantage of SQUID

Induction coils are available with moments of 10^5 turns m^2, but these have a large internal noise, and operate in the DC to 8 Hz range. Squids offer a greater frequency range (to 10^3 Hz). Close to cities a 50 Hz notch filter is used. The signal is averaged for several 100 to 1000 cycles. One sounding takes from 10 minutes to 1 hour, and 5 per day are possible in dense forest (compared with 20 in ore geophysics).

Electrical noise will affect a loop measurement much less than a magnetometer measurement, because of high levels of geomagnetic fluctuations at low frequencies.

Figure 6.11 Schematic diagram of symmetrical configuration and measurement of horizontal magnetic field component (after Gusev et al <u>in</u> Prikhoda & Rabinovich, 1979).



References

Standard curves for interpretation of a layered ground using ZSB are given in Gol'dman et al., (1976), Rabinovich & Stepanova (1972), Gol'dman & Rabinovich (1972). Curves for a disc in a halfspace are given by Shatokhin & Rabinovich (1974). Detailed discussions on ZSB instrument designs and specifications are given in SNIIGGIMS (1976).

6.11 SEPARATION OF MPP AND IP EFFECTS

The IP decay curve is of opposite sign to the MPP curve, so a combination of MPP and IP response will result in a sign reversal which decays with time. A typical profile with this response is shown in Figure 6.12. At t_1 the response is predominantly MPP; at t_2 it is predominantly IP. The IP effect is localised but the MPP effect is much more regional.

Consider measurements at times t_1 and t_2. Then a measure of the IP effect is obtained from $(\Delta V_{MPP_1} + \Delta V_{IP_1}) - K(V_{MPP_2} + V_{IP_2})$.

For $t_2 \approx 10t_1$, $K\Delta V_{MPP_1} \approx V_{MPP_2}$.

K is determined either experimentally or theoretically for each locality. This procedure has only been used for the Schlumberger array. (Note, this appears to be simply inductive coupling). Komarov has used an equatorial AB - q array for measuring IP in the Urals.

6.11.1 IP Effects in MPP

Sheinman has shown that the high current density directly under the Tx wire can cause an IP effect. Consider an equatorial AB - ab array with separation R. With large R, the predominant response is MPP, which falls off slowly with distance. If R is small only IP effects are observed. This process is large, but falls off quickly with distance. For example, consider a receiver with variable radius R_1, R_2 and R_3 at the centre of a transmitter loop, as shown in Figure 6.13a. Transient curves as shown in Figure 6.13b will be observed. Sheinman is currently publishing a paper on the TEM response of a polarisable halfspace.

6.12 Depth Sounding Methods

MPP gives better results than VES, especially when ρ_2 is high.

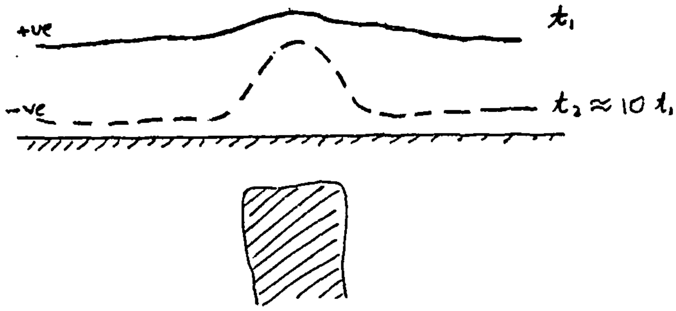


Figure 6.12 TEM profiles at two times over an IP target.

Record 1981/66

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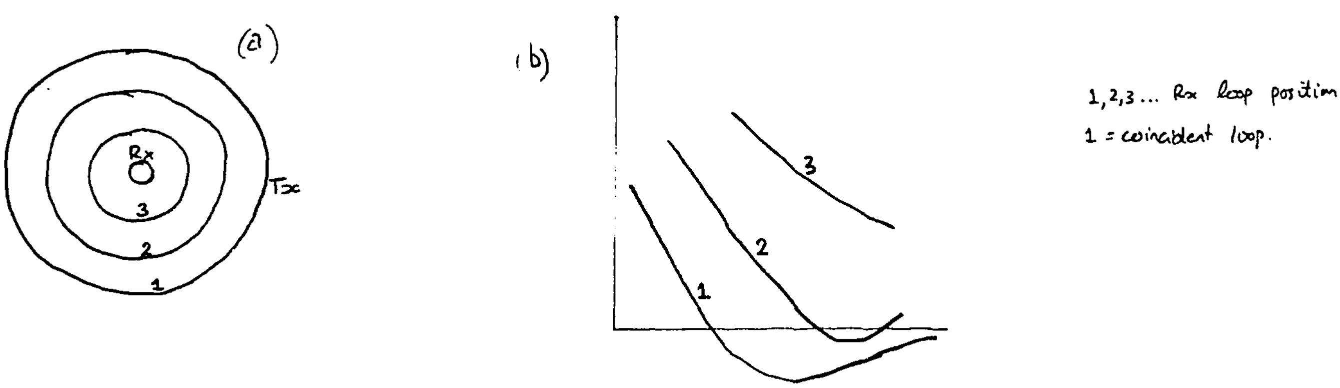


Figure 6.13 TEM curves for Qq array with three different receiver loop radii. a) loop configurations, b) TEM curves.

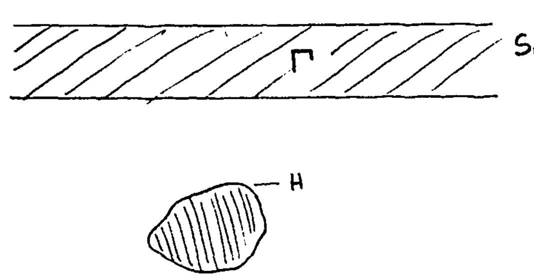


Figure 6.14 Basic model for downward continuation.

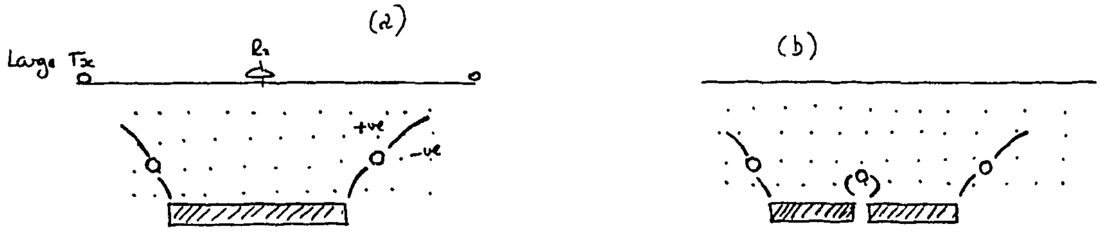


Figure 6.15 Downward continuation results for a) single plate, b) two plates.

For VES a rule-of-thumb for the depth of penetration is about one-twelfth the AB spacing.

6.13 MAGNETIC EFFECTS

$\sigma\mu$ is a joint parameter. Some resistive magnetites give no TEM anomaly.

6.14 CONDUCTIVITIES

A unique Cu-Ni ore has been found in Norilsk (pent, pyrrh, cpy, py) which has a resistivity of 10^{-4} ohm-m on a 10 cm long sample. Measurements in mines show that the resistivity of a larger scale is about 10^{-2} ohm-m, due to microfissures.

6.15 DISCUSSION

The dual loop configuration is now widely used in USSR, and has been responsible for several ore discoveries, e.g. using a loop size of 200 m and 100 m, a steeply-dipping iron ore deposit was located at a depth of 300 m.

The Russian scientists were interested in what computers we used, their speed, memory, etc; and how Soviet research compared with that in Australia.

6.16 DOWNWARD CONTINUATION

A new interpretation technique being developed is that of downward continuation of MPP data. (See also Roy, Geophysics, 1966). Consider the model shown in Figure 6.14. Measurements are made at the surface. It would be better to have an observation plane close to the depth of the body H.

Filatov determines B_z & $\dot{B}_z$ just at base of the conductive layer, then analytically continues the field. This method is long and complicated.

It is better to use the approximate $\dot{B}_z = \sum \frac{\partial \dot{B}_z}{\partial z} \cdot \frac{1}{k!}$

Replacing the overburden Γ by a thin layer S and removing several terms we obtain:

$$B_z = B_{z_1} + B_{z_2},$$

where B_{z_1} is the field due to currents induced in the orebody, and B the field due to the plate. Using Laplace's equation the field can be continued much more easily. It is also possible to use the method of images. A computer storage of 50,000 words is necessary.

Example

The field e(t) over a horizontal conducting plate is mapped out at the surface using model studies, and downward continued numerically. This method delineates the edges of the plate as shown in Figure 6.15a. The best results are obtained for a time when the apparent resistivity is a minimum. Field results show this method can even separate closely spaced bodies, as shown in Figure 6.15b. This method can also be used for a 1000 m Tx and small Rx. Filatov is currently writing this up now for a new book.

6.17 MTMPP

This method is a combination of MT and MPP and uses natural source EM fields, such as magnetic storms or Schumann resonances. Noppe has developed theory for horizontally layered media and the inverse problem.

The technique involves waiting for an impulsive signal in Ex and Hy. Measurements are made of either;

a) Ex and Hy, i.e. $Hy = f(E_x, \sigma(z))$

b) $\partial Hz/\partial t$ and Ex

Inversion of these data enables calculation of $\sigma(z)$. This method has the following advantages over MT;

(1) does not need to measure for a long time, only needs a short event.

(2) Equivalence:- Inversion is done by Laplace Transform. For a 3-layer case type Q & A, the range of parameters for which equivalence holds is less for MTMPP than for MT.

The inversion can use:

(1) Integral equation method, which is often unstable.

(2) Laplace Transform.

(3) Method of Minimisation (functional representation)

Practically, not much has been done, because of delays in manufacture of equipment. NB. Tabarovskiy considers the method is not very practical or stable. Parameters are not well defined.

7. I.G.G.: INSTITUTE OF GEOLOGY AND GEOPHYSICS, Siberia Branch of ACADEMY OF SCIENCES, USSR, Academgorodok, Novosbirsk.

7.1 Program: - Introduction to the Institute and EM Laboratory - N.N. Puzirev, Yu. N. Antonov.

- Theory of MPP in near zone and horizontal layers (L.A. Tabarovskiy), discussion of Australia (informal).
- mathematical modelling of non-stationary fields in complex media - L.A. Tabarovskiy
- ZSB applied to deep EM - L.A. Tabarovskiy
- formal seminar (Spies)
- downhole EM logging - Yu. N. Antonov, M. Epov
- magneto-electric logging - Yu. Daveshkiy
- Australian equipment (Spies), geological museum inspection.

7.2. Introduction

Puzirev (Director) spoke of the Insititute, which is one of 20 in Akademgorodok, which has a population of 40,000. There are 40 scientific institutions in the Siberian Branch of the Academy of Sciences, Novosibirsk being the largest. (Other branches are Yukutsk, Krasnoyarsk, Tyumen and Tomsk).

The Institute of Geology and Geophysics deals mainly with geology (75%) and, to a lesser extent, geophysics (25%).

GEOLOGICAL:	Oil Ore Palaeo-Stratigraphic	) Main thrust is sedimentary, since the discoveries of sedimentary rocks in the early 60s. Note that 40% of Soviet oil comes from Siberia.
GEOPHYSICAL:	Seismic	Mainly theory and new developments, and deep soundings. A new method is the combined use of shear, alternating and diffracted waves. This is very successful, especially for oil and gas
	Potential Fields	Processes in Earth & Asthenosphere and also includes variation of magnetic fields and cosmic rays.

Geophysical Techniques

There is a Siberian network for earthquake prediction - the main task is to study deep structures and properties. Much work has been done in the Baikal area, along the new railway line. Geothermal studies are becoming increasingly important. Other methods used are EM, gravity, deep seismic and geodetic. Permafrost complicates many methods.

Work is done jointly with SNIIGGIMS, Mineral Resource Branches, as well as special project tasks such as testing recommendations.

7.3 EM Laboratory

The EM laboratory has 10 scientific, 6 technical and 7 industrial staff. The main thrust of work is in oil and gas, and deep sounding. The laboratory is involved in mainly theoretical studies, even though the final results have practical applications. The group is working in two directions:

1) Improvement of old methods - Calculation of EM fields in complex situations.
2) New EM methods - calculation of simple models to aid the understanding of the physics of the methods.

The main areas of research are:

1) Theoretical Investigations of Non-stationary Fields

Includes deep investigations of earth's crust. Much of the time the team is in the field with equipment.

2) Applied Geophysics (downhole). Mainly frequency domain. Also new methods for indicating collectors for oil and gas. These are induction methods, which detect lateral resistivity changes. The aim of the downhole studies is to exclude the neighbouring zone (transition or invasion zone), using focussing arrays and theoretical studies of cylindrical models. Important points are:

1) These methods are valid for known models.
2) It is possible to determine the coefficient of anisotropy .
3) Measurement of E & H in-hole allows the introduction of a new parameter which is independent of the transition zone, enabling calculation of λ and ρ.
4) Method of lateral sounding, frequency domain.

3) Geothermal - thermal properties and heat flow (may be useful for earthquake prediction). Used in Siberia, also Baikal and Altai regions.

4) Theoretical investigations of ZSB (deep version of MPP)

In mid 60s the theory was developed for horizontal layers. This method was very successful and was applied in complex regions, and after 5 or 6 years in areas where "traps" cause other methods (magnetics, DC resistivity) to be unusable.

MPP is the only method that can penetrate beneath these layers.

Other problems studied are that of dip and lateral effects.

7.4. DEEP SOUNDING

This is one of the main tasks of the group (both theoretical studies and developing apparatus). Two of the tasks are:

1. Search for intracrustal conductive layers (melt zones or water-free zones). e.g. At Lake Baikal, seismic had detected a low-velocity zone at depths from 10-25 km. MT was not very suitable, since there were no left branches (low period asymptotes) on the curves and soundings were difficult to correlate. Also the region has a complicated block structure which distorts the curves. The method ZSB was developed for these problems. ZSB was better because -
   - i) have complete curve, and therefore can do shallow and deep interpretation, and there is no need to correlate between soundings;
   - ii) results are much more localised than MT. Much work was done 3 years ago on elaboration of the method.
2. Mapping the top of the mantle. However present equipment does not have enough power to get this deep. Sources used to date include MHD, pulse, explosion sources and electrical power stations. Note that if power W_1 is required to explore to depth h_1, then to get to depth h_2 the increase in required power is given by

$$W_2/W_1 = (h_2/h_1)^5.$$

7.4.1. Examples of Use of theoretical curves

1) For a simple two-layer model (e.g. Tabarovskiy and Goldman, 1978, Fig. 6) the minimum in the sounding curve is used to determine the depth h (knowing σ_1) and σ_2 can be considered infinite if $\sigma_2/\sigma_1 \approx 100$.

2) Effects of Lateral Inhomogeneities. The study represented in the album of curves of Tabarovskiy (1979) was developed specifically for the Lake Baikal problem. A typical model is shown in Figure 7.1, for which there are various curves for L/H.

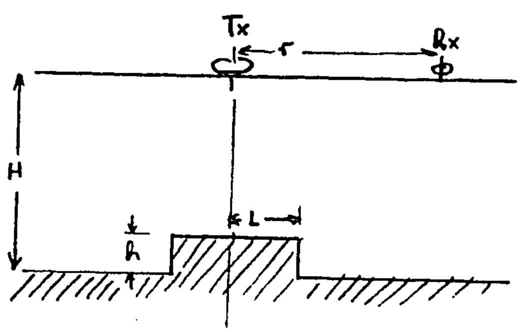


Figure 7.1 Model of lateral inhomogeneity in ZSB study.

At early times the response is controlled by the step at depth (H-h); at later times the branch gives an estimate of H. If $L/H < 1$ the curve does no correspond to any two-layer curve.

For smaller structures it is more difficult to determine the parameters. ZSB works much better than MT in the Baikal region. MT often gives depths 2-5 km (much too small), which are probably due to lateral effects.

3) Intermediate Conductive Layer

Curves are also given for a 2D intermediate layer of conductivity σi (in host of σ_e), for a range of L/H values from o to ∞. These cases result in an underestimation of depth.

Field Example - East of Lake Baikal there is a depression 12-15 km wide filled with sediments with resistivities of 100 to 2000 ohm-m. The host has resistivities of 10^4 ohm-m, overlying a highly conductive basement. MT interpretation resulted in depth estimates of 6 to 10 km, while ZSB gave smaller depths which were in error. Thus for minimum distortion of ZSB soundings, the array should be separated by a distance D which is greater than twice the depth of interest, H.

7.4.2. Computer Programs - other institutions have Cyber computers; IGG has a HP and a Russian-made computer. Programs include forward 2D. Other institutions have DC inversion, harmonic, and transient programs.

7.4.3. Current Work

1) On-axis case of conductive plate in a two-layer earth with $\sigma_2 = 0$.
2) On-axis case of vertical plug in a two-layer earth, (jointly with colleagues at SNIIGGIMS). This has application to kimberlite exploration.

7.4.4. Types of Arrays

1) For the problem of a highly resistive horizontal plate it is best to use double galvanic AB-ab.
2) For structural problems, Q-q is best, but there may be problems obtaining adequate power for great depths. AB-q may be better for great depths because the ratio increases as the 4th power (instead of 5th). ZSB can easily detect changes in the depth to basement as small as 5%.

3) Dzwinel's work in Poland is for harmonic techniques. These give different results to transient techniques.

7.4.5. Frequency or Transient Methods?

Tabarovskiy considers transient is better for all problems, e.g. its resolving power is superior. However it may be easier in practice to use harmonic for certain problems e.g. for small H & σ_1, cannot measure very early times (ns) in practice.

7.5. EM MATHEMATICAL MODELLING

Mathematical modelling of EM problems was begun 10 years ago at IGG. There are two main groups of problems.

7.5.1 DC & Harmonic - Used integral equation technique in early 1970s (e.g. Kaufman et al. 1971). First solved theoretical problems, then more practical ones such as:

- MT - E & H polarisation
- structural and deep sounding - found that phase is best parameter because it does not depend on polarisation or inhomogeneites
- magnetic variation method
- ore prospecting
- borehole - layer with finite thickness, field of focussing system
- most complicated problem is quasi-3D. This involves a plane wave source (Kaufman).

7.5.2. Non-Stationary Fields For non-stationary fields the basis was the integral equation method and Kaufman's method of poles for transforming between time and frequency domains. Although some Americans also have used integral equation the Russians now consider it unsuitable. A preferable method is the finite difference technique, begun 3 years ago. Problems studied are:

- deep investigations - inhomogeneities of upper crust and mantle (horst & graben) - only E in Rx.
- ore prospecting - 3-layer model with $\sigma_1 = \sigma_3 = \sigma_2$, and σ_2 enclosing a finite body. A large album of curves is in preparation, (Rx measures E & H, vertical and horizontal components).
- at present, for SNIIGGIMS:

(i) diamond pipes

(ii) quasi-3D problems for profiling in ore prospecting. These models consist of an off-axis cylinder in the 2nd layer of a 2-layer earth. The Tx is a loop and Rx measures all components of E and H.

The finite element method can be applied to DC and harmonic problems, but was not used because of computer storage requirements. The integral equation technique has the disadvantage that computations are very long, because of Greens function. With a method called Pieceman-Reichford, the integral equation technique can be used on the boundaries.

References:

Harmonic

The response of undulating layers is given by Kaufman & Tabarovskiy (1968), and Tabarovskiy (1968, 1969). Integral equation solutions for a spheroid in a two-layer medium are given by Kaufman, Krivoputskiy and Tabarovskiy (1971) and for an elliptical cylinder by Kaufman, Tabarovskiy and Terentev (1971). Discussions on these books are given by Kaufman et al. (1972) and (1973). A complete description of the integral equation method is given in Tabarovskiy (1975). Note that Gulf Oil has translated this book. Advanced versions of the method applied to inhomogeneities in anisotropic media are given by Tabarovskiy (1977a, b).

Transient

The finite difference method is used for axisymmetric models in Tabarovskiy & Krivoputskiy (1978). Advances of this method with applications are given by Tabarovskiy & Gol'dman (1978). Albums of curves for lateral inhomogeneities are given by Tabarovskiy (1979). Curves for a disc in a half-space are given by Gol'dman & Rabinovich (1977).

7.6 LOGGING

7.6.1. Introduction - Soviet Union produces 5×10^8 tons oil per year (40% from Siberian Platform). Downhole techniques are very important in oil search in USSR. These comprise about 30 methods, including 10 EM (not all in use now). Most are DC current methods, but also frequency, induction, and dielectric (theory was developed in late 1950s by Doll, in J. Pet. Tech.).

Purpose of logging - To determine longitudinal conductivity σ_t. One direction of research at IGG is to measure coefficient of anisotropy, because this is directly related to oil and gas locations in many areas of Siberia, i.e. if clay is anisotropic, it will probably have oil beneath it.

Early systems with axial dipoles only gave information on the longitudinal conductivity, σ_t (conductivity in x and y directions).

7.6.2. Anisotropy

The coefficient of anisotropy is given by

$$\lambda = \left(\sigma_t / \sigma_h\right)^{1/2} ,$$

and is greater than unity.

Various anisotropy models are:

(1) A sandwich of thickness H of very thin layers of thickness h, where h ≪ H. In the middle 1950s it was shown that for an n-layer section with layers of thickness hi and conductivity σ_i, the longitudinal and traverse conductivities can be expressed as:

$$\sigma_t = \sum_{i=1}^{n} hi\,\sigma \Big/ \sum_{i=1}^{n} hi \quad , \text{ and}$$

$$1/\sigma h = \left(\sum_{i=1}^{n} hi/\sigma_i\right) \Big/ \sum_{i=1}^{n} hi \; .$$

(2) Dolomite beds containing oil in horizontal fractures.

(3) Coal deposit with interbedded sandstone and clay. In the mid 1960s the Soviet scientist Edman developed a new method of measuring using a horizontal magnetic dipole as Tx and Rx. Epov is working on the theory. His first solutions were for the 3-layer problem, consisting of the borehole, the zone of invasion, and the anisotropic country rock, but he assumed 1 axis of anisotropy is parallel to the axis of the borehole. For increasing separation of dipoles, L, the effect of the borehole and invasion zone decreases, but for radius of borehole r = 0.1 m a separation of L = 15 m is needed.

7.6.3. Theory

When logging, there is a charge density on the surface of the borehole. If the medium is anisotropic, there is an additional volume density.

For low frequency (neglect displacement currents),

$$H_x \approx -(L/\delta)\,\sigma^2,$$

where $\delta = (\mu\sigma\omega^2)^{1/2}$.

Q = geometric factor

M, N = dipole moments of Tx, Rx

For $L \gg r$,

$$Hx = -(L/\delta)\left\{(MN/L^3).\ f\left[\sigma_t, \sigma_h, \ldots \sigma_x, \sigma_{3h}\right]\right\} + (MN/L^3)\ \ln L + 2(\ldots) + Hx \text{ homogeneous}$$

The item in square brackets is the influence of borehole and invading zone, and is regarded as "noise".

7.6.4. Geometric Focussing

Consider the array shown in Figure 7.2, consisting of a transmitter S_1 with moment M_1, and 3 receiver dipoles R_1, R_2, R_3 with moments N_1, N_2 and N_3. This array is designed such that

$$\sum_{i=1}^{3} \frac{M_1 n_i}{L_i^3} = 0 \qquad \ldots(1)$$

$$\sum_{i=1}^{3} \frac{M_1 n_i}{L_i^3} \ln L_i = 0 \qquad \ldots(2)$$

The resultant field is the sum of Hx_i and all terms except the whole-space term are zero.

Practical and model results show that over a wide range of geological conditions the system is insensitive to the borehole and invading zone. The length of the array is usually L = 1.5 m and the frequency f 400 kHz. Frequency Focussing uses two frequencies f_1 and f_2 (usually f_2 = 300 kHz; f_1 = 150 kHz)

Measure $\Delta Hx = Hx(f_1) - (f_2/f_1)^2\, H_x(f_2)$

In most cases this does not depend on the borehole and invasion zone. If L = 1 m, the invasion zone can be excluded if r = 0.6m.

All these devices give radial properties. Noppe is now working on:

7.6.5. "IKT" - (Induction Logging of Transverse Conductivity):

This is a new technique, with only 2 sets of equipment, the anisotropy is in an arbitrary direction (except σ_t which is parallel to the surface), i.e. σ is a tensor quantity.

The source is arbitrary, not necessarily a dipole.

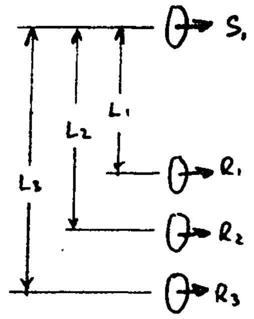


Figure 7.2 A 4-element logging system.

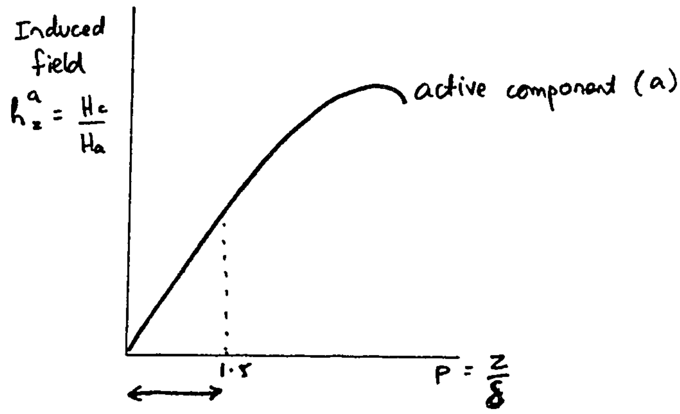


Figure 7.3 Range of "small parameter" or induction number in traditional logging.

7.6.6. VIK (High Frequency Induction Logging)

Five years ago, Antonov & Kaufman studied high-frequency harmonic response downhole. Conventional equipment uses geometrical focussing (6 or 7 coils) to exclude borehole effects. Traditionally frequencies were in the range 20-50 kHz, in the region of "small parameter" (induction number), P, (see Figure 7.3) where

$$P = Z\,(\gamma\mu\omega/2)^{1/2}$$

where Z = separation of Tx and Rx, and
γ = conductivity

Using this small parameter for induction EM downhole methods, $P = z/\delta$ is used, where δ = skin depth. However this region has low sensitivity for ρ. It would thus be preferable to increase frequency to increase the sensitivity to resistivity. Antonov & Privorotskii (1975) give details of new equipment that extends the range of resistivity measurement by a factor of 5.

Early sondes (50 kHz) measured in range of 0.3 to 20 ohm-m. The new sondes extend this range to 150 ohm-m (sonde at 70 kHz).

The dielectric effect must be considered if the frequency is increased to 12 MHz. Amplitude and phase functions for ω, σ and ϵ as a function of $Z/Z_o = \omega/\omega_o = \omega\epsilon/\gamma$ are given by Antonov (1978, p. 88). Note that the phase response is less sensitive to the dielectric permittivity. This led to new logging technique measuring the relative phase response, called isoparametrical logging.

7.6.7. VIKIZ (Isoparametrical Logging)

Reference: Antonov & Zhmayer (1979). The main aim of this method is to cancel some sounding parameters (better metrologically), to reduce the effect of inhomogeneities. As the sonde length, z, is changed, there is also a change in ω so that whole-space response is unchanged, i.e. $z\sqrt{\omega}$ is kept constant, since

$$P = Z_i\sqrt{\omega_i}\;.\;\sqrt{\gamma\mu/2}$$

But as ω is changed, the depth of investigation is also varied. A large spread and therefore low frequency thus results in the biggest penetration. It is possible to get very good interpretation in inhomogeneous media. Present research includes the study of effects of radial inhomogeneities.

In Deep Logging for oil and gas the temperatures reach 150°C. Pressure is not so much a problem as temperature. Use special vacuum flasks which enable logging for 6 hours (5-6 km) deep. Pressure OK to 1000 atmospheres - see design in Antonov & Privorotskii (1975) or Antonov & Zhmayer (1979).

7.6.8. MEL (Magneto-Electric Logging)

(The patent of this method is held by Tabarovskiy and Daveshky)

Most logging methods are DC, and involve either:

a) method of lateral logging: 7 electrode current focussing, or

b) method of lateral sounding, using different separations. With this method it is not possible to remove distortion due to the borehole).

In some geological situations these methods are impractical, e.g. if the invasion zone is 1 m thick a sonde length of 20 m would be required.

Aim of MEL

The aim of the method is to (i) measure the coefficient of anisotropy, (ii) develop a shorter sonde. Studies showed that a non-symmetrical array must be used, and that both E and H should be measured.

The geometry of the system is shown in Figure 7.4. The source measures:

a) E_x parallel to the Tx (no practical problems).

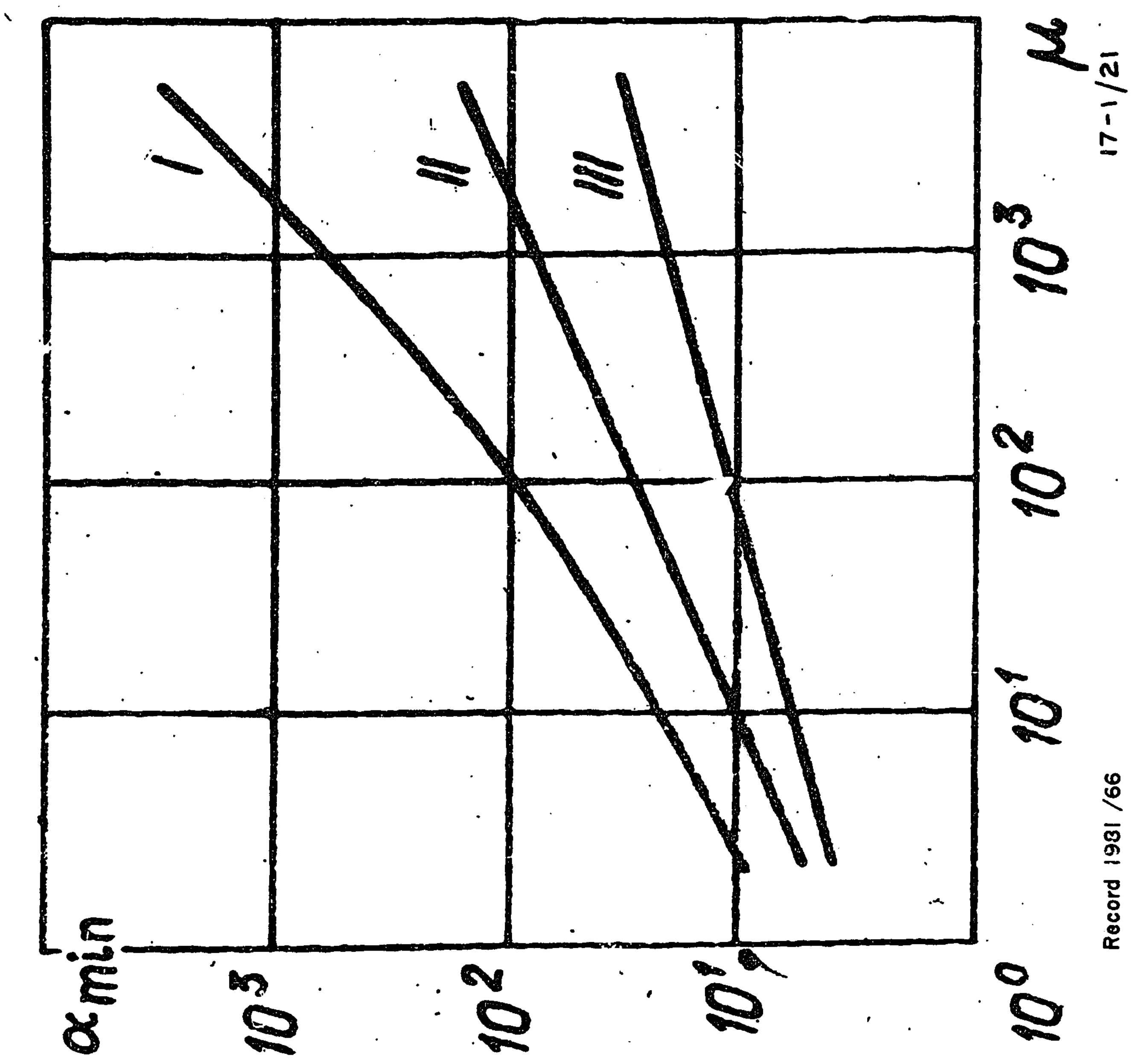
b) H_y radial, horizontal and 90° to E_x (main practical problem).

The following parameter (apparent resistivity) does not depend on the borehole and the invasion zone:

$$\rho_K = \frac{ME_x}{4\pi Z H_y^2}$$

The effect of different lengths of sonde can be seen from Figure 7.5. It can be seen that with MEL and geometrical focussing the sonde length can be drastically reduced. Similar performance is obtained from a 10 m lateral sounding sonde, a 3 m MEL sonde, and a 1 m 4-component MEL sonde. This sonde (Figure 7.6), with 3 Tx of different moments, enables small lengths to be used, while still eliminating the effect of the invasion zone.

Figure 7.5 Length of sonde needed to obtain true resistivity for three types of sondes. I: lateral sounding sonde, 10 m length, II: MEL, 3 m length, III: MEL with geometrical focussing (4 component). $\mu = \rho_n/\rho_e$, $\alpha_{min} = Z/a_n$ (from Antonov, 1979).



Anisotropy

The coefficient of anisotrop is Λ_π (usually λ in western literature). The longitudinal resistivity is ρ_{nt}, and the transverse resistivity is ρ_h. If ρ_{nt} is known, then Λ can be determined from a measurement of k (apparent resistivity), from the equations: $\rho_K = \frac{ME_x}{4\pi Z H_y^2}$, and

$$\frac{\rho_K}{\rho_{nt}} = \frac{4\Lambda_n^2}{(1+\Lambda_\pi^n)^2}$$

(Tabarovskiy & Daveshky, 1979).

This overcomes the anisotropy paradox (e.g. Kunetz & Moran, Geophysics 23(4), 1958). To a conventional technique, any anisotropic model is equivalent to some isotropic model.

This method is going to be elaborated, and perhaps equipment made. The main problems are concerned with measuring the magnetic field. It is hoped to use squid magnetometers to fit in 15 cm hole. May use the coils described in Antonov (1979) and low frequencies (1 kHz to 100 kHz).

8. VITR (ALL-UNION SCIENTIFIC INSTITUTE FOR METHODS AND TECHNIQUE OF PROSPECTING

8.1. Program

- Welcome by M.B. Kravtsov (Director)
- introduction to VITR (Kravtsov, Fokin)
- frequency domain borehole EM (Lebedkin)
- MPP 4 (Borakov, Bronsky)
- Piezoelectric methods (Neishtadt)
- Chim and KSPK (Vjacheslavovich)

8.2. Introduction

VITR is 25 yrs "young" and has a total staff of 800 people. Geophysically it specialises in borehole methods, comprising interborehole (to 300 m) and around borehole (to 150 m) techniques (cf. logging, which involves studies within the 10s cm of borehole).

VITR is composed of 3 main branches:

1) <u>Technique of Diamond Drilling</u>

- diamond bits
- technique of directed boreholes
- wireline drilling techniques
- new drilling needs & well protection
- increasing % recovery
- special techniques for regions
- safety aspects

2) <u>Drilling Rigs and Installations</u>

- design of new rigs & equipment for drilling hard-rock mineral resources at depths 300-3000 m
- drill string & casing
- automatisation
- preparation of core

3) <u>Borehole Geophysics</u>

- electrochemical, especially KSPK
- electromagnetic
- radiowave
- magnetic
- seismic
- X-ray spectrometry (geochemical)
- piezoelectric
- surface MPP

Note - surface MPP is the only method which involves surface work.

N.B. All those methods (exc. radiowave) were initially developed as surface methods to define drill target.

A fourth branch supervises all methods. VITR is involved in development of technical, methodological and interpretation techniques.

8.3 NEW METHODS AND RESEARCH AREAS

VITR is a pioneer of new methods:

- KSPK geo-electrochemical method
- CHIM method of partial extraction of metals) electrochemical
- MPF method according to element types (by oxides & sulphides))

Important research areas are:

8.3.1. Borehole Magnetometer - 3 component. First apparatus was TSM-3, with 60 mm dia.

Then built TSMK-40 (40 mm dia.)

Since 1972 TSMK-30 (30 mm) - allows simultaneous measurement of two components, eg. vertical & magnetic susceptibility (uses a 1 coil induction probe). If results interesting measure the other 2 components using another probe.

8.3.2.. Interborehole Radio-Wave Shadowing

Prototype in 1949. Really started in 1956. From 1975, built CPP-30 (30 mm). Frequencies range from 160 kHz to 37.7 MHz. This is commercially available, and over 200 are in use. The configuration is shown in Figure 8.1a.

Applications - are there orebodies between the holes?
- if one hole intersects, where are the edges? Are there barren parts?

There is also a 1-borehole variant (Figure 8.1b). The antennae effect of the orebody gives information on its lateral extent.

8.3.3. ASMM-40, SINUS - Instruments used for Harmonic Borehole Induction Prospecting.

8.3.4. MPP4 - Inductive MPP Prospecting - MMP was initially designed as a method to locate a drill target, and later was applied to borehole.

8.3.5. Method of Charge (misse-a-la-mass) - Ground equipment is used. The Tx uses DC or low frequency. The Rx is used in all holes, measuring either the potential or gradient. The spacing is 10-20 m. This method can also be used for correlation of thin beds - better resolution is obtained using gradient measurement (see Fig. 8.2).

8.3.6. MYSG (2D Analogue Geophysical Modelling System)

This uses conductive paper as the modelling material and is used for

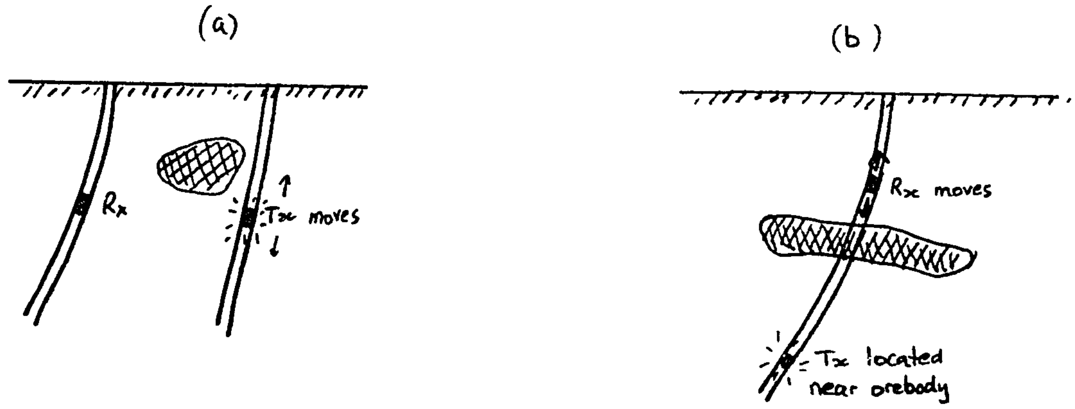


Figure 8.1 Radiowave shading: a) interborehole, b) single-borehole variant.

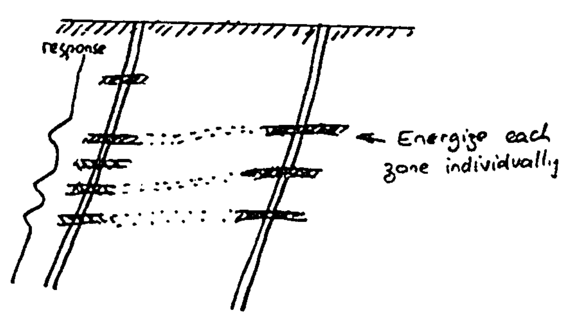


Figure 8.2 Method of charge.

solving forward and inverse problems such as electroprospecting, DC, IP, SP, magnetic, gravity. It can model borehole, surface and airborne methods.

The system consists of an electric field generator and electrodes to measure vectors. Results are displayed on a CRO, and by switching to appropriate electrodes the profile can be measured. A pointer gives the amplitude at each point of measurement.

For magnetics and gravity, mathematical relationships are used to derive the parameter from E, e.g. to measure H_z over cylinder, locate a dipole (2 electrodes) in the centre. The gradient of E measured with electrodes MN is equivalent to H of vertical magnetized body.

Examples of the use of this system for modelling vertical electric probing (VES) are given by Avdevich in Lebedkin (1977). One such example, Figure 8.3, shows field results (a) and MYSG model results (b) of apparent resistivity pseudo-sections obtained using vertical electrical profiling.

8.3.7. Piezoelectric methods. Have designed 8-SEV2m, and more recently KVARTs-1.

8.3.8 Geo-Electrochemical - direct methods.

These include CHIM and KSPK which are detailed in section 8.15 and 8.16. The method of exploration according to the form of occurrence of minerals (MPF) is an electrochemical/geochemical method, which is widely employed in the early stages of exploration. This method involves analysis of metallic organic compounds.

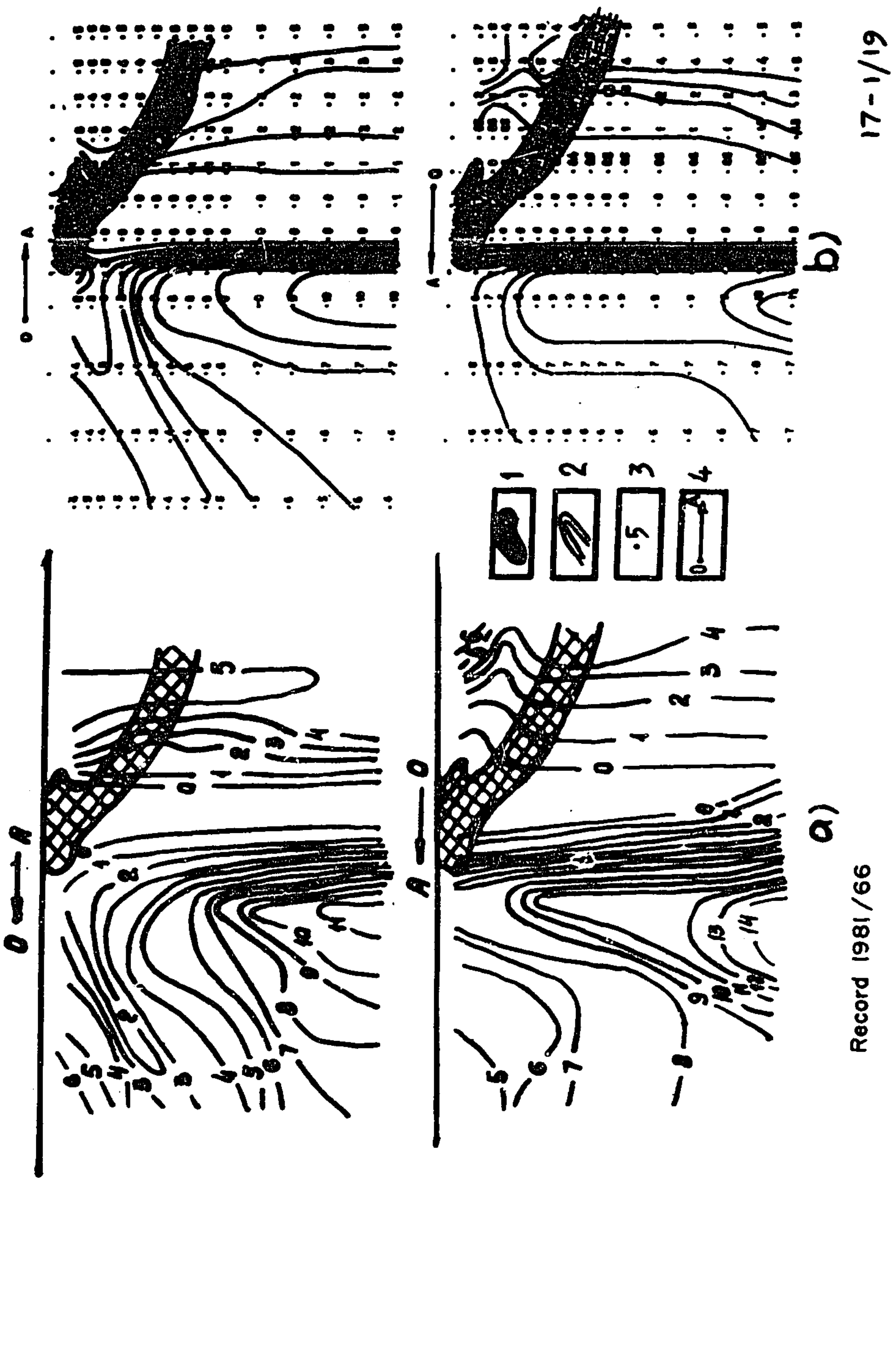
8.4. TYPICAL EXPLORATION PROGRAM

1) Geologist drills where he wants
2) Survey hole using Method of Charge
3) Survey hole with borehole dipole-dipole (DEMPS)
4) Drill again only if a DEMPS results interesting.

8.5. BOREHOLE INDUCTION PROSPECTING

These are harmonic methods, of which there are few variants, and are designed to have a large radius of investigation ("logging" methods, in contrast, give information on the rocks in the immediate

Figure 8.3 Apparent resistivity pseudosections obtained from (a) field observations, (b) MYSG modeling. 1: orebody, 2: ρ_a contours, 3: ρ_a values, 4: direction of movement of Tx electrode (after Avdevich in Lebedkin, 1977).



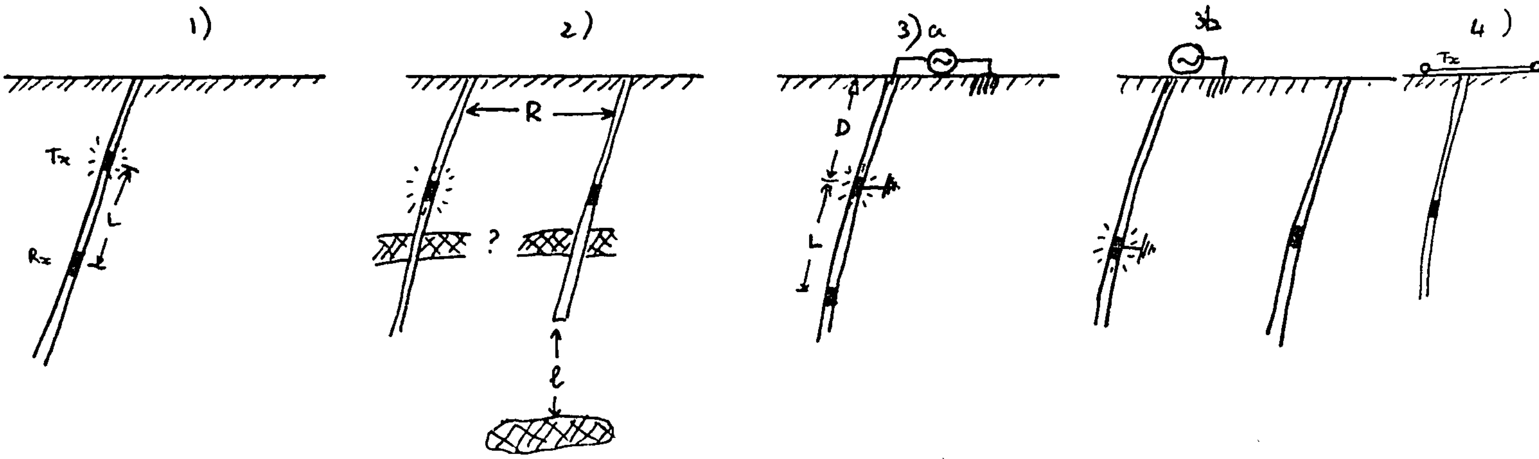


Figure 8.4 Variants of borehole induction prospecting. 1: DEMPS (dipole-dipole); 2: MDEMP (inter-borehole); 3: MPT (method of field of currents), (a) one hole, (b) two holes; 4: large transmitting loop.

vicinity of the drill-hole). The Rx consists of a 3-component coil, and the primary field is inductive. The Rx measures real and imaginary components. The four variants are shown in diagramatic form in Figure 8.4.

8.5.1. DEMPS (DIPOLE-DIPOLE)

These systems were developed in the 1960s. The Rx measures 3 components. Probes are 40 mm diameter. (Holes are 46 mm & 59 mm diam.). Orientation is achieved by Pb weights on probes. These will soon be replaced by small orientation coils. Holes in the Urals are up to 1500 m deep. Probes are designed for a pressure of 22 atmospheres. The Tx - Rx separation, L, can be 25, 50, 75 and 100 m (for ASMM-40).

Advantages . By varying L can get much information on size, shape, strike, homogeneity and edge shape.

. Depth of use virtually unlimited.

Disadvantages . The dipole field results in a small radius of investigation.

Details of the DEMPS method, description of the apparatus ASMM-40 and field results are given by Lebedkin (1973). Further results are discussed in Lebedkin (1977).

DEMPS has been used in 15,000 boreholes over 5 years. The Ministry of Geology now requires that each borehole be logged with DEMPS, since this saves much drilling. Interpretation is so simple "even the geologist" (or the operator) can do it in the field. It is not practical to use computer interpretation because of lag time. Usually only 30-40% of the information on the curve is used.

8.5.2. MDEMP (INTER-BOREHOLE) Developed 2-3 years ago, as a secondary method, but has proved to be much more useful, especially in:

(i) Search for orebodies beneath the bottom of holes, max R = 200-300 m, max L = 0.6 to 0.8 R (see Figure 8.4)

(ii) Determine continuity of deposits and whether they lens in or out.

(iii) Since anomalies are broad, can measure at reading intervals of 5 cm - 10 m. The method is especially good in areas of sparse bore-holes.

(iv) Tx & Rx can be at same or different depths.

Limitation - For diverging or converging holes the primary field will change. The error is subtracted graphically or by inclinometer data.

8.5.3. MPT - Method of Field of Currents

a) This uses a transmitter, grounded on the orebody or drill casing. The receiver is lowered down the same hole. The radius of investigation is increased to 150 to 250 m. L is usually 50 m, but is relatively unimportant - the main factor is D (Fig. 8.4).

Advantages - Increased radius of investigation. Can determine whether there are any conductors. The main factor controlling the response with this variant is the conductivity contrast (cf. induction methods). This is often a disadvantage.

Disadvantages - Doesn't have great resolving power. Needs a conductivity contrast of 3 to 7, e.g. cpy is 0.45 - 0.1 ohm-m, py 0.5 - 2 ohm-m, in a resistive host.

b) 2-borehole variant.

This has a large radius of investigation. If grounded on casing very smooth curves are obtained.

Field Example: Figure 8.5 shows MPT results from copper/nickel ores in the Kola Peninsula.

8.5.4. LARGE TRANSMITTER LOOP

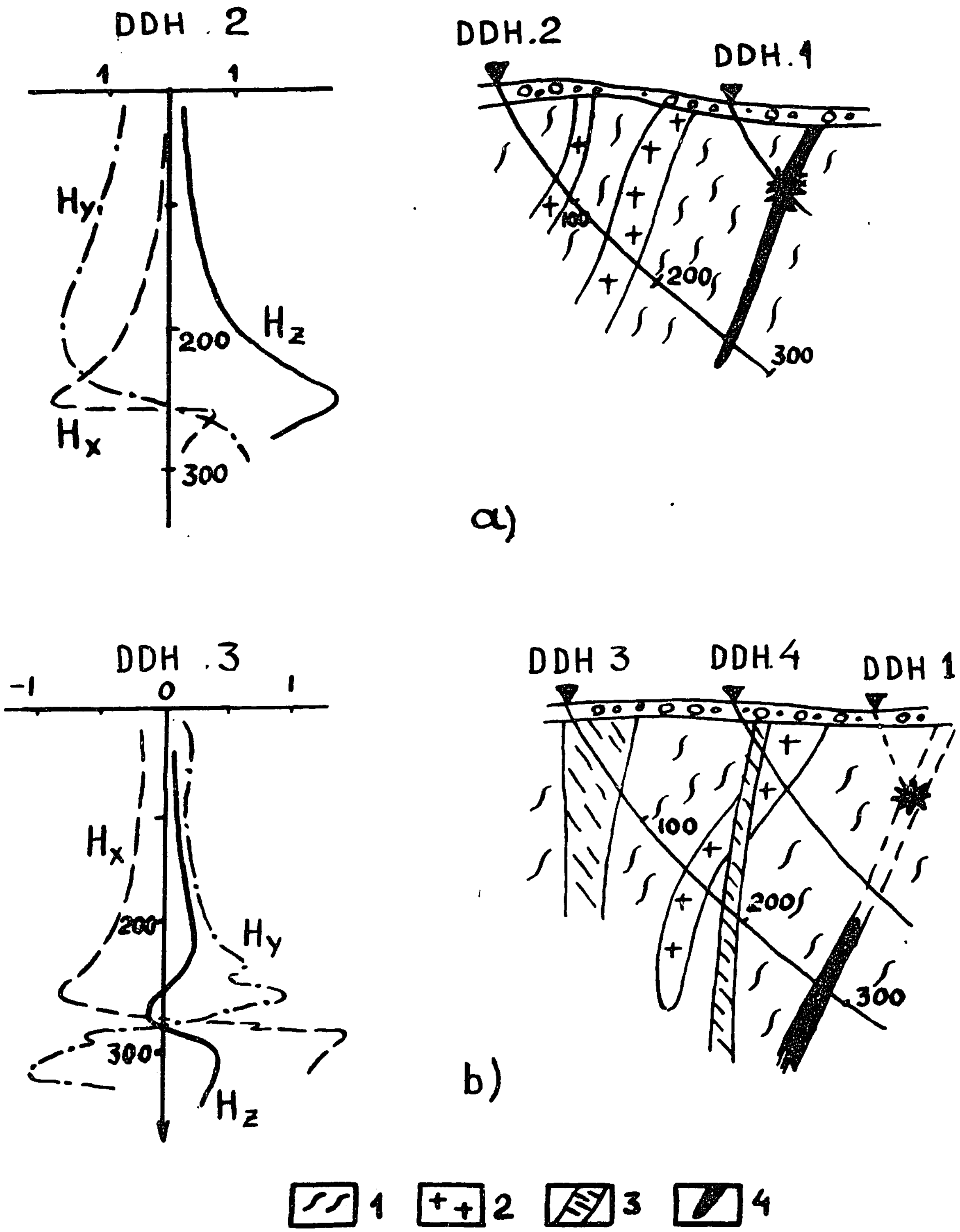
MPT-0: one borehole

MPT-2: 2 holes

With this variant, smaller 300 mm Rx probes can be used because of stronger Tx field. Presently used in Canada & Sweden (eg. Scintrex DHP-4). VITR does not consider this variant is useful because of its limitations:

1) anomalies are superimposed on large background field,
2) depends on induced currents in overburden and host, and the position of Tx or Rx with respect to hole
3) maximum depth 350 m
4) difficult to energise steeply dipping bodies (angle between hole & body small)
5) when hole not in centre of loop the effect of the E field (IP etc) also plays an important role; and therefore inhomogeneities near the loop give big anomalies.

Figure 8.5 MPT results from Kola Peninsula, 1: granite biotite gneiss, 2: granite gneiss, 3: diabase dyke, 4: copper-nickel orebody (after Veksler & Podderegin in Lebedkin, 1977).



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8.5.6. Choice of Variant - Always use several variants. Each variant has its best application:

DEMPS best for prospecting

MPT best for searching

MDEMP best for answering question: "Do we keep drilling?"

8.5.7. Equipment

ASMM-40M (or ASMI-40M) (Since 1971. Modified in 1977, hence M). Have produced 70 sets but some have "drowned". Is mainly used for DEMPS and large Tx loop systems. For MDEMP a special generator is used. For MPT small alterations are necessary. These are outlined by Kulagov et al, in Lebedkin (1977).

Frequencies: 125, 375, 1125, Hz (usually include two). Axial component has 0.3% sensitivity.

Min. Angle Probe must be less than 4° from vertical to obtain x, y orientation.

Radius of Investigation 40-80 m. The equipment is sold with 2 sets of probes; a different Tx coil for each frequency. A description of the ASMM-40 equipment is given by Kulagov & Lebedkin in Lebedkin (1973).

SINUS - This a new system; serial production will begin in 1982.

Frequencies a) 125, 375, 1125 Hz

b) 5000 & 22000 Hz

Threshold sensitivity 0.1% in DEMPS mode

Min. Angle 2°

Readout digital

Separation 60 or 120 m

Radius of Investigation 120 - 140 m.

Transmitter

z-component only. The Tx core consists of 3 cm diameter thin steel sheets; a Tx current of 1A is used. The dipole moment n IA = 1000 and the effective μ = 150 (n is limited by saturation effects). Two phase-sensitive detectors (Im and Re) are mounted under the Tx probe. Can be used for variant 1) or 2) or 3) or 4).

Receiver

Ferrite cored coil with nA (axial) = 500 and nA (perp) = 70 to 100. The Rx probe contains a wideband preamplifier, located above the coil.

PROBE DESIGN

The probe is plastic, with metal electrostatic screens. These have thin slits to prevent eddy currents (vertical slits for axial component, and horizontal slits for perpendicular components). For DEMPS & MPT the problem of electrostatic interference is very important.

ERRORS due to curved holes are minor in axial component (cos θ) and less than expected in perpendicular components (sin θ), possibly owing to the fact that the probe diameter is often much less than the hole, and the taut cable tends to align the probes. With more sensitive equipment this will be bigger problem, but erros can always be checked with the imaginary component.

8.5.8. Applications

1) mainly for massive and banded sulphides; not suitable for disseminated sulphides.

2) better for magnetite bodies than magnetic logging, because
   a) can distinguish between remanent and induced magnetisation
   b) gives information on size and shape.

   Field example from the Ukraine. Host beds of high permeability, low conductivity, and an orebody of low permeability and high conductivity. Magnetic logging was useless. The body was clearly detected with induction logging Im component. (Dobrohotova at MGRI has done this with the surface method). (The downhole magnetometer used at VITR is TSMK-30, 3 component, 10 nT resolution).

3) when orebodies have complex forms.

4) can differentiate between economic & sub-economic bodies.

5) DEMPS gives very good results when host conductivity is high, and other methods fail.

8.6. MODEL RESULTS - DEMPS (Dipole-Dipole)

Models are 1:1000 scale Pb, Ni, Cu conductors in air, and include plates (infinite, semi-infinite, thick, thin), ribbon (thick, thin), disc. Correlation between model and field results (borehole) is always better than with surface results.

8.6.1. Horizontal Plate

(i) Non-Intersecting Hole

The primary field lines and a typical DEMPS profile are shown in Figure 8.6. The perpendicular component allows dip determination for small values of dip.

Distance "a" can be determined from 1) axial component H/H_i.
2) perpendicular component H/H_i.
3) distance between peaks

Using at least 2 of these methods gives good results.

Strike extent is estimated by changing L (measure with L and 2L). Use parameter $p = \omega\mu\ \sigma\ Q$ (Q = geometrical factor). If plate is semi-infinite, Q = mL.

Plot ρ at L and 2L; and H at L and 2L.

(ii) Intersecting hole

Typical DEMPS anomalies for an intersecting hole are shown in Figure 8.7:

a) thick plate - the length of "saturated" response gives L + M (see also studies by Semenov in Lebedkin, 1977).
b) thin plate - the response does not saturate
c) semi-infinite plate
d) strip
e) disc.

The distance from the borehole to the edge of plate in c, d and e can be obtained from graphs similar to that in Fig. 8.8.

8.6.2. Dipping Plate

The axial component is symmetrical, and dip has no influence for $\phi = 60°$ to $90°$ (Fig. 8.9). For $\phi > 45°$ a positive anomaly is obtained on the flanks. Dip can be estimated from this and amplitude. However a more accurate technique is to use the perpendicular component, which is asymmetrical. For $\phi = 90°$ no anomaly is obtained. For other angles definitive anomalies of up to 200% are obtained. Dip is determined from L or A. In the field an accuracy of 3° is obtained. Strike is given by the 2 perpendicular components.

Use of Real and Imaginary Components

All the above results are the the Re component. The assumption is

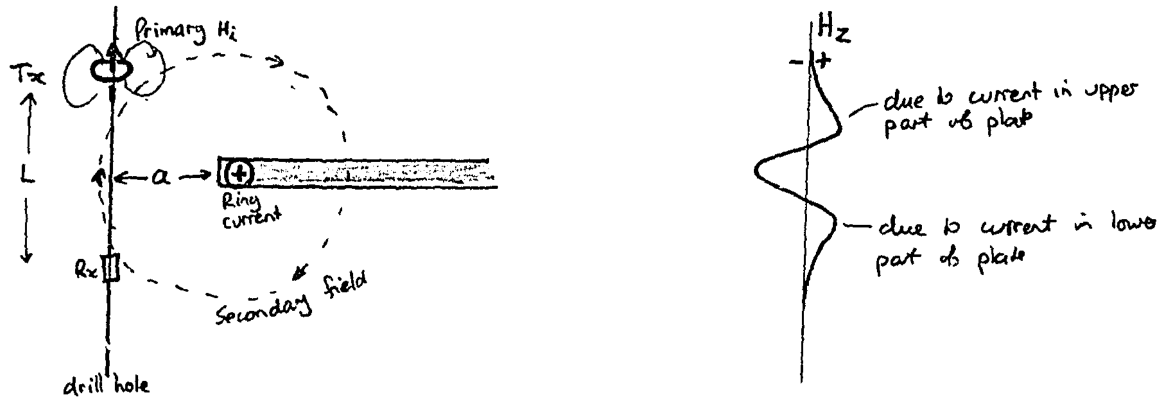


Figure 8.6 Geometry and profile shape for DEMPS in non-intersecting hole.

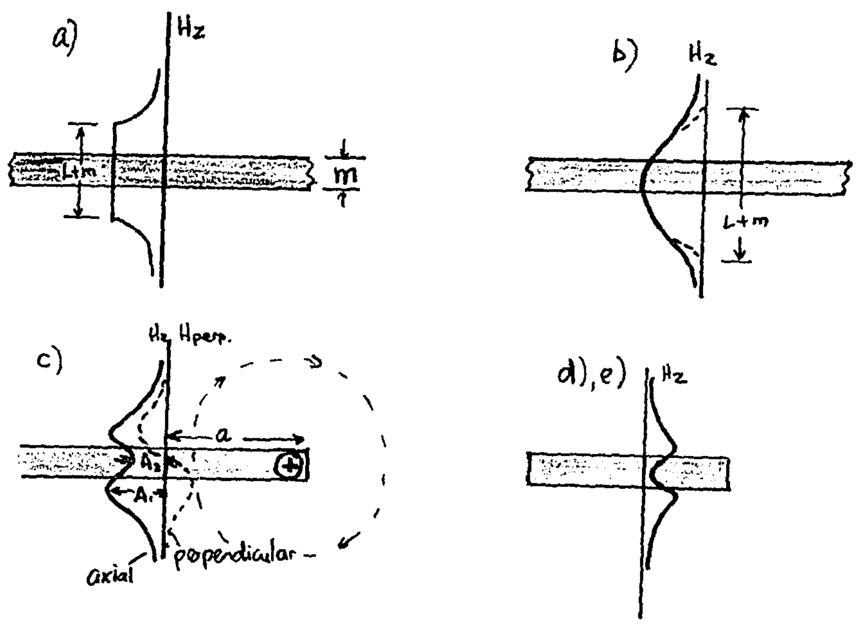


Figure 8.7 Profile shapes for DEMPS in intersecting hole: a) thick plate, b) thin plate, c) semi-infinite plate, d) strip, e) disc.

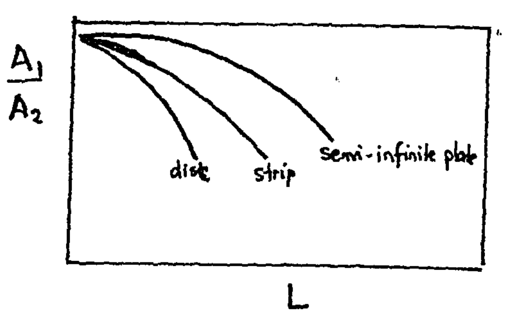


Figure 8.8 Graph of ratio of A_1/A_2 versus L.

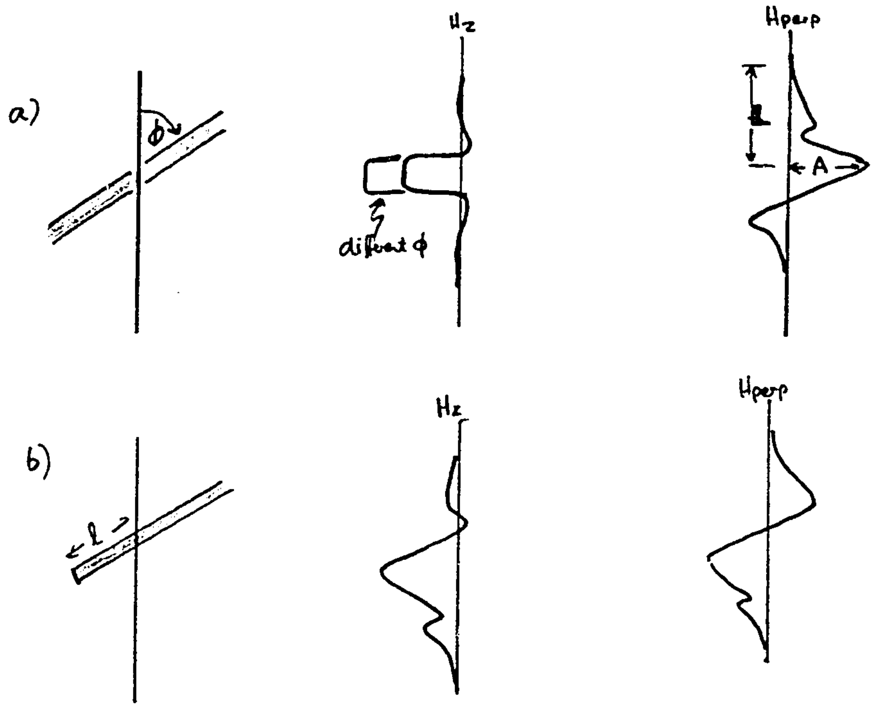


Figure 8.9 Profile shapes for DEMPS in intersecting holes through dipping plates. a) infinite plate, b) finite plate.

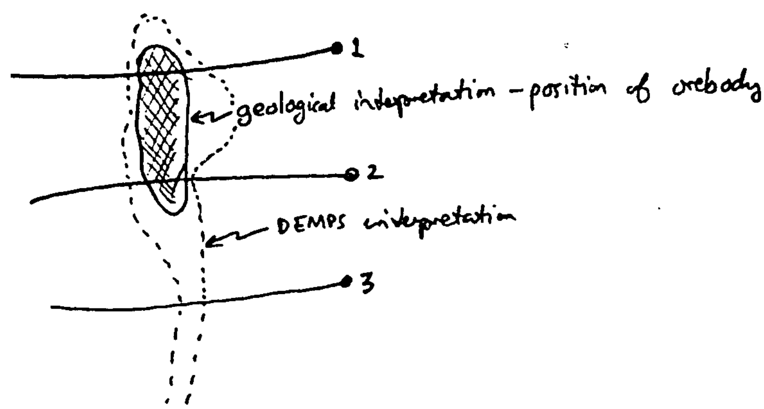
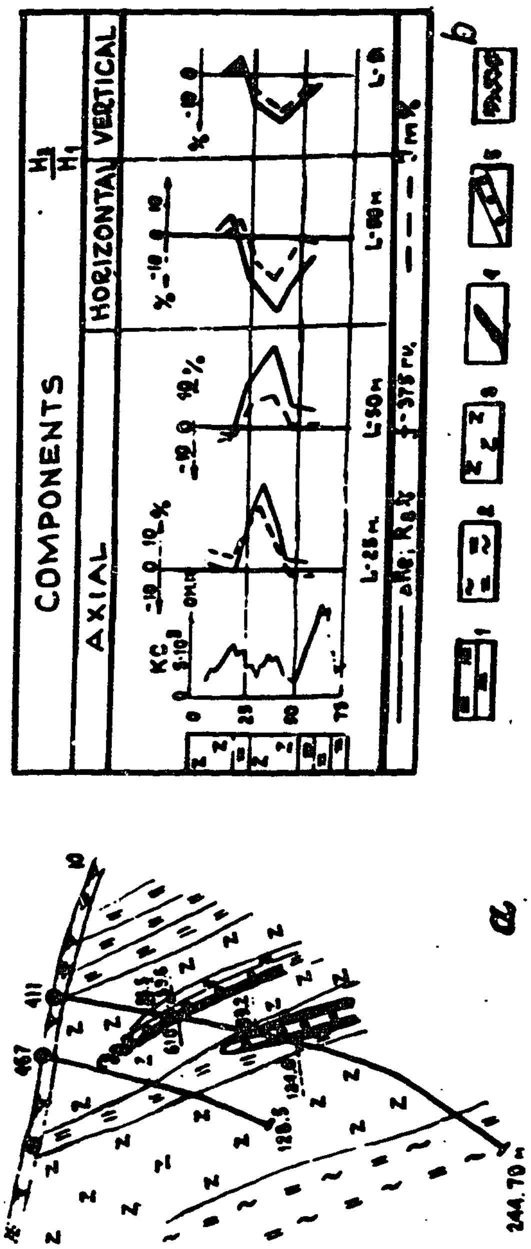


Figure 8.10 Example of use of DEMPS in the Urals. Drill-hole 3 missed the ore by 5 m.

Figure 8.11 Case history of DEMPS in a polymetallic deposit in the Rudni Altai region. (a) geological section, (b) DEMPS results from hole 1089. 1: alluvium, 2: calcareous chlorite schist, 3: tuff, 4: sericite chlorite quartz schist, 5: rich polymetallic ores, 6: orebody outline interpreted from DEMPS data, 7: hole location (from Kasimov, in Lebedkin, 1973).



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made that the high frequency or conductivity asymptote (inductive limit) is reached and Re $\gg$ lm. For lower conductivity or frequency the Im component is used, which gives same shape but the amplitudes will be different. Correction graphs are available for this.

In the field try to use frequencies where Re $\geqslant$ Im. From ratio of Im and Re, S (conductivity-thickness) can be determined. Using DEMPS with 2 separations it is possible in practise to determine thickness to 2% in an intersecting hole, or 20% for non-intersecting. If the body is inhomogeneous, different types of anomalies in Re & Im are obtained.

8.7. FIELD EXAMPLES - DEMPS

1) In the Urals, massive pyrite body (0.5 ohm-m in 5-10 ohm-m graphitic host). For massive conductors, superposition holds to about 10% accuracy. Cu content of greater than 2% in the Urals results in a sharp increase in conductivity.
2) In the same area the method has been very good for mapping and delineating the shape of orebodies. It is especially useful for near-misses. Later drilling showed that the predictions from DEMPS were correct (Fig. 8.10).
3) A rich polymetallic deposit in the Rudni Altai region (Figure 8.11). A strong anomaly is obtained at the ore intersection, and the profiles are interpreted to be due to a steeply dipping conductor, as shown.

8.8. MODEL RESULTS - MDEMPS - (InterBorehole Inductive Surveying)

8.8.1. Horizontal body intersected by one hole

Typical results are shown in Figure 8.12. When a conductor lies underneath the holes its position can be determined from examination of the positive anomaly flanks. Conductors can be detected at depths of up to 0.8L.

The perpendicular component anomaly is not as wide, but the width is less dependant on size c. Thus a good estimation of c can be obtained by interchanging the Rx and Tx.

8.8.2. Horizontal body intersected by two holes

Typical profiles are shown in Figure 8.13. The plate has a discontinuity of width b. In the axial component the discontinuity results in the disappearance of the positive flanks.

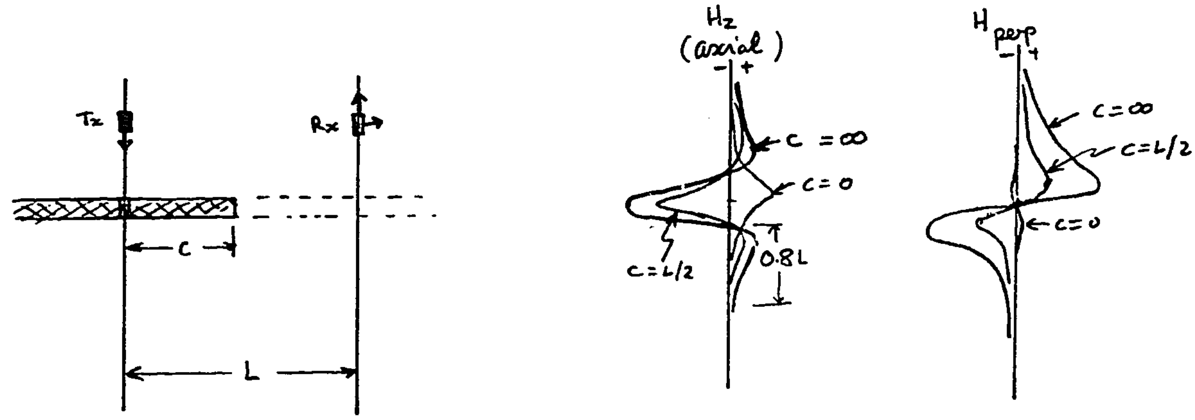


Figure 8.12 MDEMPS model profiles for a plate intersected in one hole.

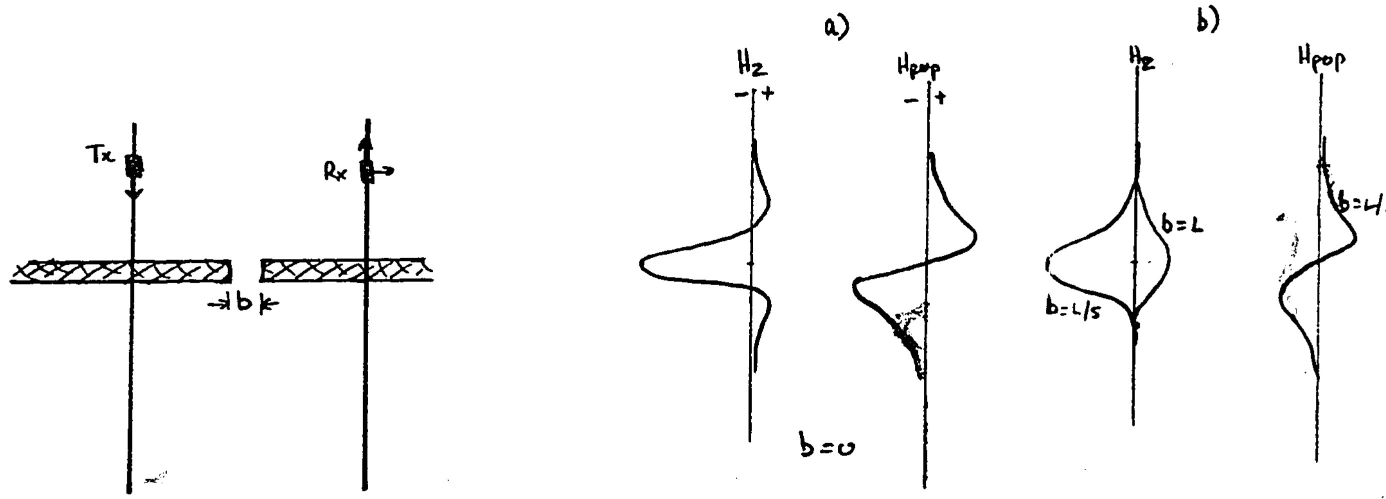


Figure 8.13 MDEMPS model profiles for a plate intersected in two holes. (a) continuous, (b) discontinuous plate.

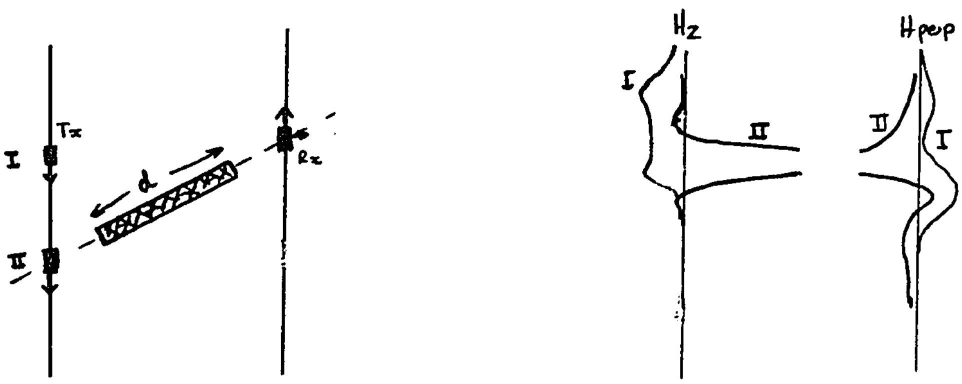


Figure 8.14 MDEMPS model profiles for a dipping plate between two holes.

I: arbitrary position, II: probes aligned with plate.

In the perpendicular component the shape is not influenced by the discontinuity, but the amplitude is. It is difficult to determine the position of the discontinuity.

8.8.3. Dipping body not intersected

The geometry and profiles are shown in Figure 8.14. This method can result in an accurate determination of dip, if d > 1/3 of separation. When the sensors are aligned as shown a maximum anomaly is obtained. It does not take much time to move probes around in ore area. Usually, about 10 points are measured. The method works a little worse than radio-wave methods in resistive areas, but much better in a conductive host, or if there is a small conductivity contrast.

8.9. FIELD EXAMPLES - MDEMPS

These two examples are from deeply buried bodies in the Urals (from Lebedkin et al. 1978).

1) Copper-zinc pyritic ores of Polosk (in Bashkir ASSR). MDEMPS profiles and interpretation are shown in Figure 8.15. MDEMPS enabled the delineation of the continuous zone between DDH 48 and DDH 127. In this area DEMPS almost worked but had insufficient range.

2) Copper pyritic ores of "50 Years of October" deposit (Aktiubinsk) in Bashkir. The ore zone gives clear MDEMPS anomalies (Figure 8.16) which aid in evaluation of the deposit.

8.10 RELATIVE BENEFITS OF HARMONIC AND MPP METHODS

Harmonic methods are better for detailed prospecting (eg. using DEMPS). MPP methods have the advantages when searching for orebodies at shallow and intermediate depths.

In studying magnetic bodies, harmonic methods are better since anomalies in Re and Im components have different characteristics. At a suitable frequency (eg. 125 Hz) the Im component is a function of σ. and the Re component is a function of μ. Thus the effect of σ and μ can be separated.

8.11 MPP-4 TEM EQUIPMENT

MPP methods were developed for searching applications (esp for non-intersected bodies) and siting drillholes. Since FEM dipole-dipole borehole methods (DEMPS) were successful, there was no need to develop a similar TEM system.

Figure 8.15 Case history of MDEMPS (interborehole profiling) from copper-zinc pyritic ores of Podolsk (in Bashkir ASSR, Urals). (a) Examples of discovery of orebody discontinuity in holes 105/48 and continuity in holes 125/48 and 127/48. (b) Interpretation of continuity of deposit. 1: chalcopyrite ore zone. 2: discontinuity in ore zone. 3: continous ore. 4: projection of drill-hole. 5: location of instrument (from Lebedkin et al, 1978).

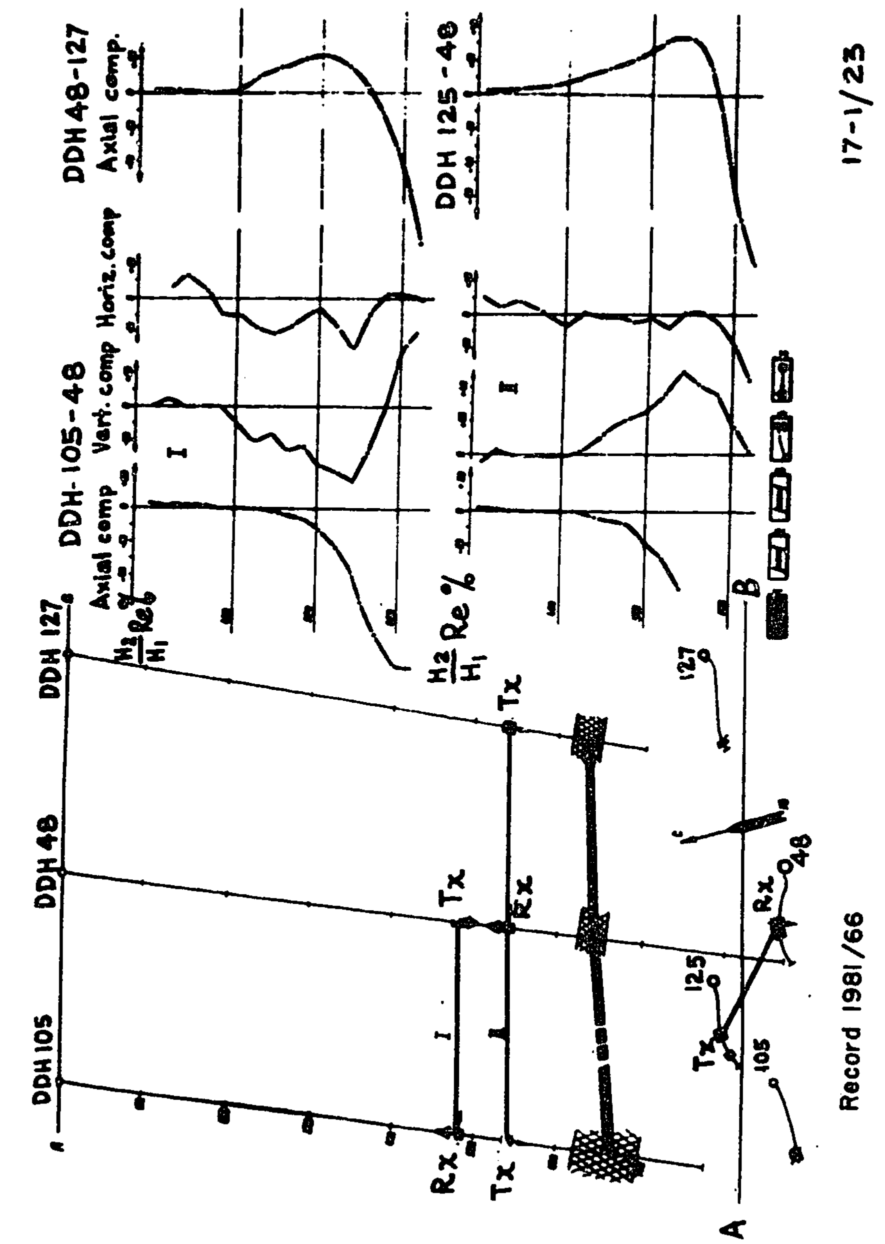
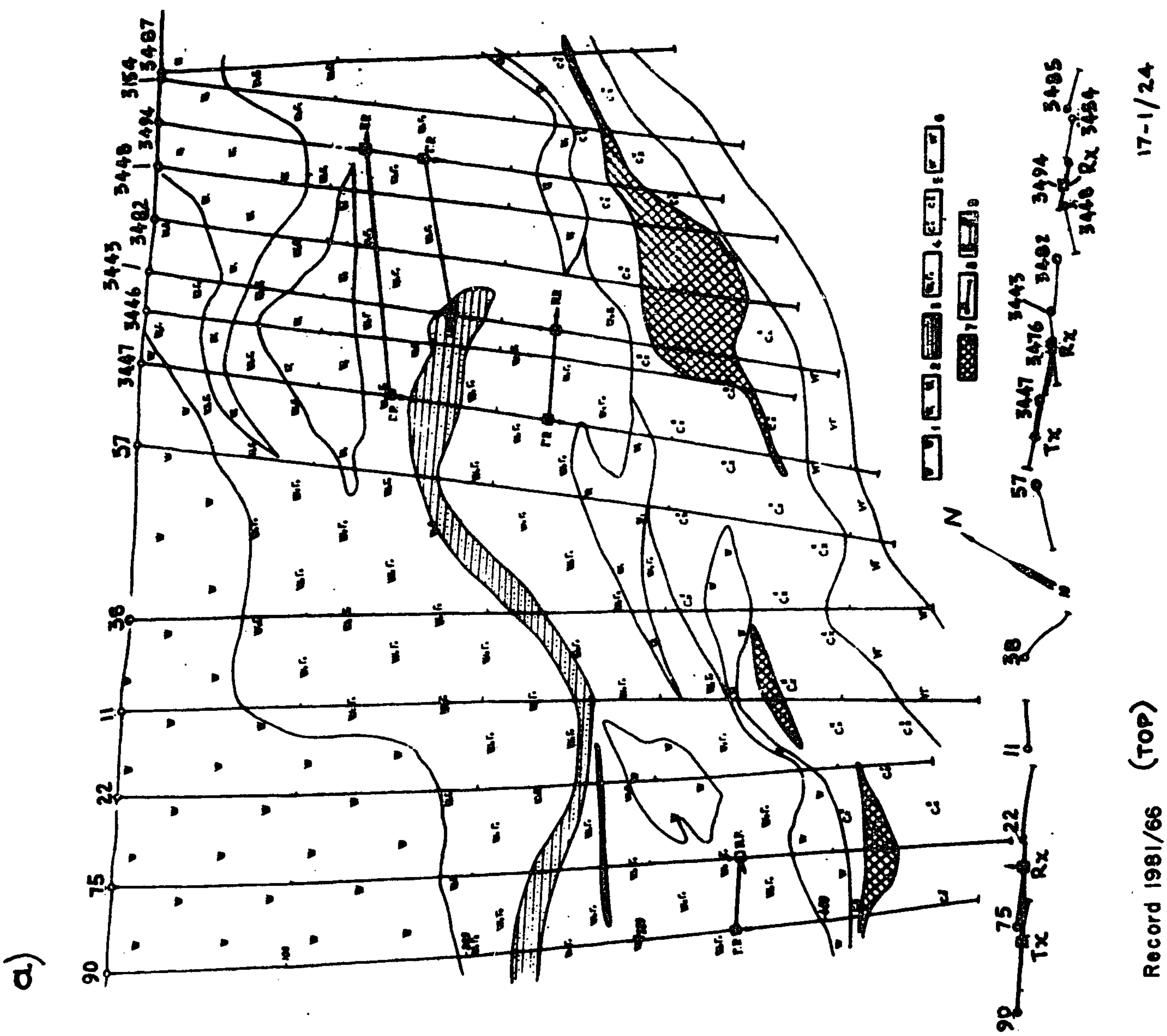


Figure 8.16 Case history of MDEMPS from the copper pyritic deposit of Oktiabrskoe ("50 years of October") deposit in Bashkir. (a) Geological section through hole 90-3487 and position of probes in MDEMPS: 1: lava breccia of dacite and porphyrites, 2: liparite-dacite porphyrites, 3: sandstone clays, 4: mixed tuffs, 5: sericite-chlorite-quartz bodies, 6: andesite-basalt porphyry, 7: copper pyritic ores, 8: drill-hole, 9 :Tx-Rx position. (b) Results of MDEMPS in holes 3443-3493, 3443-3447 and 3494-3447.



The MPP-4 has three variants, all using the same Tx and Rx units. The development is at the test stage (2 units), and commercial production should begin in 1981. (Note the MPP-3 has been produced at a rate of 20-30 per year).

8.11.1. Transmitter Unipolar rectangular pulses 24 or 48 ms wide with an off-time of 48 or 96 ms.

Current: 20A

Power supply: a) AC 150 V or 220 V; 400 or 50 Hz, rectified. This feeds 60 V or 100 V into loop.

b) DC 30 V (supplies up to 7A) Ni Cd batteries - NB would like to use Ag Zn cells but this is now prohibited due to metal shortages.

Switching: SCRs - maximum switching time $t < 0.1$ ms, for the worse case of 400 m square loop (L = 5 mH) and 2.5 ohms resulting in 20A current.

8.11.2. Receiver

- Two samples are taken simultaneously at T_1 & T_2, and the voltage difference is measured (read from meter). T_1 = 1 ms to 48 ms, T_2 = 20 ms or 40 ms (suppresses 50 Hz)
- Width of sample: 1 ms
- Time Averaging: 5 to 30 s, exponential
- Ranges: 5 µV to 150 mV f.s.d.
- The normal operating procedure is to switch polarity after 1st set of readings, resulting in two readings, V_1 & V_2; finally take $(V_1-V_2)/2$. This takes twice as long as a bipolar pulse. This is necessary for borehole variants to cancel spurious signals from leads. It is done in other variants because of habit, or because the MPP-4 gives better results using this procedure.

- 50 Hz suppression - 10 000 times better than MPP-3, because of feed-back amplifier design.
- Synchronisation is radio link for frame-loop and borehole variants, up to 1 km distance.
- Bandwidth 100-150 kHz. Note total bandwidth controlled mainly by sample width. For exponential signal the 1 ms width gives error 3% for τ = 1 ms).

8.11.3 Variants

1) One-Loop up to 400 m square.

2) Frame Loop, radio synch, 3 component. Vibration problem means that very sturdy tripod is required for coil. The Rx is similar to the borehole coil.

3) Borehole

The Rx probe diameter is 40 mm and the length is 1750 mm. The coil is ferrite-cored and has 3 sets of orthogonal windings, above which is a 2X preamplifier. The cable length is 500 m.

- Perpendicular components: nA=800 m^2, f_o = 2 kHz. Self process 250-300 µs.
- Axial component: nA=200 m^2, f_o = 4-5kHz. Self process $<$200 µs.
- Orientation: by means of a potentimeter and a weighted eccentric on axis. This results in an accuracy of 10° for worse case of steep dip (85°). A minimum of 5° from vertical is required.

8.12 INTERPRETATION OF SURFACE MPP METHODS

8.12.1 Choice of Variant Normally use one-loop, then frame-loop, then borehole variants.

ONE-LOOP - economical, and used always, for large areas in a reconnaissance mode. It can detect to 200 m, and is also used for some detailing although it is labour consuming.

FRAME-LOOP - better for detailing. The detection limit is about 200 m for a body of size 200-500 m with high conductivity (50-100 S/m) in a resistive host.

BOREHOLE - depths up to 400 m. Usually use 3 or 4 Tx loop positions.

8.12.2. One-Loop - Information on this variant is given in Fokin (1971). No further work has been published. Since 1973 VITR has concentrated on the frame-loop variant.

8.12.3. Frame-Loop

Interpretation aids consist of

- Theoretical halfspace

- Model curves for thin sheets, finite and infinite, for different dips and depths. The parameter used is:

$$\frac{t \cdot L}{S \cdot \beta} \cdot \frac{e(t)}{I}$$

where $\beta = t/\mu SL$ for a receiver with a dipole moment of 1.

- Model curves for sphere, on and off-axi inside and outside the loop.

Radius of Investigation - practically <3 radii of body (for any body). e.g. a sphere of radius 20 m and ρ = 0.02 ohm-m can be detected at 60 m if it is located 100 m outside the loop (200 m square loop). Two articles are being prepared for publication but do not know when.

Field of Loop (see also Fokin, 1971)

The primary field from the Tx loop is shown in Figure 8.17. Within the loop the field is relatively uniform.

8.13 BOREHOLE TEM

Borehole TEM methods have only been in use for 3 years. The coordinate axis are shown in Figure 8.18. For some bodies, the results are identical for Frame-Loop and downhole variants.

Time characteristics are important for separating thin conductive bodies associated with thick, less-conductive ones. Scientists at VITR like the idea of "smoke rings" in conductive media.

Typical model interpretation results are:

8.13.1. Plate

Models studied include thin and thick plates 50, 100 and 200 m in size. Other bodies can often be approximated by a plate which moves with time. The dip of a thick body does not have much effect. The width and amplitude of anomaly gives the position of the nearest edge and dip. Component measurements enable the direction of the body to be determined.

Vectors can also be used to interpret the direction of the body.

For interpretation of the axial component, the frame-loop curves of Kamenetskii (1976) can be used.

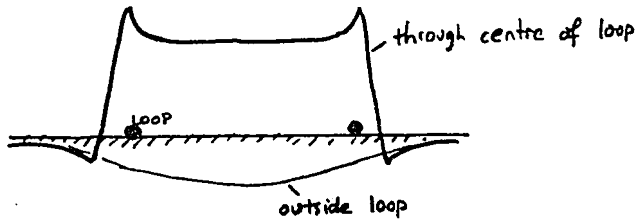


Figure 8.17 Primary magnetic field distribution about a loop.

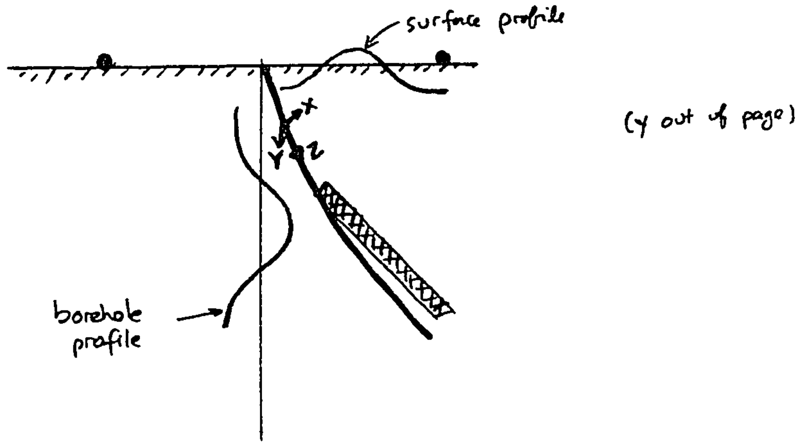


Figure 8.18 Borehole MPP sign conventions. Note that anomalies from frame-loop and borehole variants are identical.

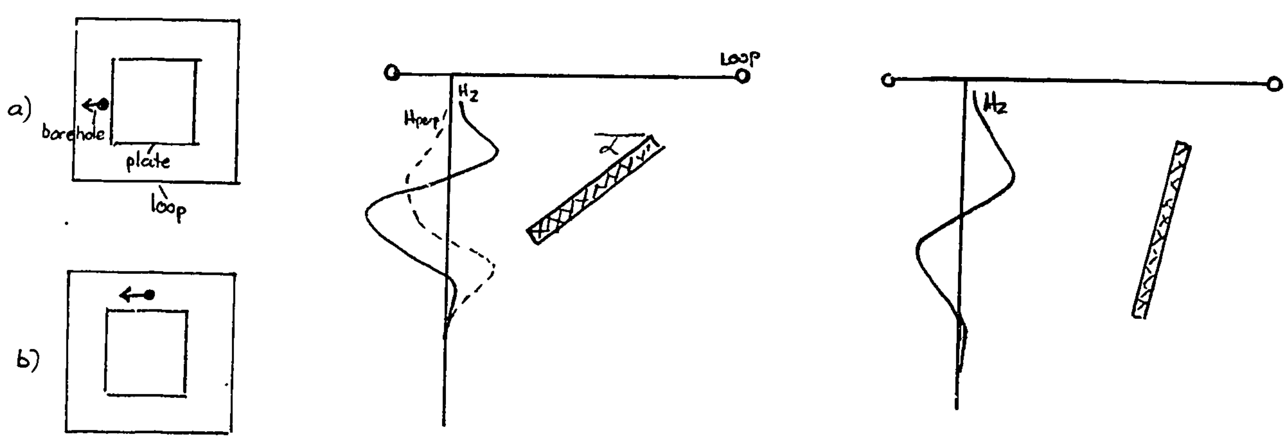


Figure 8.19 Borehole MPP curves for a dipping plate, for geometry (a).

Two parallel plates behave as one plate when their separation is approximately equal to the distance to a borehole.

Effect of dip

Typical curves are shown in Figure 8.19. All curves are symmetrical when the body is perpendicular to the borehole ($\alpha = 0$). As α is increased the curves become asymmetrical and the shape of t flanks change.

The geometry (shown in Figure 8.19b) results in symmetrical curve in the axial component, but not the perpendicular component. This is also the case when the plate is outside the loop.

8.13.2. Sphere

Model studies for all positions of sphere and borehole have been conducted. At each sample time the sphere can be replaced by an equivalent disc with the same time constant τ , as shown in Figure 8.20. The same approach can be used for a cylinder. In this case th disc moves down along the primary field lines.

Typical profiles for a sphere are shown in Figure 8.21. Further curves are given by Kamenetskii, 1976 (ch. 4.3). The maximum detecti range for the equivalent disc is given by the graph shown in Figure 8.22.

The position of the body in relation to the borehole can be judged from the position of the two anomaly peaks, as shown in Figure 8.23. This shows curves from the two spheres in locations I and II. Graphs such as shown in Kamenetskii (1976) enable estimates of distances d an τ to be determined from the half-width b and the ratios of the anomalies. Time characteristics enable calculation of the σa^2 parameter.

8.13.3. Effect of Conductive Overburden

The effect of conductive overburden is great, even in the borehole variant, because of large eddy currents induced in the overburden. Th small anomaly due to the body is superimposed on the overburden anomaly. For these conditions it is better to use dipole-dipole techniques.

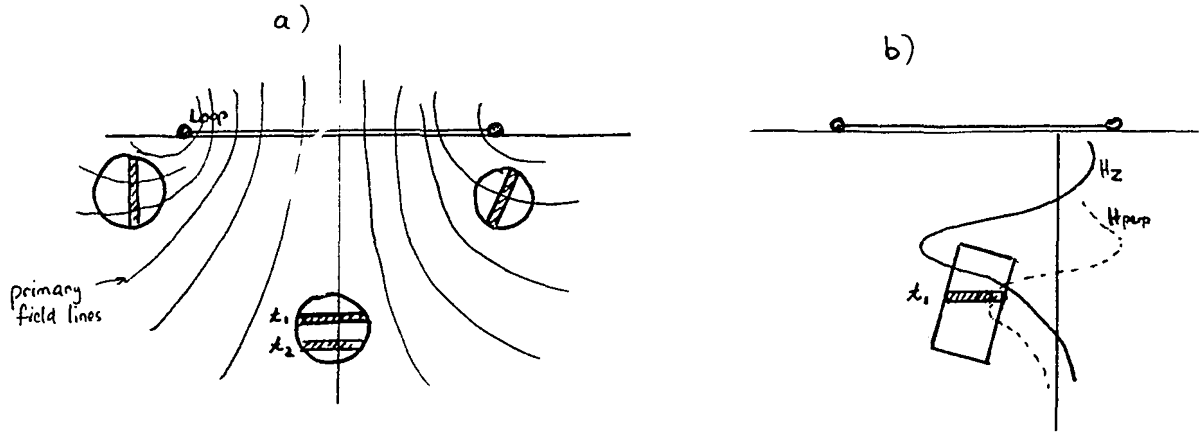


Figure 8.20 The use of equivalent discs for simulating the response of a) sphere, b) cylinder.

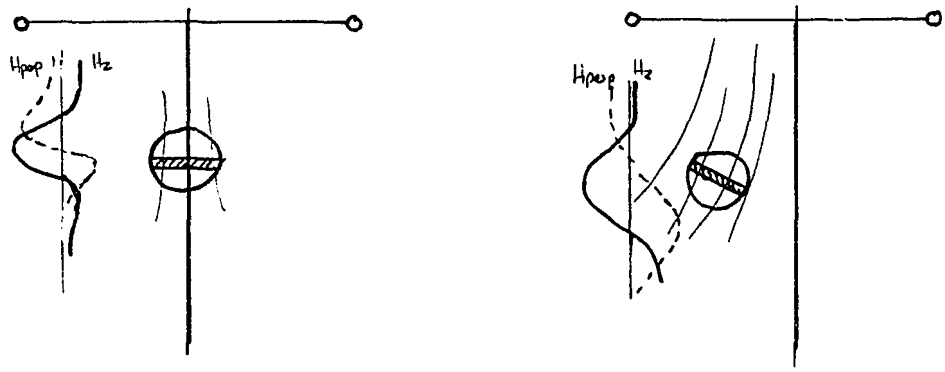


Figure 8.21 Typical borehole MPP curves for a sphere.

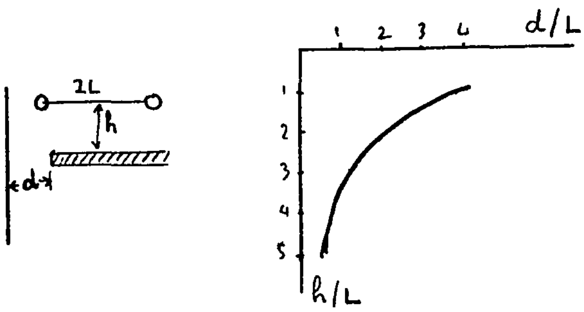


Figure 8.22 Graph showing maximum detection range of disc.

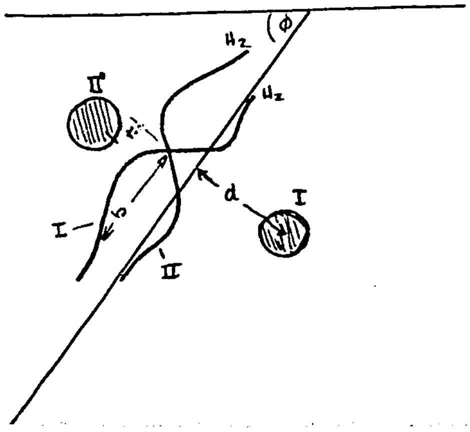


Figure 8.23 Typical borehole MPP curves for a sphere in two positions.

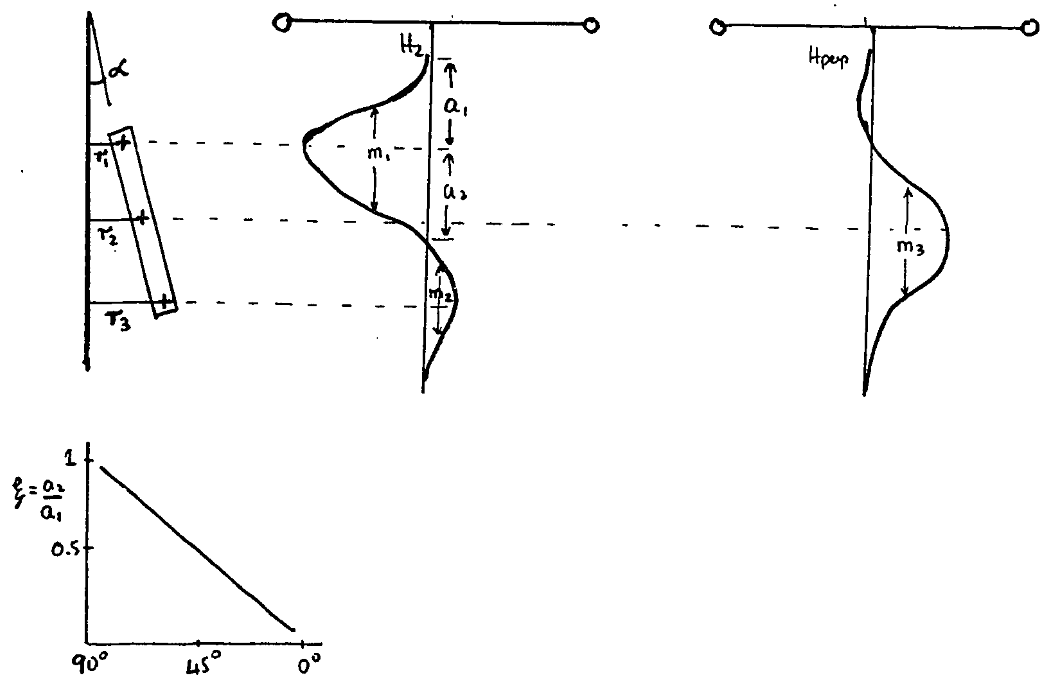


Figure 8.25 Interpretation guides for axial and perpendicular components.

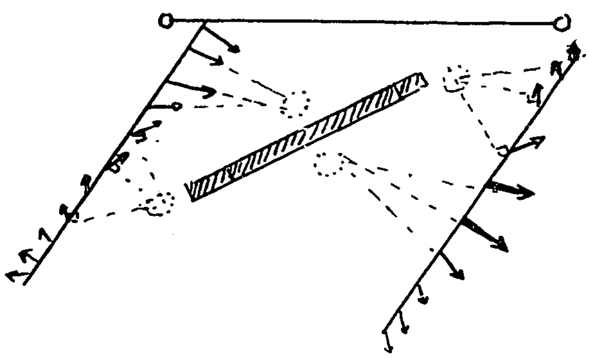


Figure 8.24 Vector plots of disc response.

8.13.4. Vectors

Vector plots are also useful for interpretation (Figure 8.24). The vectors point to positions near the centre of the disc. Perpendicular lines to the vectors near the position of the sign change point to the edges of the disc. The maximum vectors are located at about the middle of the disc.

8.13.5. Interpretation of Axial and Perpendicular Components

Consider the plate shown in Figure 8.25. The interpretation steps are:

1) half-width to determine distance to nearest edge

$$r_1 = 1/2\ m_1.$$
$$r_2 = 1/2\ m_2.$$
$$r_3 = 1/2\ m_3.$$

2) use half-width of perpendicular component to calculate distance to centre of body

3) the dip is obtained from the ratio of a_1/a_2 (works best for 20° to 70°).

N.B. If only the axial component is available, it is possible to determine distance to nearest edge, and dip. The T_x loop can be moved to obtain the position of the body.

8.13.6. Plate - Intersected

The response is positive, symmetrical for a horizontal plate and vertical drillhole, and decays with time. A dipping plate results in an asymmetrical anomaly. If the plate is infinite the response will be positive at all times. A finite plate will result in a sign change as the current ring moves across the borehole.

8.14. PIEZOELECTRIC METHODS

8.14.1. Theory

Piezoelectric bodies convert seismic waves into EM waves which propagate almost instantaneously (Figure 8.26a). These EM waves are received by antennae or electrodes at the surface, amplified, filtered and recorded, usually on a CRO.

Four types of signals are recorded:

(1) Seismoelectrical Effects, E

These are observed in sedimentary rocks and are produced by

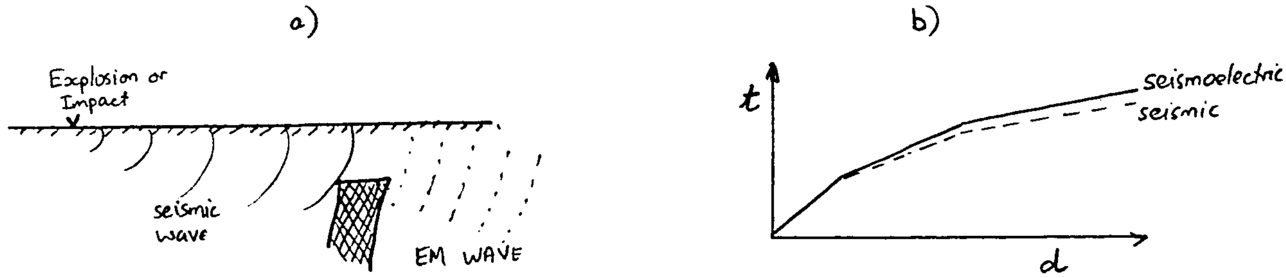


Figure 8.26 Piezoelectric method. a) conversion of seismic waves into piezoelectric EM waves, b) travel-time curves.

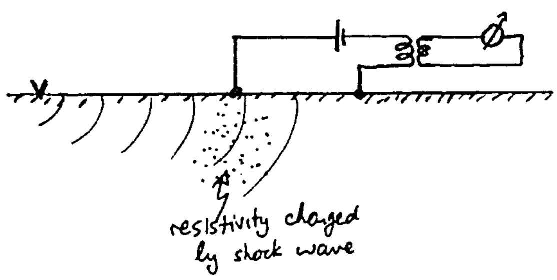


Figure 8.27 Measurement of seismoelectric effect I.

variations in the double electrical layers which exist at a solid-liquid interface. First discovered by Ivanov in 1940 (see Izvestia Acad. Sci., 1940 :- patent No. 58473, 1940), who developed it as a method of prospecting, although the effect was observed much earlier by German and American workers.

This can be used as a auxiliary method to seismic, producing curves as shown in Figure 8.26b. The seismoelectric effect is a "noise" in the piezoelectric method. In 1953 VITR recommended this as a method for routine field use.

(2) Piezoelectric effect

First detected by the Curie brothers in 1880 in France in single crystals. They determined the optical axes and piezoelectric activity of quartz to be 2.3×10^{-12} C/N (Coulomb/Newton) along the X axis.

In 1953 Volarovich & Pakmenko (VITR) detected this effect on the polycrystalline rock samples in the laboratory and also in the field in pegmatite veins. This was the impetus for future work.

(3) Near-explosion effects

These are produced at the time of the explosion and are used as a time marker. They are caused by ionization of gasses and fracturing of rocks. It is best to locate the explosion in a drillhole covered with water, or buried in a pit. This produces a narrow signal. This effect can be found in all rocks and thus is not piezoelectric.

(4) Seismoelectric Effect I (current)

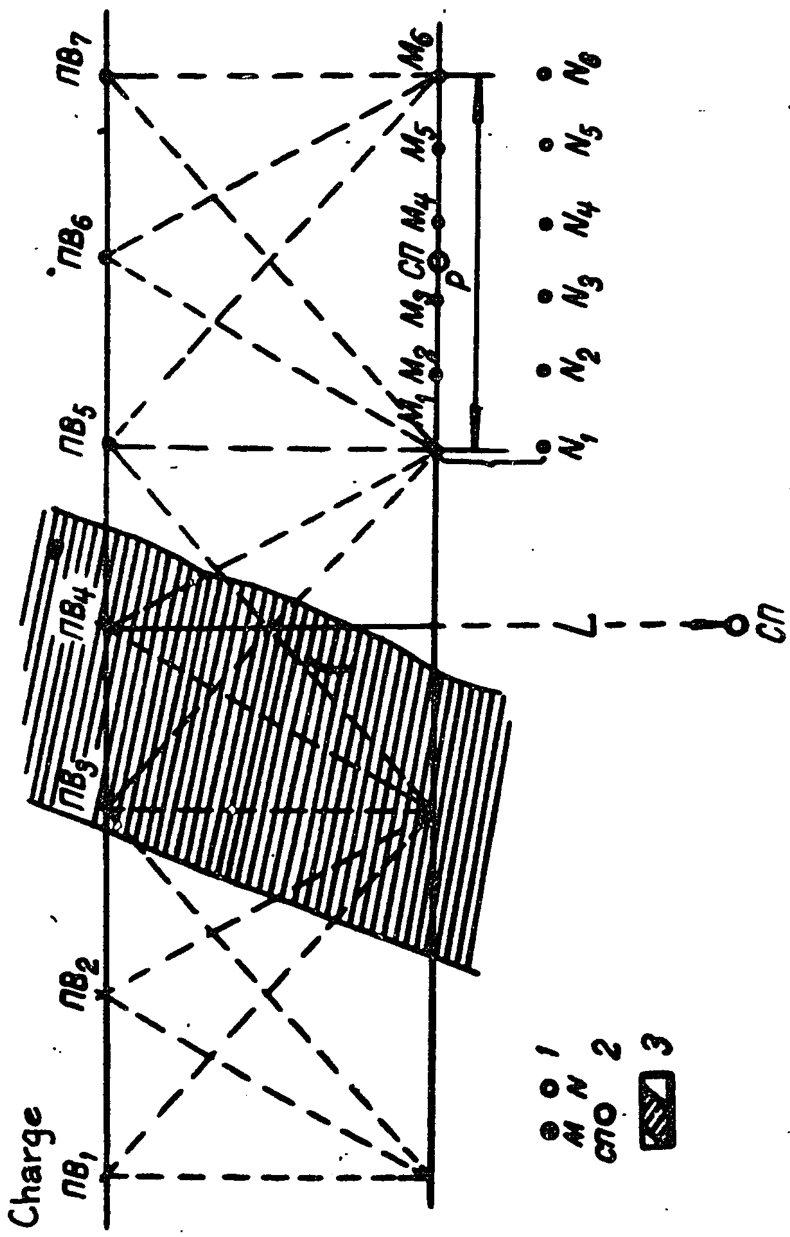
These effects are measured using A.C. devices and occur over sulphides where there are constant electric fields (see early work in Geophysics in 1936 and 1939). A typical setup is shown in Figure 8.27. Sometimes both seismoelectric I or E effects can be obtained over bodies (type (1) & (4)).

8.14.2. Equipment

8S3F-2M apparatus was developed in 1966, and 100 sets have been produced. This is now obsolete.

KVARTS-1 (quartz-1) produced since 1973; 100 sets have been produced. It is commercially available and is mainly used for surface and borehole work. TSNIGRI has developed PAM3-8 for underground mine use.

Figure 8.28 Scheme of piezoelectric profiling. 1: Rx electrodes (piezoelectric channel), 2: seismometer (geophone), 3: quart or pegmatite seam (after Neishtadt, 1970).



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The normal field crew consists of 6 to 7 people (ground variant) and 2 to 3 people for the mine variant.

Measurement

A typical field setup is shown in Figure 8.28. The piezoelectric effect is created simultaneously in all channels. A geophone is used to determine the mean velocity V, and electrodes are used to measure the delay time Δt. The distance, S, to source given by

$$S = V \Delta t.$$

8.14.3. Applications of PE Method

(1) Differentiation of different genetic types of quartz veins, e.g. deep origin gives coarse-grained quartz with high PE activity; a shallow origin results in fine grained quartz with low PE activity. The method works well for this application.

This has application in the search for ore-bearing quartz e.g. Au, Sn, W, Mo, pure quartz.

Note the PE effect is:

(i) volumetric (depends on total volume)

(ii) depends on texture - the more ordered the texture, the higher the PEA (PE activity)

(iii) depends on grainsize - larger grains results in larger PEA. Some very finegrained quartz may have PEA = 0.

(2) Pegmatites with rare-earth minerals, mica.

(3) Polymetallic deposits containing sphalerite.

The scale of PE surveys can be:

Mapping	1:10 000
Prospecting	1:5 000
Mine development	1:2 000

8.14.4 Ground Variant - used for depths less than 10-20 m. Greater depths are impractical because of the influence of overburden. First, the feasibility for a particular deposit needs to be determined. Typical field recordings over bodies with different PE characteristics are shown in figure 8.29. The piezoelectric contrast between ore and host rocks must be greater than 3 or 5. Field data are plotted in the form of profiles.

Laboratory measurements are also used, using equipment such as shown in Figure 8.30. This is a portable laboratory unit. A standard

Figure 8.29 Piezoelectric recordings above bodies with different piezoelectric characteristics. Records 1, 2, 3,: electrodes, 5-7: seismo-receiver (geophone). 8: time-mark (after Neishtadt, 1970).

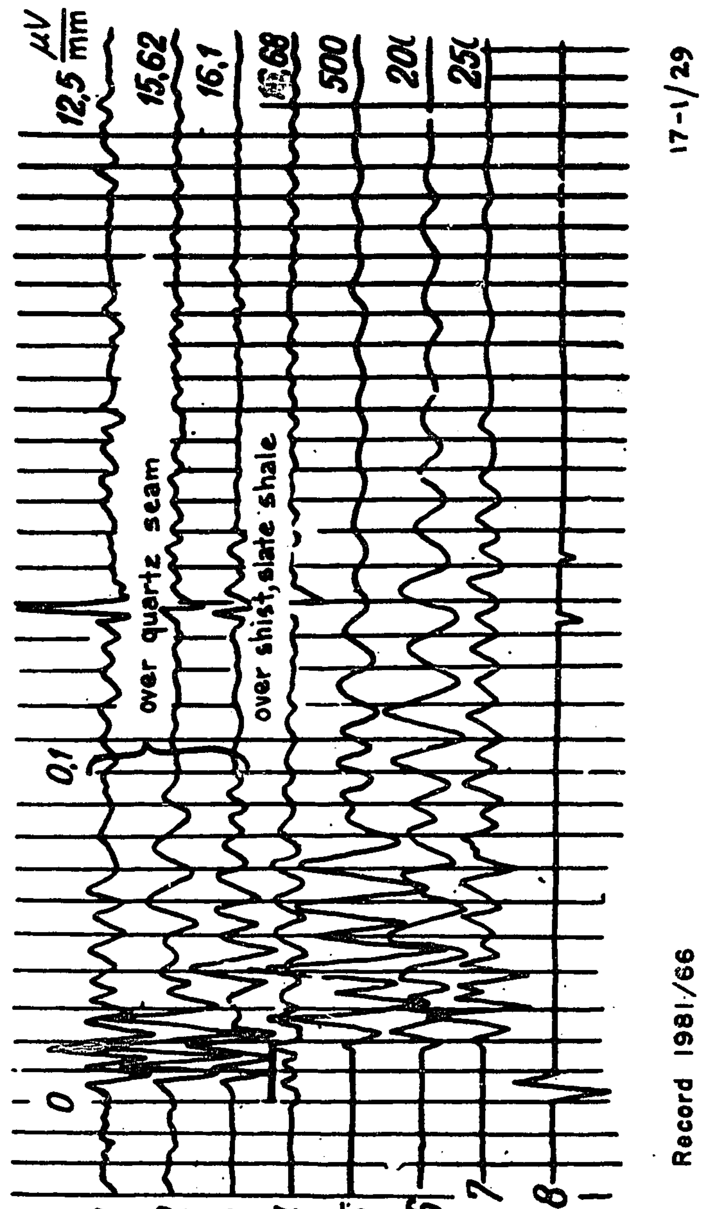
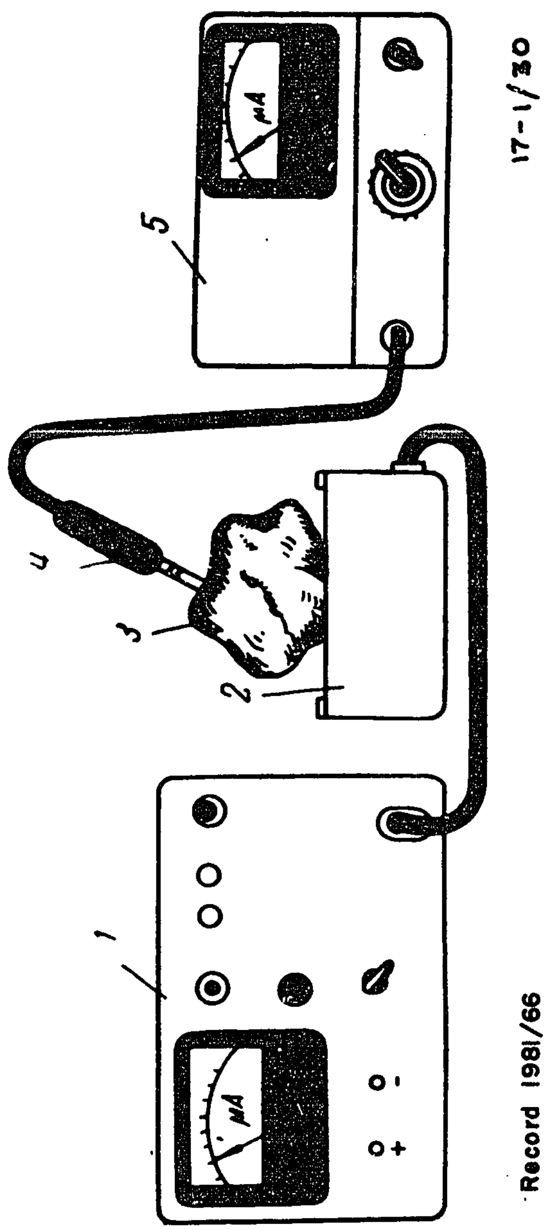


Figure 8.30 Laboratory device for measuring piezoelectric modulus of rock samples (after Neishtadt, 1970), 1: 20 kHz generator, 2: magnetostrictive transmitter, 3: rock sample, 4: probe, 5: amplifier with meter indicator.



is a quartz monocrystal cube with a piezoelectric constant of 2.3 x 10^{-12} C/N. This is used as standard to compare PE in the ore and host, to give the piezomodule (describes texture in each direction).

ARRAYS

(1) Standard array, shown in Figure 8.28. The array usually has about 12 channels (more or less). One geophone is located at the centre. MN is usually 5 to 20 m. Different spacings are used to obtain the most distinct record. The usual spacing is about 15 m - this is associated with the wavelength of elastic waves (one wavelength per width to body).

P is selected so that at least one set of electrodes will be on the target, e.g. if the target is 10 m, use spacing of 5 or 8 m. For mapping this will be greater.

The distance between shots is about 10 m. An optimum signal is obtained when both the shot and Rx are on the body.

d is selected to distinguish, and reduce, the great near-explosion impulse, usually 15 to 20 m.

(2) Longitudinal array (in line): this is uneconomical.

(3) Circular (radial) array. This is useful if the direction of maximum effect is not known, and is used for experimental work.

SOURCES

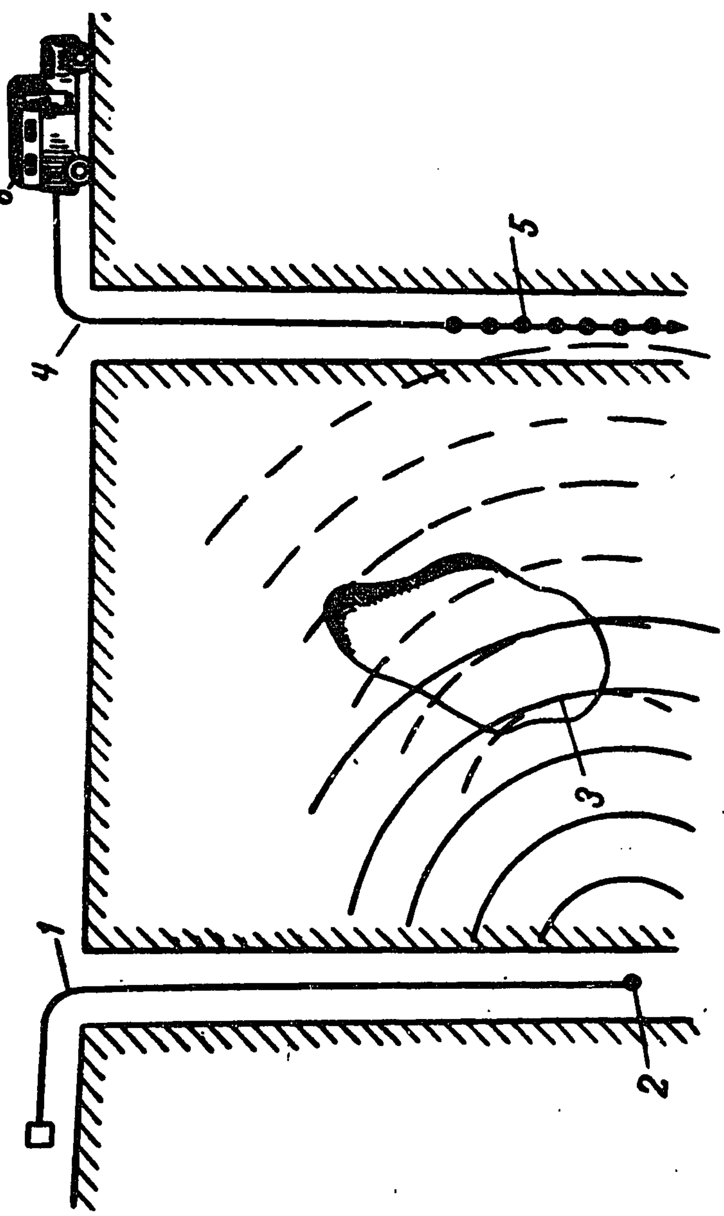
(1) explosive (2 to 3 kg) to result in large signals. Slow electric detonators are used to reduce the big spark (need 0.25 ms to 1 ms). This delay is allowed for in the results.

(2) non-explosive, e.g. weight drop and Dinoseis (not Vibroseis because the frequency is too low). This is a more economical technique and results in high quality, accuracy, and repeatability.
The frequencies of interest are 200 to 1000 Hz.
The range can be increased by using grouped explosives, parallel to the body being sought. This results in a linear wave.

8.14.5. <u>Borehole Variant</u>

This variant can be used for 2 or more boreholes. The range is about 100 m. The normal field setup is as shown in Figure 8.31, and profiles are measured down the hole. If the body is isometric (equi-dimensional), the shot can be fixed in the central hole, into the

Figure 8.31 Scheme of downhole piezoelectric observation. 1: cable, 2: charge, 3: body, 4: Rx cable, 5: train of Rx electrodes and seismometer, 6: seismoelectrical unit, (after Neishtadt, 1970).



orebody, the measurements made in surrounding holes.

Interpretation

The centre channel is defined as the one with the earliest arrivals. In the borehole there is an electrokinetic effect, created on the boundary of the wall of the borehole and the drilling mud near the electrodes. This effect can be used for seismic effect (may not need to use geophones). For the PE method, this effect is often an interference.

Usually, the region before the electrokinetic effect occurs is analysed. This avoids confusing the signals. Experience is very important.

8.14.6 Mine Variant

The shots are located in mine shafts using directional explosives, or in drill holes. The range is about 100 m. The configurations are similar to traverse profiling.

Interpretation

Interpretation includes one-layered and two-layered interpretation, and distance to PE body. The dip and strike can also be estimated.

8.14.7 Field Examples

(1) Figure 8.32 shows the seismoelectric amplitude (in μV) measured over a quartz seam covered by a few metres of overburden.
(2) Isometric pegmatite deposit in the North Ukraine. Results in Figure 8.33 show the success of delineating the body. The borehole variant was used because of the presence of thick friable overburden.
(3) Pegmatite bodies in North Karelia; Figure 8.34. In these displays the ratio of the amplitudes of the PE signal/seismic signal has been plotted. This allows the elimination of variations in the intensity of the explosion.
(4) Pegmatite body in North Ukraine. The results shown in Figure 8.35 were obtained with the borehole variant, and enabled determination of the boundaries of the deposit.

Figure 8.32 Amplitude graph of the seismoelectric effect. 1: alluvium, 2: quartz sericite beds, 3: green beds, 4: vein quartz, 5: quartzite (after Neishtadt, 1970).

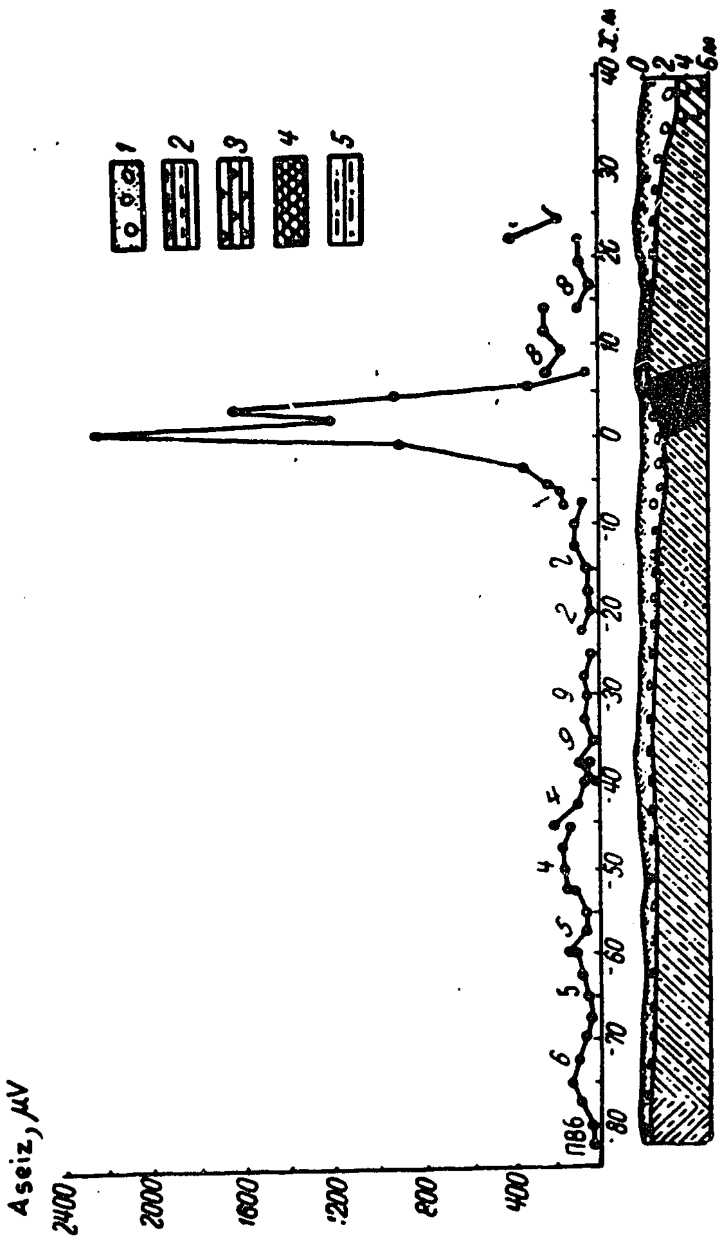


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Figure 8.33 Determination of position of pegmatite deposits in North Ukraine ores, using borehole piezoelectric method, plan view. 1: contour of feldspar and graphitic zone, 2: pegmatite zone and quartz core, 3: position of pegmatite body inferred from piezoelectric method (after Neishtadt, 1970).

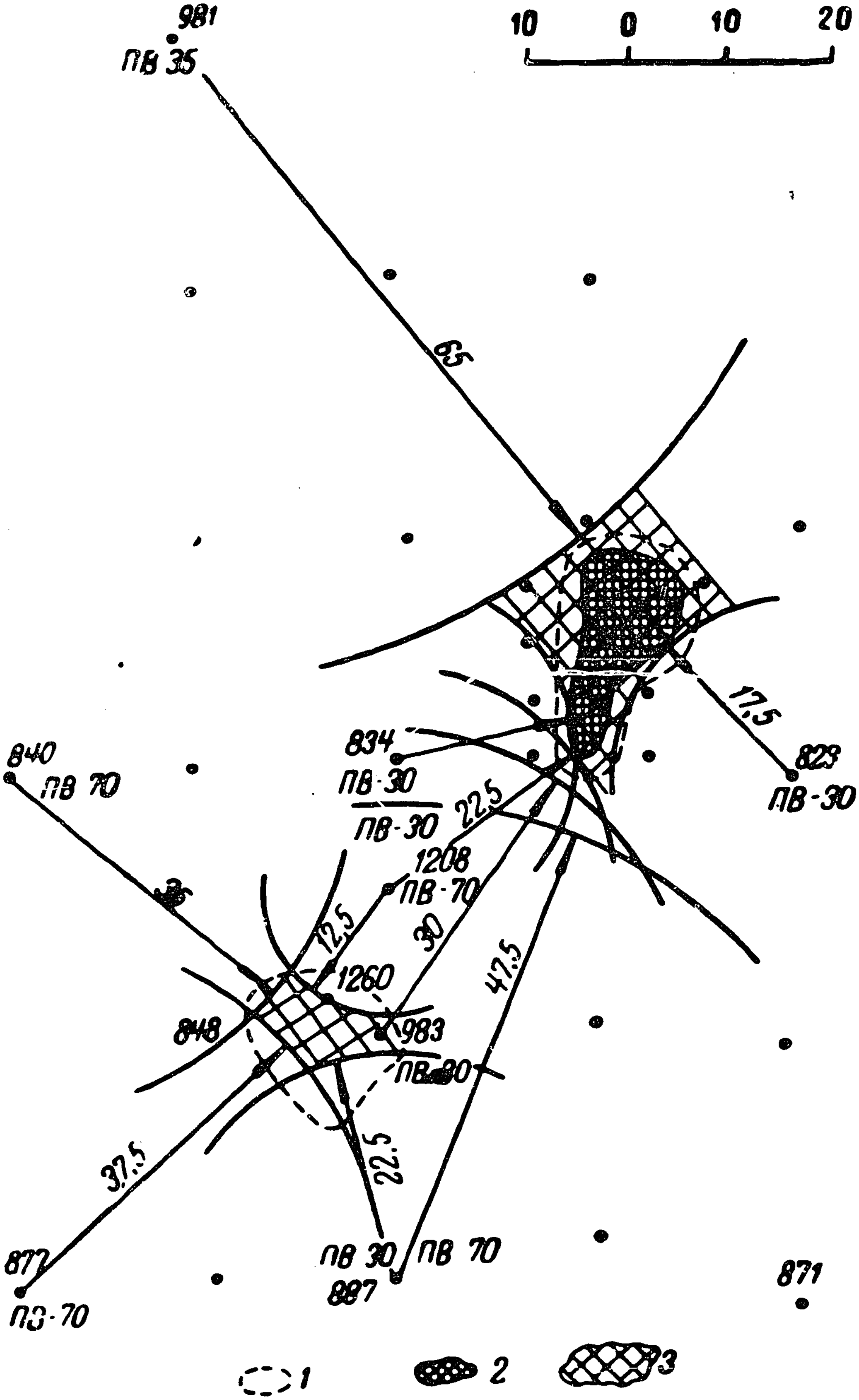


Figure 8.34 Profiles of ratio of piezoelectric/seismic amplitudes from North Karelia. 1: Quaternary deposits, 2: pegmatite seams, 3: gabbro-norites, 4: amphibolite, 5: pegmatite seam with quartz core (after Neishtadt, 1970).

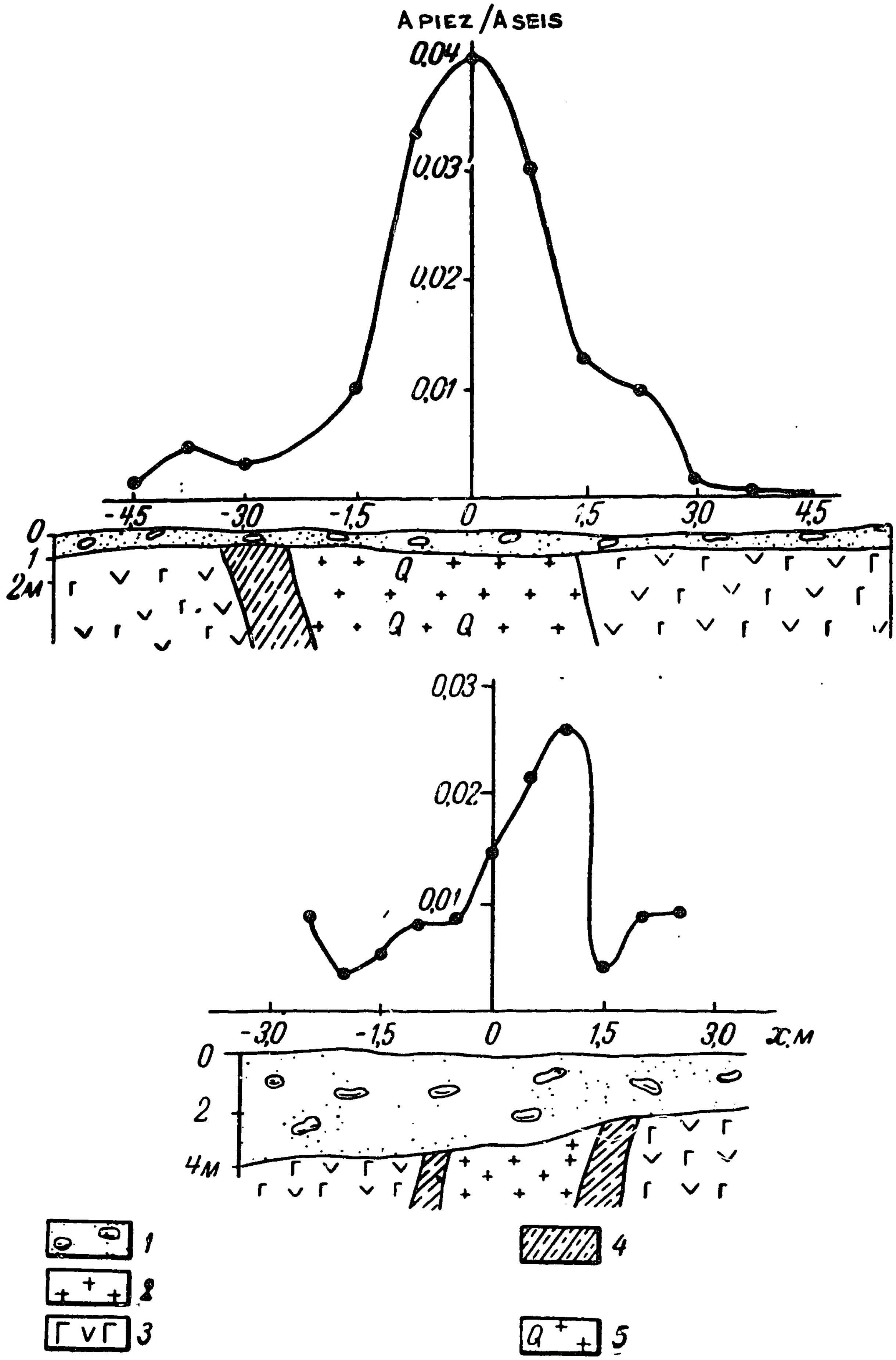
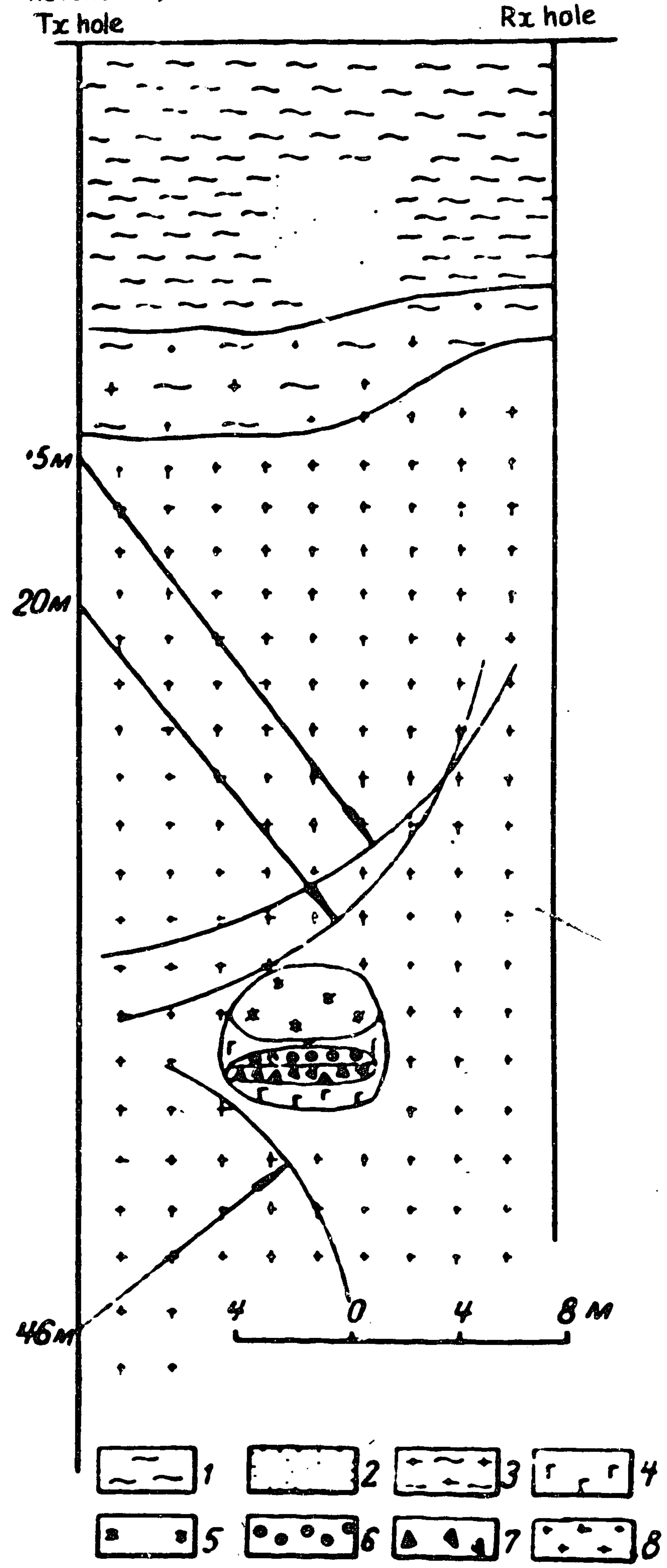


Figure 8.35 Determination of the position of a pegmatite body of isometric form using the borehole PE method, North Ukraine ores. 1: sandy loam, 2: sandy soil, 3: in-situ kaolinization on granite, 4: graphitic zone, 5: pegmatite, 6: grey quartz, 7: smokey quartz, 8: granite (after Neishtadt, 1970).



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8.15 CHIM (PARTIAL EXTRACTION OF METALS)

8.15.1. Theory

This is an electrochemical method. Under the application of current, water-soluble components are extracted from soil or rock, and later analysed with a polarographic unit. (Note that XRF or Atomic Absorption would be better methods). The elements Cu, Pb and Fe are analysed to 0.01 µg/ml, and Au to 0.003 µg/ml.

Since the water-soluble phase only is extracted, the method is very sensitive to sources of mineralisation such as orebodies and mineralised water.

A diagram of the receiving element is shown in Figure 8.36. The membrane is made of "pergamon" (organic), or a thin film (sausage wrap).

8.15.2 Variants

(1) HALO CHIM

This is designed for searching for polymetallic and gold ores covered by loose overburden up to 200 m thick. It is used when geochemistry sampling fails owing to thick overburden (Note - geochemical sampling = "metallometric").

The field arrangement is shown in Figure 8.37. The current is normally 1 to 2 amps per electrode, and up to 40 electrodes are used. A volume of 1 m^3 of soil (rock) is sampled.

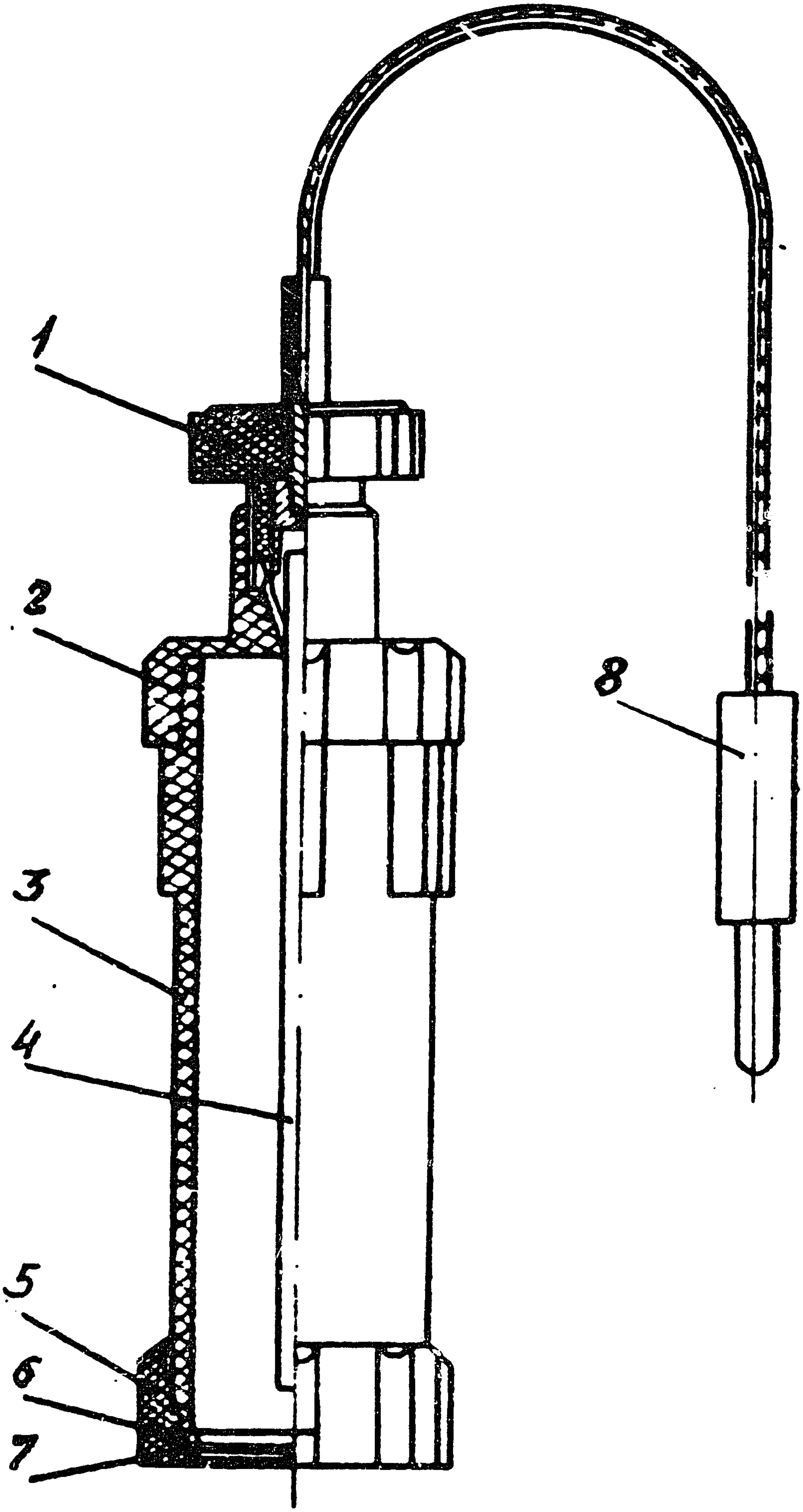
Field Example

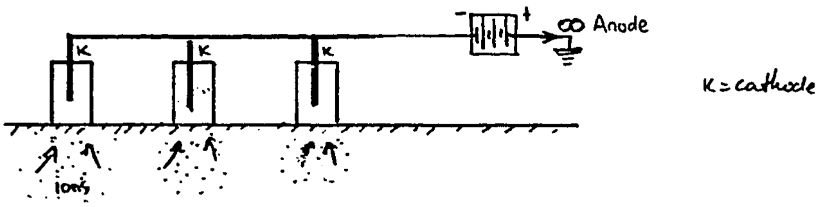
(a) Polymetallic ores have been detected at depths up to 200 m under loose overburden. An example of deep detection is shown in Figure 8.38, where anomalous Pb and Cu values are plotted. In one area a polymetallic body was detected 400 m under a 150 m thick layer of overburden (probably influenced by circulating solutions).

(2) CHIM LOGGING

This is used in conditions of poor core recovery. The setup is shown in Figure 8.39. The receiving element is moved with a 2 m spacing or an array of receiver elements can be used. An anodic reaction occurs on the ore:

Figure 8.36 Receiver element for CHIM surface exploration. 1: contact, 2: cap, 3: cylinder, 4: Ti electrode, 5: nut, 6: seal, 7: membrane, 8: single-hole plug (after Gol'dberg et al, 1978·





(Figure 8.37 Halo CHIM. The setup shown has an auxiliary earth. The anode can also be earthed on the receiver element case.

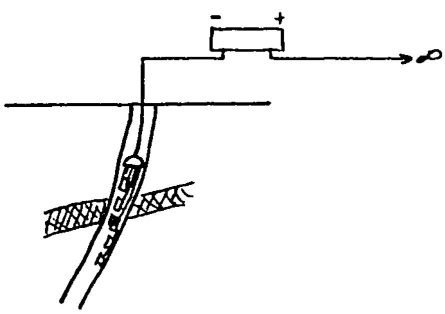


Figure 8.39 CHIM logging device.

Figure 8.38 CHIM profiles of Pb and Cu above a polymetallic ore.

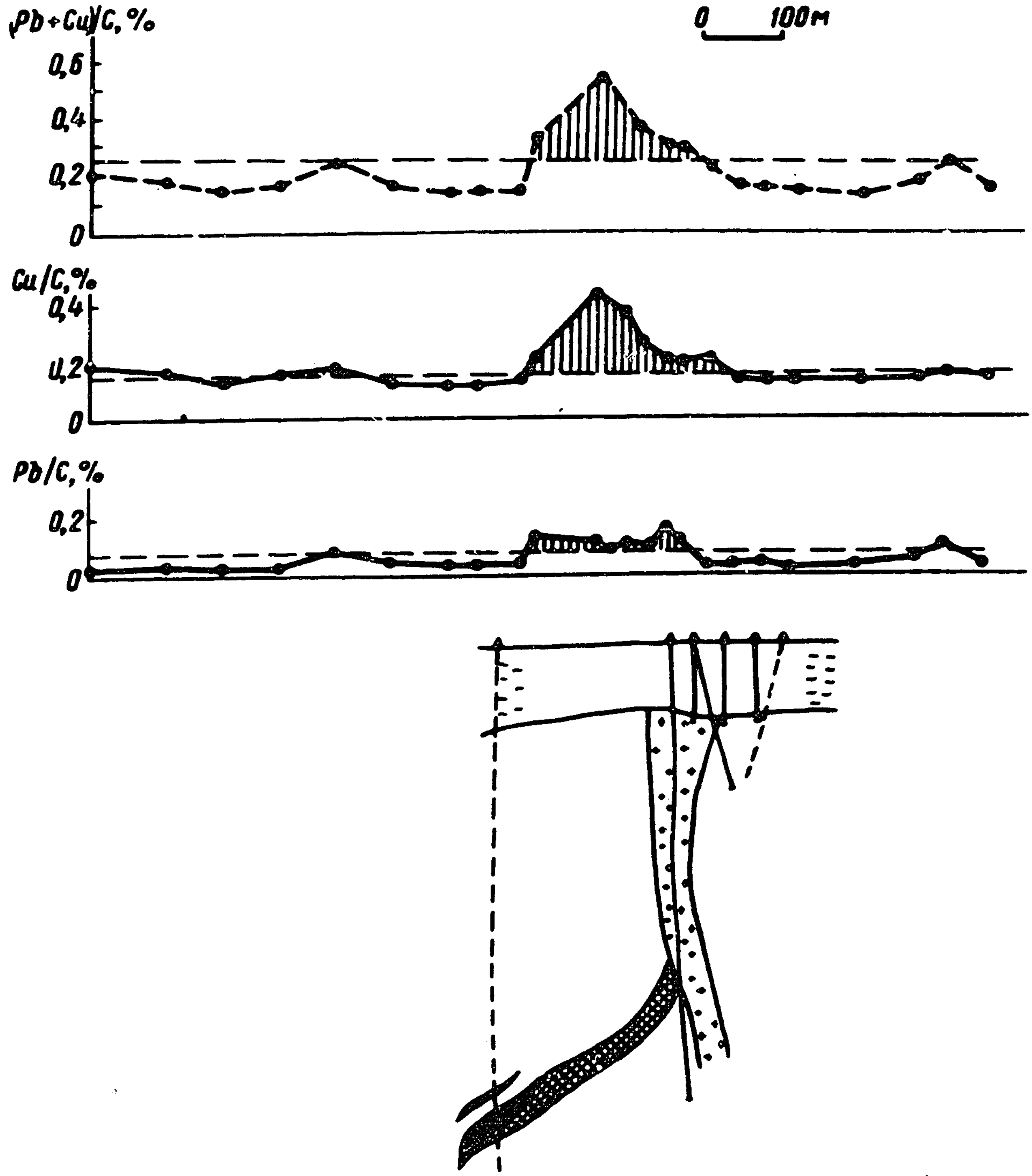


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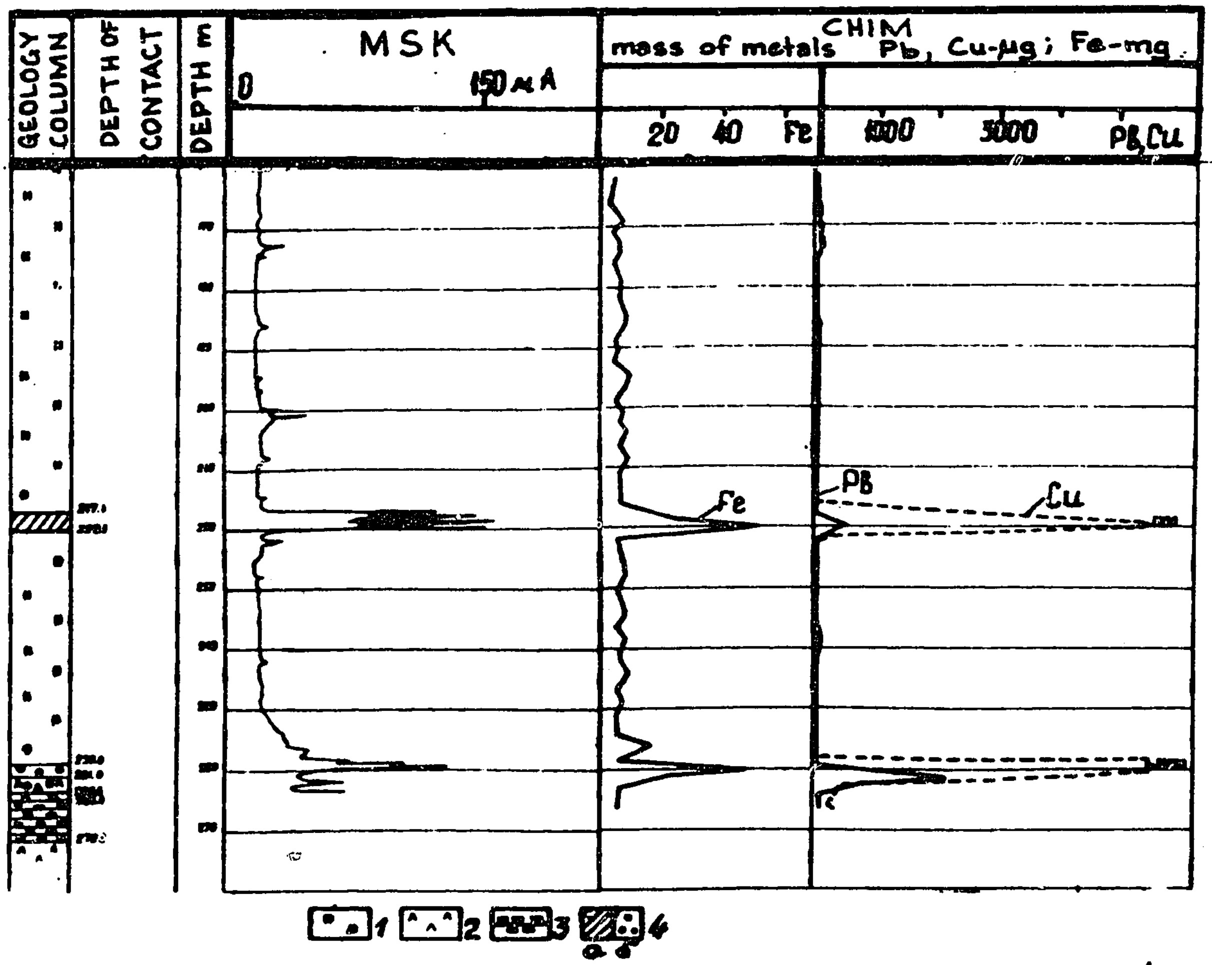
Figure 8.40 CHIM logging results. Both the resistance and CHIM logs give a strong anomaly over the pyrite-polymetallic ore zones. 1: quartz, albite, 2: diorite, 3: siltstone, 4: pyritic polymetallic ore, a: veinlike, b: disseminated (after Gol'dberg et al, 1978).



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10-60

$$MS \rightarrow M^{2+} + S^{\circ} + 2e$$

The metal (M) is deposited on the rocks.

8.15.3. Field Example

CHIM logging results from a pyrite-polymetallic deposit are shown in Figure 8.40. Receiver elements are analysed for Fe, Pb and Cu using a polarographic unit.

8.16 K S P K (Contact Technique of Polarisation Curves)

KSPK has been widely used since 1972, in the Far East, Khazakstan, Middle Asia, Caucuses, North Altai (Pechenga Cu Ni) & Urals, east Siberia (Baikal Amur railroad), and is now also used in Bulgaria.

8.16.1. Theory

(1) Sulphide and other minerals are electronic conductors and thus can be used as electrodes, and have electrochemical reactions on their surface when in contact with an electrolyte.

The charge curve contains steps which are caused by electrochemical processes; these may be cathodic or anodic.

Cathodic Reactions

Cathodic reations involve:

1) recovery of oxygen

$$O_2 + H^+ + ne^- \longrightarrow \begin{matrix} (OH^-) \\ (H_2O_2) \\ (H_2O) \end{matrix}$$ depending on pH of solution

2) decomposition of mineral

$$Me\,S + ne^- \rightarrow Me^{\circ} + S^{2-}.$$

i.e. metal (Me is recovered)

3) recovery of hydrogen

$$2H^+ + 2e^- \rightarrow H_2$$

Can also have ions in solution which change the potential of the solution. These are called "potential determinants", e.g. Cu^{2+}, Fe^{2+}, Fe^{3+}, and Mg^{2+}.

e.g. $Cu^{2+} + 2e^- \longrightarrow Cu$

$Fe^{3+} + e^- \longrightarrow Fe^{2+}$.

In the first example, Cu is the potential determinant and forms Cu metal. In the second example an ion with a different valency is formed.

Anodic Reactions

1) oxidation, decomposition

$$\left.\begin{array}{l} MeS \rightarrow Me^{2+} + S^{\circ} \\ S^{\circ} \rightarrow S_2O_3^{2-} \\ S_2O_3^{2-} \rightarrow SO_4^{2-} \end{array}\right) \text{ depending on strength of current}$$

The effect of water is not seen in practice because of the high potentials.

N.B. The orebody has electronic conductivity and the host has ionic conductivity. The conversion (current flow) involves the electrochemical reactions $\Delta\phi$, of each particular mineral.

$\Delta\phi$ in practice depends on total charge Q and not I.

2) Different sulphide minerals at different potentials can have all these reactions, but cathodic 2) is especially common. e.g. the of common minerals is:

Pyrite	0.6 V
Cpy	0.3 V
Galena	0.8 V
Sphalerite	1.1 V (approx.).

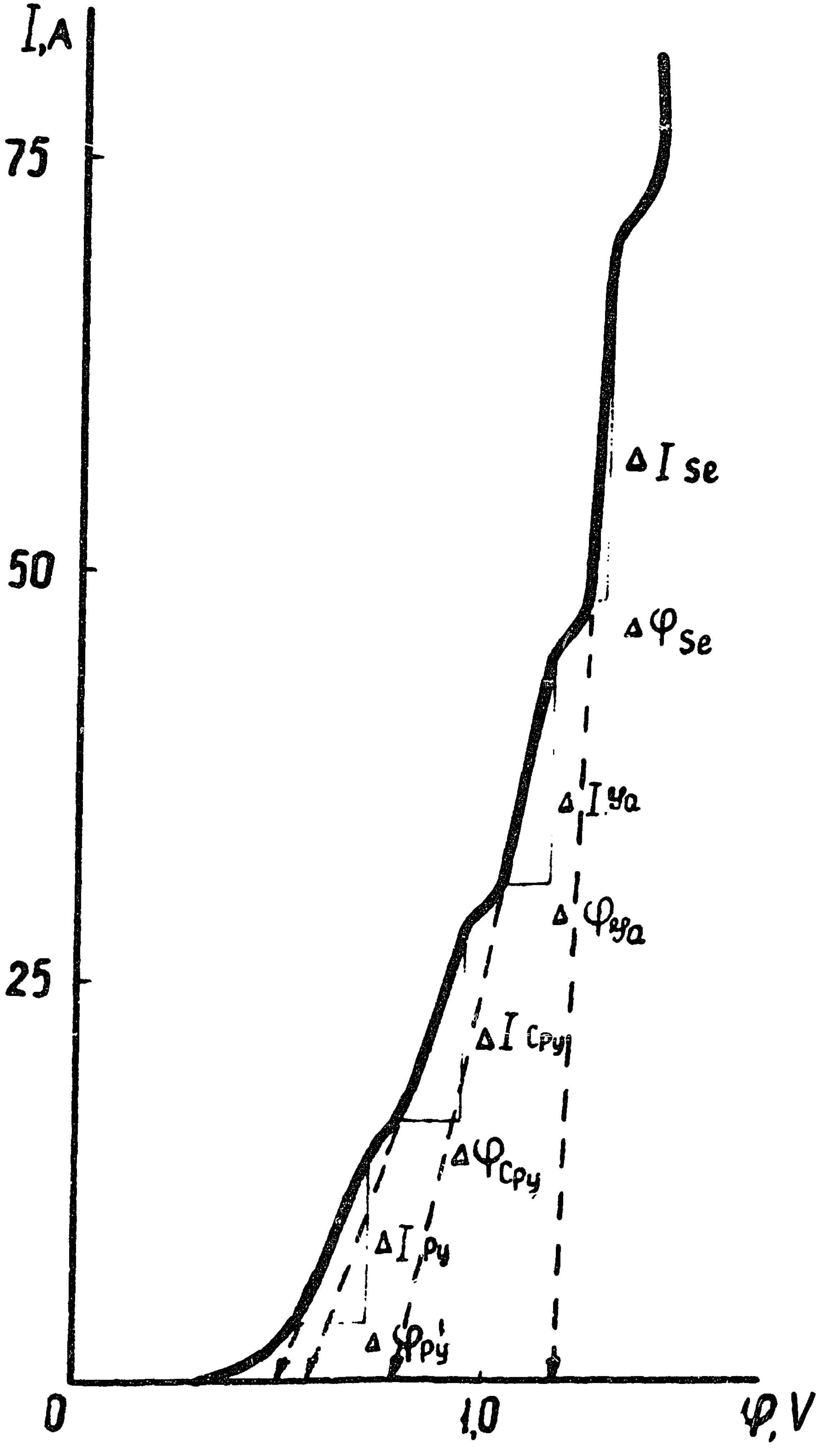
In practice, the relation between strength of current and potential is used.

The reaction potentials are obtained from the polarisation curve, as shown in Figure 8.41.

3) The relative percentage of various minerals controls the amount of current, ΔI, needed to produce the next step. If we sum the reactions, $\Sigma\Delta I$, the total size of the orebody can be derived.

Minerals. Minerals that can be determined include Py, Cpy, Chalcocite, Ga, Sphal., Pentlandite, Pyrrhotite ($Fe_{n-1}S_n$), and magnetite.

Figure 8.41 KSPK polarization curve showing ΔI and $\Delta\phi$(compensation) for various reactions (after Ryss et al., 1978).



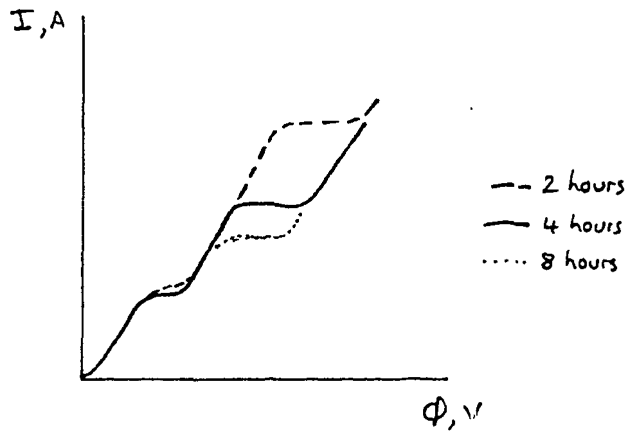


Figure 8.42 Effect of different rates of curr nt application in KSPK.

Rate of Polarisation

The effect of different rates of current application is shown in Figure 8.42. The important parameter is Q, and not current, where Q = IT (total charge). Each reaction must take part over the whole of the body before the next stage can occur. At later stages, the earlier ones are still going on.

For a body 10-15 m in size, KSPK measurement usually takes about 1 hour; for a body 500 m in size it takes about 1-2 days. If more current is used, less time is needed.

8.16.2. Variants

There are three variants of the KSPK method that can be used (Figure 8.43).

(a) Basic variant. The surface electrode is located away from the S-P anomaly.

(b) Interconnecting variant.

(c) Searching variant. This is used to locate the body and to find areas of different mineralisation.

8.16.3. Equipment

KSPK - 1

This is a one electrode system used in mode a) or possibly b). The current is up to 200A.

3-5 units are produced each year. This is insufficient to meet demands. 12 units have been built so far.

The system consists of 3 5-ton trucks:

a) Transmitter with 230 V, 400 Hz, 30 kW AC generator with rectifier;

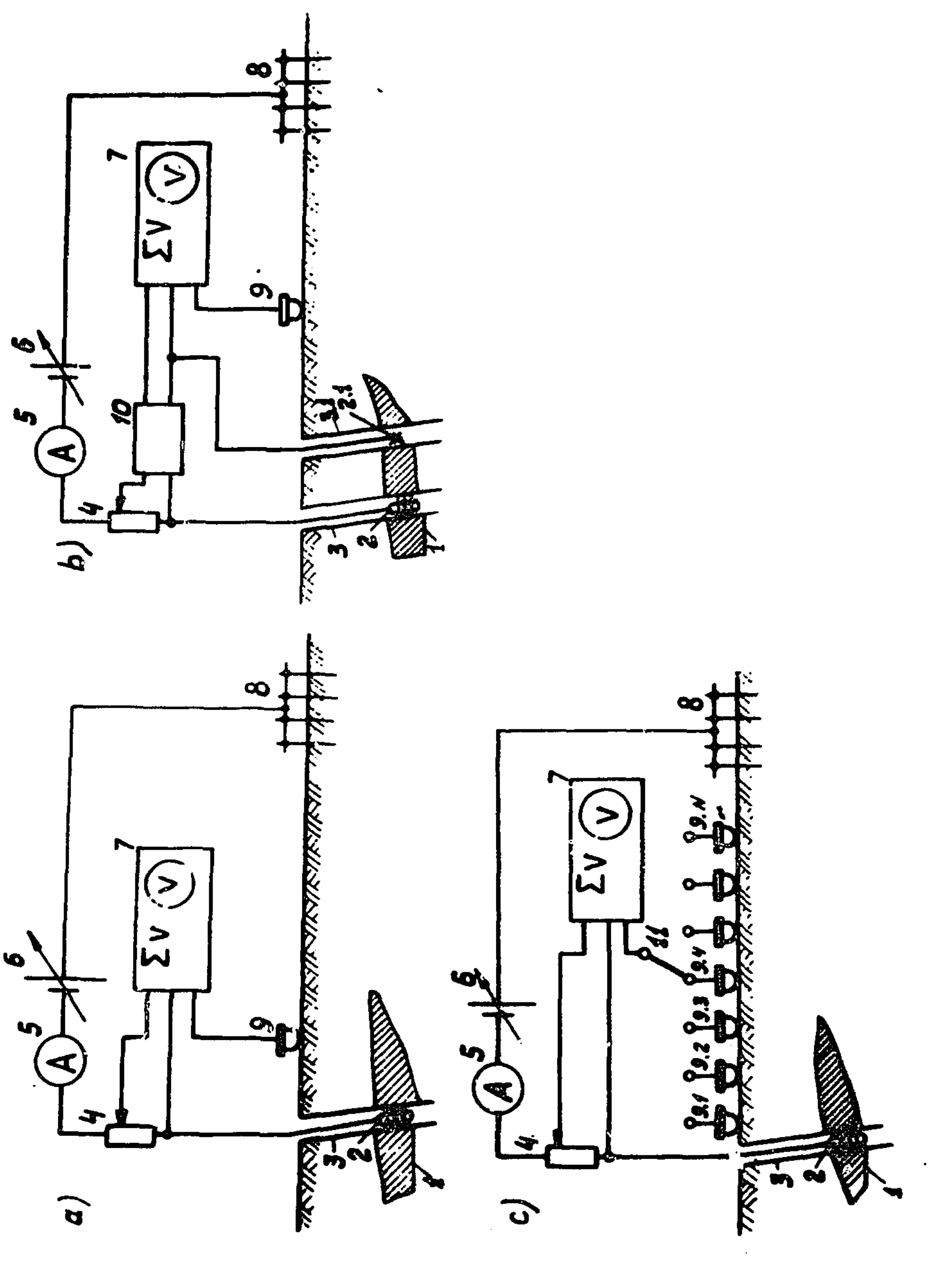
b) cable winch truck (1000 m)

c) control truck.

SPK

12 channel system for c) variant. It also can be used in variants a and b, or as a surface method. This is more modern than the KSPK, and will be commercially available in 1-2 years. In b) variant, up to 4 boreholes can be used simultaneously. The current is up to 160 A, using a 30 kW generator.

Figure 8.43 Variants of KSPK field arrangement (a) basic variant, (b) inter-connecting variant, (c) searching variant. 1: orebody, 2: hole with transmitting electrode, 2.1: receiving electrode, 3: main hole, 3.1: connecting hole, 4: compensating resistor, 5: ammeter, 6: continuous current source, 7: voltmeter, 8: auxiliary replacement transmitter, 9: non-polarizing receiving electrodes, 10: galvanic isolator connection, 11: switch-over. (from Ryss et al, 1978.



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8.16.4. Applications

I. Polymetallic, Cu-Ni, and Py-Cpy deposits. The most favourable conditions are large massive orebodies (100 to 300 m in size) with massive texture, i.e. good conductors. KSPK will give

- mineral composition
- concentration of individual minerals, and
- reserves of total minerals (proportional to total charge)

II. To determine whether intersected zones are connected (Figure 8.44). By "method-of-charge" or IP, the zone of conductivity is defined (σ_1 and σ_2). KSPK enables the differention of the zones. There are two methods for this:

1) polarisation curve measured in each hole. If the ore zones are one body the curves will be identical.
2) a faster technique is to locate the Tx and Rx in the ore in both holes. A polarisation curve will only be measured if there is connection of the zones (Figure 8.44b).

An exception is the example showin in Figure 8.45. KSPK responded to the total deposit because of the highly conductive graphite.

Further Applications. In mines, and also for exploratory mine boreholes.

The method reduced drilling by a factor of 10. In favourable conditions, irrespective of the size of the body, it is sufficient to have 5 to 7 ore intersections and KSPK. (cf. normal drill grid of 50 or 100 m). Even in unfavourable conditions is better to use KSPK than not use it.

8.16.5. Field Procedure

The simplest field setup is shown in Figure 8.46. The transmitter uses one electrode on the surface and one in contact with the body. Contact is made with the aid of an array of radiating steel wires. The current I is increased gradually and ΔV is measured. In the system shown the ohmic component is included and this will mask other minor changes in potential. Thus a special system of compensation is employed, as described later. Normally the surface Rx electrode is located away from the S-P anomaly, and far from the Tx electrode.

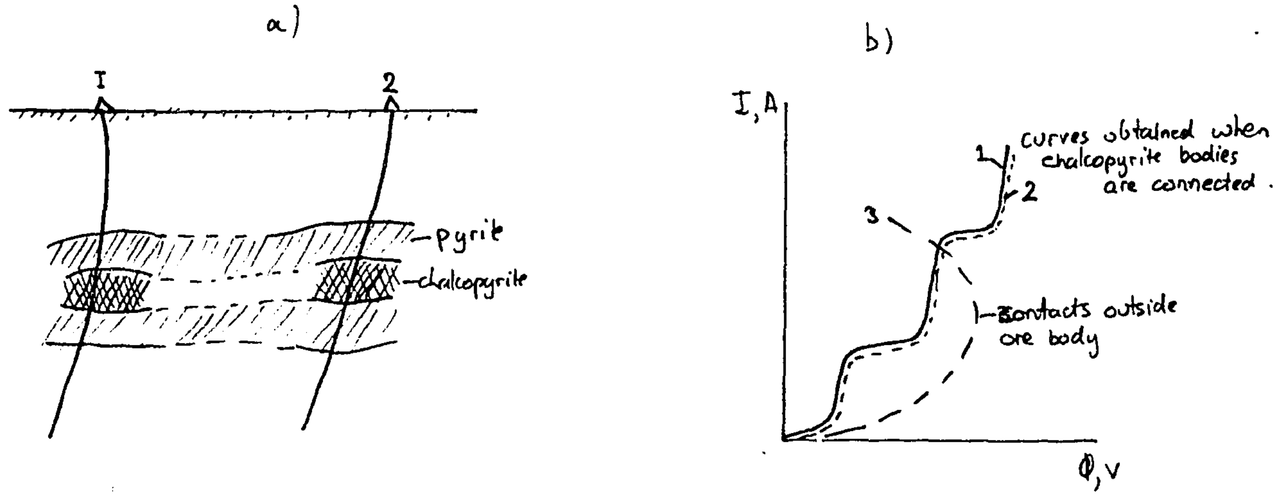

Figure 8.44 Determination of connection of ore zones. a) geological section, b) polarization curves.

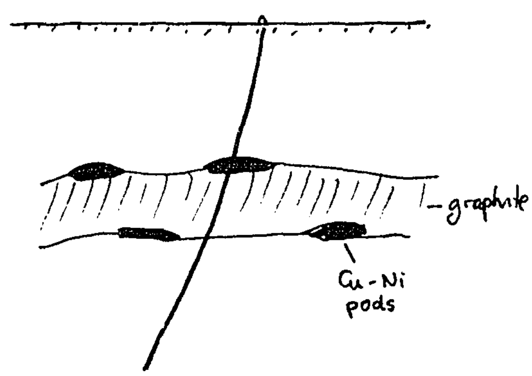

Figure 8.45 Field example where KSPK responded to total deposit and not the individual pods.

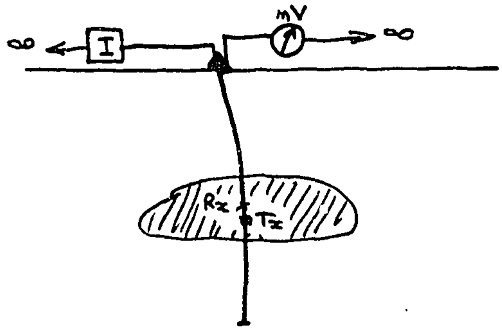

Figure 8.46 KSPK basic field setup. In this arrangement ohmic components will mask other changes.

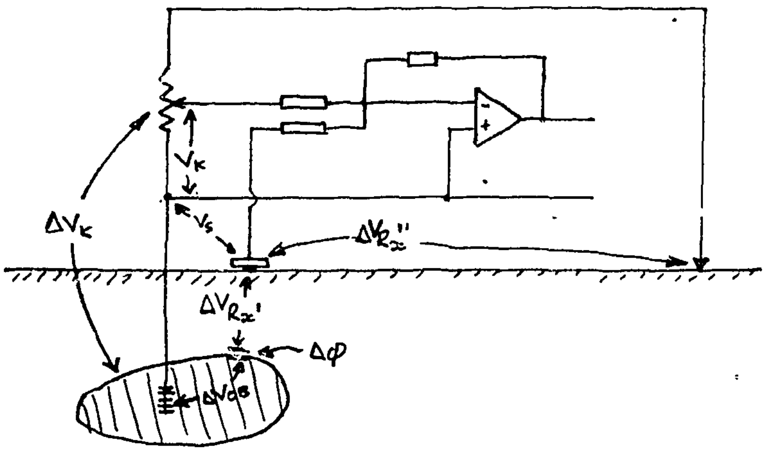

Figure 8.47 KSPK compensation arrangement.

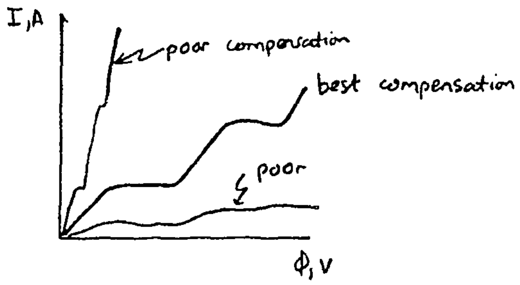

Figure 8.48 Examples of poor and good compensation.

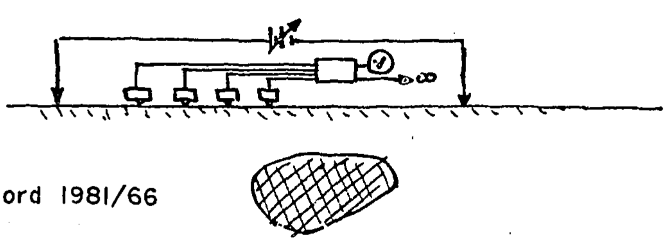

Figure 8.49 Surface variant of SPK.

8.16.6. Unfavourable Conditions

1) Disseminated ores. Anodic and cathodic reactions take place on opposite sides of grains.
2) non-equipotential area, i.e. those with high resistivity regions, such as ones with a large component of non-ferrous sphalerite.

In these conditions the total polarisation curve gives anodic + cathodic reactions, with no potential steps, as with curve 3 in Figure 8.44. The total size and sulphide reserves can be determined but not the individual minerals.

8.16.7. COMPENSATION

A block diagram of the compensation scheme is shown in Figure 8.47. The aim is to determine the electrochemical reaction $\Delta\phi$. and cancel normal ohmic processes $\Delta V\Omega$ by use of compensation factor K.

Let
$$\Delta V_{\Omega} = \Delta V_{K} + \Delta V_{OB} + \Delta V_{RX'}$$

$$\Delta V_{K} \cdot K = \Delta V_{\Omega}$$

where the subscripts S and OB stand for signal and orebody respectively.

Now
$$V_{S} = \Delta V_{K} + \Delta V_{OB} + \Delta V_{Rx'} + \Delta\Phi$$

$$= \Delta V_{\Omega} + \Delta\Phi$$

The field procedure consists of measuring the initial part of the curve and varying V_K until the shape corresponds to a theoretical curve. This procedure is difficult and takes much experience (2-3 years !!). If the compensation is incorrect, curves such as shown in Figure 8.48 will be obtained. Note that the method is subject to electrical interference.

8.16.8. KSP

KSP is a new development of the surface variant which is being tested with the arrangement shown in Figure 8.49. This presently uses 20 to 30 A but this current will have to be increased by 1 order of magnitude. 200A may be sufficient for small bodies at depths less than 150 m. The variant will be the record sum of anodic + cathodic processes.

MACHINOEXPORT

A summary of the discussions on commercial equipment is:

1) The MPPO-1 is no longer being produced.
2) The MPP-3 is available, but is not being bought in Australia (still having enquiries for MPPO-1).
3) The MPP4 not yet available.
4) IP equipment: VPR-70 portable IP unit, and also a larger vehicle mounted one is available.
5) TSIKL, IMPULSE - not yet commercially available. Needs special tests, etc, and the Minister has yet to decide whether the equipment will be made available commercially.
6) KSPK-1 - patented in all major countries (US, Canada). In principle it could be bought without trucks but will need to do careful calculations on cost because of special packing etc. Also, it may be possible to use western-bought generator and winch.

APPENDIX 3

PROTOCOL

on visit of Australian specialist from the Bureau of Mineral Resources, Geology and Geophysics (BMR) to the Siberian Scientific Institute of Geology, Geophysics and Mineral Resources (SNIIGG&MS).

Novosibirsk 17.10.79

In accordance with the programme on scientific and technological cooperation between the USSR and Australia from the 3rd to the 17th of October, 1979, at SNIIGG&MS consultations were held for B.R.Spies, Australian geophysicist, on the theme "Improvement of methods and techniques of electromagnetic and electric prospecting".

The SNIIGG&MS personnel participating in the consultations were:

1. Prikhoda A.G. - Head of the apparatus department;
2. Rempel G.G. - Head of the department of ore geophysics;
3. Kunin D.I. - Head of the section (laboratory) of electric prospecting instrumentation;
4. Isaev G.A. - Head of the section (laboratory) of electric ore prospecting;
5. Rabinovich B.I. - Head of the section (laboratory) of oil electric prospecting.

Leading specialists of these departments took part in these talks as well.

During the consultations specialists of SNIIGG&MS acquainted B.R.Spies with their methods of investigation in the field of structural and electric ore prospecting making use of the techniques ZSB and MPP as well as electric prospecting instrumentation "Tsikl-2", "Impulse-II" and cryogenic magnetometer "Kriom" (with their demonstration).

In his turn B.R.Spies acquainted the specialists of SNIIGG&MS with the results of the research carried out by Australian scientists in the field of electromagnetic prospecting of mineral resources.

To achieve these goals B.R.Spies, BMR specialist, proposed:

a) A Soviet-Australian EM workshop be held with the aim of increasing the mutual understanding of the applications, limitations and research into EM in the two countries. This would include comparison of data, discussion of the state-of-the-art in instrumentation and modelling, and discussion of future directions of research.

To this end, it is suggested that an EM workshop be held in Canberra in 1980, involving 5 specialists from each country. The Australian contingent would include scientists from the BMR, CSIRO and Macquare University.

At the same time, it would be highly desirable to compare Soviet instrumentation (Tsikl, Impulse, MPP-3, MPP-4 for example) with those used in Australia. Field tests could be conducted over several Australian ore deposits and in sedimentary provinces.

b) A further exchange of scientists between the two countries in order to exchange information, to conduct joint experiments and theoretical investigations. Specific areas of interest include transient electromagnetic (MPP and ZSB), induced polarization, magnetotellurics and EM modelling (both mathematical and analogue).

Participants at these talks confirmed the significance of mutual exchange of scientific information.

B.R. Spies,
Specialist of the
Australian Bureau
of Mineral Resources,
Geology and Geophysics

A.G. Prikhoda,
Head of the apparatus
department, SNIIGG&MS
G.G. Rempel,
Head of the department
of ore geophysics,
SNIIGG&MS

APPENDIX 4

LIST OF SCIENTISTS - THEIR INSTITUTIONS AND SPECIALITIES

ANTONOV, Yuri N. - I.G.G., Novosibirsk. Head of EM laboratory. Specialist in EM logging.

BERDICHEVSKIY, M.N. - Moscow State University. Specialist in MT.

BEZRUK, I.A. - VNII Geofizika. Specialist in MT, oil exploration.

BGATOV, Vasilii I. - SNIIGGIMS. Assistant Director (Science), specialty is resource assessment, ferrous and non-ferrous metals and other minerals.

BORAKOV, Alexander - VITR. Specialist in TEM variants, incl. downhole (eg MPP-4).

BRONSKY, Vjacheslav. - VITR. Specialist in interpretation of surface and downhole TEM.

CHERNJAVSKIY, George - VNII Geofizika. Specialist in MT.

CULIKOV (KULIKOV), Alexander - VNII Geofizika. Specialist in phase-frequency IP method.

DAVESHKIY, Yuliy - I.G.G., Specialist in MEL technique. Currently writing Ph.D. dissertation on determination of anisotropy using MEL (magneto electro logging). Holds patent jointly with Tabarovskiy. Speaks English.

DOBROCHOTOVA, Alexandrovina Trina - MGRI. Specialist in induction methods, incl. LFIM.

EPOV, Mikhail (Misha) R. - I.G.G., Specialist in induction logging techniques. Speaks English.

FAINBERG, Edward B. - IZMIRAN. Specialist in solid earth geophysics.

FILATOV, Vladimir - SNIIGGIMS. Working with ISAEV on TEM theory, esp. downward continuation.

FOKIN (PHOKIN), Anatoly Ph. - VITR. Assistant Director, candidate of technical science.

GITARTS, Yan - SNIIGGIMS. Specialist in superconducting devices; writing Ph.D. dissertation on SQUIDS.

ISAEV, Gennadii A - SNIIGGIMS. Specialty is TEM applications in ore geophysical prospecting, theoretician.

ITSKOVICH, Grisha - SNIIGGIMS. Working with ISAEV on TEM theory.

KAMENETSKII, Felix M. - MGRI. Specialist in TEM, ground and airborne, speaks excellent English.

KOMAROV, V.A. - NPO - Geofizika. Specialist in IP and electrical phenomena in the ground.

KOZLOV, Ergenil Alexscevich. - VNII Geofizika. Vice-Director.

KRAVTSOV, Boris Ph. - VITR (Director). Candidate of technical science.

KUNIN, David I - SNIIGGIMS. In charge of electrical laboratory, designed IMPULSE and TSIKL, and received Ph.D. for this work in 1981.

LOTYSHEV Vassily - SNIIGGIMS. In charge of regional geophysics; spent 6 months in USA, and speaks excellent English.

LEBEDKIN, Lev-VITR. Specialist in borehole induction (FEM) prospecting.

(MACHINOEXPORT)
- contacts are Sergei M. Habibrahmanov and V.G. Gorohov.

NEISHTADT, Naum - VITR. Specialist in piezoelectric methods.

NOPPE, Misha - SNIIGGIMS. Working with Isaev on TEM theory, esp use of natural fields (MTMPP).

POLETAELLA, Nata - SNIIGGIMS. Working with Isaev on MPP theory.

POPOV, Yuri N. - VNII Geofizika. Specialist in artificial field EM, sounding.

POSTELNIKOV - TSNIGRI. Chief of Geophysical Department.

PRIKHODA, Aleksandr G. - SNIIGGIMS. In charge of geophysical laboratories, specialty is geodesy.

PUSHKOV, Alexander N. - IZMIRAN. Chief of EM fields department.

PUZIREV, Nickolai N. - IGG. Director; Corresponding Member of the Academy Science USSR, specialist in seismic techniques.

PYATNITSKY, V.I. - TSNIGRI. EM specialist.

RABINOVICH Boris I. - SNIIGGIMS. Specialty ZSB applications in oil geophysical prospecting in Siberia.

REMPEL, Henry, H. - SNIIGGIMS. In charge of ore prospecting geophysics. M.Sc. candidate.

RYSS, Iu. S. -VITR. Specialist in electrochemical techniques esp. KSPK.

SEDELNIKOV - TSNIGRI. VLF and Radio wave methods.

SEMENOVICH, Safonov Anatoliy - VNII Geofizika. Specialist in computer processing.

SHEINMAN, S.M. - NPO - Geofizika. Specialist in IP and electrical phenomena in the ground.

SHUEZEV, Vitaly - IZMIRAN.

SURKOV - SNIIGGIMS. Director; also in charge of geophysics.

SVETOV, Boris S. - Institute of Oceanology. Specialist in marine MT. Earlier he worked on ground EM.

TABAROVSKIY, Lief A. - IGG. In charge of theoretical studies of electrical methods, specialist in mathematical modelling of non-stationary fields. Speaks some English.

TIMOFEEV, V. - MGRI. Specialist on ground TEM.

VARENTSOV, Ivan. - IZMIRAN.

VELIKIN, Alexander. - VITR. Specialist in surface TEM theory.

VJACHESLAVOVICH, Voronin Dmitri - VITR. Specialist in CHIM and KSPK (works with RYSS).

VOLAROVICH, Gueorguiy Pavlovitch (Prof). - TSNIGRI. Vice Director.

YAKOBOVSKIY, Iouri-MGRI. Specialist in induction methods.

ZHDANOV, M.S. - IZMIRAN. Chief, Dept. of Marine EM Investigations.

APPENDIX 5 : ADDRESSES OF INSTITUTIONS

VITR
USSR
199106 Leningrad B-106,
VESELNAJA ST., 6

INSTITUTE OF GEOLOGY AND GEOPHYSICS, (IGG)
Siberian Branch of Academy of Sciences.
USSR
NOVOSIBIRSK 90,
INSTITUTE OF GEOLOGY AND GEOPHYSICS.

SNIIGGIMS
USSR,
NOVOSIBIRSK, 630104
KRASNII PR., 67
SNIIGGIMS

M.G.R.I.
USSR, MOSCOW
PROSPECT MARKSA, 18
MGRI

TSNIGRI
USSR,
MOSCOW 115Y30
VARSHAVSKOYE SHOSSE 58,
TSNIGRI

VNII Geofizika
Moscow - USSR
101808 MOSKVA,
YL, GERISHUEBSKOGO ?
GOM. 22
VNII Geofizika

IZMIRAN:
USSR, MOSCOW Region
142092,
P/O ACADEMGORODOK,
IZMIRAN.

MACHINOEXPORT
Moscow, 117330
Mosfilmovskaya, 35
V/O "Machinoexport"

APPENDIX 6 : SELECTED TRANSLATIONS OF CONTENTS, ABSTRACTS OF REFERENCES.

Antonov, Yu. N., 1978. High frequency inductive electromagnetic methods for use in oil and gas wells. Geologiya i Geofizika No. 4. p. 86-95.

SUMMARY

The analytical treatment of magnetic field of the vertical magnetic dipole has been performed using generalized parameters of medium and homogeneous medium model. The boundaries of a quasistationary regime were determined for various methods dealing with magnetic field component measurements, which permitted one to use a more rigorous approach to the choice of constructive parameters (frequency, probe length and its base) of the bore-hole devices of inductive logging, electroconductivity and dielectric permeability. The classification of absolute and relative characteristics of the field have been defined with a discussion of the main aspects of the possibilities to apply this method to studying radial inhomogeneity in the distribution of specific resistivity of the reservoir beds.

Antonov, Yu. N., and Privorotskii, B.I., 1975.

HIGH FREQUENCY INDUCTIVE LOGGING. Siberian Research Scientific Institute of Geology and Geophysics, Issue 332. Novosibirsk, "Nauka", 260 pp.

ABSTRACT

This book is about the physical basis, apparatus and method of high-frequency induction logging (VIK) in oil shales. The geoelectrical requirements and parameters at which geometrical focussing of sonde of VIK is preserved are determined. Principles of the construction modelling of inductive logging IK sondes, reasons of interference and influence of manufacture errors on focussing characteristics are discussed.

Principles of measurement, the choice of optimal parameters of electrical circuit of sondes apparatus, methods for calibration and control, and method of work are described.

Examples of data presentation, tables and interpretation are given; also detailed tables of geometrical factors depending on the size of the radius of the cylinder.

The book is for specialists working in the field of electrometry in the borehole.

Contents

7. Antonov, Yu. N., and Zhmayer, S.S., 1979. HIGH-FREQUENCY INDUCTION LOGGING AND ISO-PARAMETRICAL SOUNDING (VIKIZ). Siberian Res. Inst. Geol. & Geophy. Novosibirsk, 103 pp.

CONTENTS

SUMMARY

Methodical recommendations are given for high frequency induction logging isoparametrical sounding (using VIKIZ) for investigation of the section for oil and gas bearing layers; also investigation of non-uniform radial gradient of electrical probing direction from the section to the thickness of the layer, determination of electrical resistance of this section.

Also investigation of physical basis, methods and instrumental procedures of VIKIZ.

This book is meant for geophysicists, geologists and specialists employed in electrical measurements in sounding.

Antonov, Yu. N. (Ed.) 1979. ELECTROMAGNETIC METHODS OF BOREHOLE LOGGING. "Nauka", Novosibirsk, 246 pp.

ABSTRACT

The book is about theoretical and methodical problems in electromagnetic methods of boreholes. The possibility is developed to apply high-frequency methods for determination of (inhomogeneous) of the zone near the well. A lot of suggestions are given on possible variations of geometrical and isoparametric sounding using relative characteristics of the field. Suggested focusing systems (geometrical and frequential) for studying the coefficient of rock anisotropy near the well. Theoretical problems have been solved, calculations implemented, characteristics of probes investigated. Theory of the new method on constant current-magnetoelectric sounding is developed.

In magnetoelectric sounding the horizontal electric dipole is used as a source and first time in the practice of constant current information on the profile is involved, which is produced by a magnetic field.

Some articles, devoted to 2- & 3- frequency methods, are connected with problem of depth increase. They describe possibility of excluding the zone of penetration in depth up to 1.5 m at the relatively short spacing of no more than 1 m. Some theoretical and problems of interpretation of sounding are described.

The book is meant for geologists, geophysicists.

CONTENTS

12. Tabarovsky, L.A.

Electromagnetic fields of shear-electric and shear-magnetic type in multilayered media.

13. Brylkin Yu. N., Dubman, L.I.

On dielectric penetration (constant) of wet sandy rocks.

Berdichevskiy, M.N., 1968. ELECTRICAL PROSPECTING USING MAGNETOTELLURIC PROFILING METHODS. "Nedra", Moscow, 255 pp.

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Bolosyuk, G.A., & Safronov, N.I., 1971. BOREHOLE ORE GEOPHYSICS - "Nedra", 1971, 536 pp. Leningrad.

CONTENTS

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Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63. VNII Gε fizika. "Nedra", Moscow, 168 pp.

CONTENTS

(Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63 ..con't)

CONTENTS (contd)

CONTENTS (contd)

(Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63 ..con't)

<u>CONTENTS</u> (contd)

(Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63 ... con't)

ARTICLE 11 Page

Abstract: Behaviour of components of the electromagnetic field of infinitely long cable (BDK), laying on the surface of similar uniform wedging out layer has been discussed. Method of registration of influence of change of the capacity of the upper layer on the normal field BDK with help of specially calculated function S' is suggested. Such registration allows to cut out false anomalies, connected with ununiformity of the layer and more effectively to separate anomalies from local conductors, which are the object of search in method BDK. 46

ARTICLE 12

Abstract: Suggestions are made that instead of the generally accepted electric prospecting representation of results in the form of curves of apparent resistivity, it is better to represent results of measurements of the build-up field in graphical form f(u) and their derivatives. Such representation will help to get rid of unjustified separation of the method of sounding with building-up field on the modification of near zone or far zone, also make easier the choice of the size of installation and interpretation of received data. 53

ARTICLE 13

Abstract: Discussion on analysis of results of time characteristics of polarization curves as a result of the drop of field registered in the process of VEZ VP on gas + oil bearing deposits. Obtained results show some logging of drop of induced polarization inside the outline, of oil-and-gas-bearing field which can be connected with presence of electroconducting minerals. 57

ARTICLE 14

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(Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63 ... con't.)

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(Brodovoiy, V.V., (Ed), 1974a. EXPLORATION GEOPHYSICS. Vol. 63 ... con't.)

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P. 57 - 63
(Kruglova, Z.D.)

Study of time characteristics of decay of induced polarization by observation data on gas fields.

To obtain more information on the characteristics of anomalies of induced polarization in the region of gas deposits, the time characteristics of decay were analysed by data of potential difference of induced polarization (VP), registered during the process of VEZ.

Three methods were used:
Expansion of the decay of curves by the sum of exponents;
calculation of speed of the drop concerning the difference of potential VP on two fixed times;
approximation of curves of the drop through graphs of different functions.

Time characteristics of the field IP curve, expressing the reduction process, can be represented as a sum of exponents:

$$\eta_K(t) = \sum_{n=1}^{m} C_n e^{-\alpha_n t} ,$$

where coefficients C_n and indexes of a degree α_n dependence on parameters of the polarizing field & characteristics of studying environments.

The degree of polarization is indicated by the value of coefficients C_n, but characteristics of the decay were determined by values of coefficients α_n. Decomposition of the decay curves into sum of exponents was realized by a graphical method (2). Results of such decompositions of 500 oscillograms showed that the decay curves registered per minute over 0.5 s after switching off polarizing current, representing as a rule, the sum of three exponents.

The first exponent $C_1 \exp(-\alpha_1 t)$ continues 2-5 min after switching off the current. The second exponent $C_2 \exp(-\alpha_2 t)$ was observed at 15-30 seconds. The third one, a fast falling exponent $C_3 \exp(-\alpha_3 t)$, continues 5-6 s. Sometimes a fourth exponent appears, attenuating in 1 - 1.5 s. The relative value of mean square errors determining coefficients C_1, C_2, C_3 for build up 12 - 16%, a_2:- 13 - 14%, a_{12} - 25%, a_3 - 20%.

Study of the regularity of parameter changes of the exponents, depends on the conditions of field excitation, shows that time characteristics of the drop practically does not depend on the strength of the polarizing current and noticeable changes with the increase time of continuation of its transmission. As the all field observations were carried out with same time loading (t_3=2 min), one could expect that substantial changes of the values of exponent parameters is not connected with the condition of excitation but with particularities of the environment.

In connection with significant errors in determination of values Cn and α_n with the analysis of results of decomposition, statistical methods were used. Calculation of correlation coefficients among values C_1, C_2, C_3. and values of apparent polarization η_K, (or η_a) determined at 0.5s after switching off current, showed that among them there is close connection.

Table 1:

Parameters	Correlation Coefficients
C_1	0.96 ± 0.01
C_2	0.91 ± 0.02
C_3	0.89 ± 0.03
α_1	-0.20 ± 0.12
α_2	-0.14 ± 0.13
α_3	-0.26 ± 0.12
γ	-0.30 ± 0.1
β	-0.31 ± 0.11
σ	-0.34 ± 0.11

Results show that use of separate coefficients C_n or their sum in the role of independent parameters does not have an essential advantage in comparison with use of parameter ηk. But analysis of relation of values C_n is advisable for understanding the essence of the processes stipulating the decrease of IP curves. The separate exponent $C_n/\sum C_n$ in general polarization process changes over a small range from 0.2 to 0.5. The change depends on the installation size and value of apparent polarization. It was elucidated that the values C_n and $C_n/\sum C_n$ do not depend on specific electrical resistivity of the deposit. As a rule, the long-time exponent

$C_1/\sum C_n$ increases with the increase of installation's size, but the fast falling exponent $C_3/\sum C_n$ at the same time decreases. The same tendency to change relations of the exponent character was observed during the increase of the apparent polarization values in the range of each separate area. In this way with an increasing size of installation and increasing η_K corresponds to some delay of the drop of IP potential difference.

Values of α_n change in much narrower range than value of η_k. Relation of maximum and minimum values α_n in the deposit field build up by 2 - 4, but η_K by 50 - 100. Small values of correlation coefficients among values a_1, a_2, a_3 and η_K (Table 1) witness that in the first approach (approximation) the speed of the fall does not depend on the value of the apparent polarization. As a result, one cannot expect considerable change of decay speed in the zone of IP anomalies. The comparison of values of correlation coefficients among time characteristics of the decay and values of η_K, in oil field contour and beyond its ranges in certain extent confirms this conclusion (Table 2). There is a tendency to slow down the time characteristics of the decay for the long-time exponent $C_1 e^{-a_1 t}$ inside the contour of oil field. Beyond the contour the increase of apparent polarization correlates with the increase of C_1 and the decrease of C_3 in general polarization effect. This correlation in the contour was expressed very faintly.

The growth of the part of the first exponent for the regions beyond the contour on the time characteristics of the decay can be explained this way. In case of a section of non-productive sedimentary deposits the growth of apparent polarization, as a rule, correlates with the increase of the installation size which brings to the significant growth of the part of this component.

The results of decomposition of time characteristics of the fall on exponents were confronted with the results of three rates;

$$\gamma = \Delta V_{VP}^{0.5S} / \Delta V_{VP}^{1.5S}$$
$$\beta = \Delta V_{VP}^{0.5S} / \Delta V_{VP}^{15S}$$
$$\sigma = \Delta V_{VP}^{0.5S} / \Delta V_{VP}^{30S}$$

The relative value of the average square errors for the determination of first value is 2%, second -8.2%, third -11.8%.

Table 2.

	Uzensk gas field		North - Stavropol gas field		Oil Zone in Karasiaz' region	
Coefficients of correlation	Inside the contour of gas field	Beyond the boundaries of gas field	In the middle (inside) of contour of gas field	Beyond the contour of oil field	In the middle (inside) of gas field	Beyond the boundaries of gas zone
$r_1(\alpha_1, \eta_K)$	-0.01 ± 0.20	0.39 ± 0.17	-0.34 ± 0.08	-0.1 ± 0.24	-0.57 ± 0.15	0.51 ± 0.18
$r_2(\alpha_2, \eta_K)$	-0.36 ± 0.17	-0.13 ± 0.20	-0.19 ± 0.08	0.26 ± 0.22	-0.10 ± 0.22	-0.01 ± 0.25
$r_3(\alpha_3, \eta_K)$	-0.41 ± 0.17	-0.48 ± 0.15	-0.30 ± 0.08	0.10 ± 0.23	0.06 ± 0.22	-0.23 ± 0.24
$r_4\left(\frac{C_1}{\sum C_n}, \eta_K\right)$	0.08 ± 0.20	0.48 ± 0.16	0.39 ± 0.09	0.67 ± 0.15	0.19 ± 0.22	0.63 ± 0.13
$r_5\left(\frac{C_3}{\sum C_n}, \eta_K\right)$	-0.20 ± 0.25	-0.27 ± 0.19	-0.26 ± 0.10	-0.60 ± 0.14	-0.08 ± 0.23	-0.41 ± 0.23
$r_6(\gamma, \eta_K)$	-0.32 ± 0.18	-0.28 ± 0.19	-0.28 ± 0.09	0 ± 0.20	-0.23 ± 0.21	-0.40 ± 0.21
$r_7(\beta, \eta_K)$	-0.04 ± 0.20	-0.16 ± 0.20	-0.35 ± 0.09	-0.32 ± 0.18	-0.71 ± 0.11	-0.30 ± 0.23
$r_8(\sigma, \eta_K)$	0.09 ± 0.20	-0.15 ± 0.20	-0.44 ± 0.08	-0.36 ± 0.17	-0.79 ± 0.08	-0.18 ± 0.24

An attempt was made to find the more rational way to determine time characteristics of the decay.

Small values of correlation coefficients among values $\gamma, \beta, \sigma,$ and η_K (see Table 1) show that there is no clearly expressed dependence among them. Some regularities are noticed with the comparison of analog correlations coefficients for the curves of the decay obtained in the contour of the oil/gas field and beyond it (Table 2). Inside the contour after switching off the current there was observed a faintly expressed slowing-down of the rate of the fall with an increase of apparent polarization.

<u>Fig. (p. 61)</u>

Vertical profiles ;

1 - Centre VEZ VP and their numbers

2 - contours of σ

3 - position of gas contour

4 - location of surface

Thus, the influence of oil/gas deposit manifests more on the changes of parameters of long time exponent $C_1 e^{-\alpha_1 t}$ or on the rate of the fall σ. For visual demonstration on each section vertical profiles σ were constructed. On sections with fixed oil/gas deposits more or less there was clearly expressed a decrease of the speed of the decay fall (see Fig. P. 61). Even on Uzensk deposit where no relative regularity was determined by the correlation analysis, there was a narrow zone of small decrease of the rate of decay inside the oil/gas contour. Conclusion was made that the use of the decay rate σ for characteristics of explored sections is of the great interest.

For the description of IP decay process mostly has been used 2 types of equation (3) :

$$\Delta V_{VP}(t) = \Delta V_{VP}(0) \frac{1}{(1+bt)^k} \qquad (1)$$

and

$$\Delta V_{VP}(t) = \Delta V_{VP}(0) e^{-(\alpha t)k'} \qquad (2)$$

where ΔV_{VP} (0) and ΔV_{VP} (t) are values of difference of the potentials of induced polarization the time of zero and t after the current was switched off;

and b, k, a, k' are constants, depending on the physical and chemical characteristics of medium (environment).

In the work (3) has been indicated, that the curves of the decay based on the given formulae combine very well with experimental observations on the medium, containing electronic conductors. Also clear differences were observed in values of parameters of the decay b, k, a and k' for different media, for example, sulphide ores and graphitic species.

For the purpose to analyse the given parameters, also for comparison of time characteristics of the decay observed on the gas/oil fields and on the ore deposits using given formulae above two tables of theoretical curves were calculated, and by combining them with experiments an attempt was made to determine values b, k, a and k'. It was found that in the middle part of curves of the decay at t = 1 - 10 s, both equations were correct. At t < 1 s on the practical curves a much slower decay was observed than by formula (1) and much faster than by formula (2). At t > 10 s reverse regularity was observed. Altogether, experimental data combined better with theoretical curves, designed by formula (2).

In view of differences between practical and theoretical curves determination of parameters b, k, a and k' was fulfilled to a limited extent. Relative magnitude of mean-square error by determination of parameter b makes up 19.5%, k - 11%, a - 24%, k' - 2%. Analysis also shows that the given parameters practicaaly do not depend on the strength of the polarizing current but considerably changing with the increase of duration of the change.

Graphs b, k, a and k' built up on different profiles, witnessed a much wider range of changes of quantities b and a in comparison with k and specially with k'. In the region of IP anomalies there is a tendency to deceleration of the speed of the decay which appears in the decrease of values of parameters k, k', a and increase of parameter b. Graphs with data of values and rate of the decay γ, β, σ, correlate very well. Seemingly, the use of indicated parameters in practice has no essential advantage in comparison with rates of the decay.

Obtained results allow one to make a conclusion about expediency of analysis of time characteristics of the decay of induced polarization in the gas/oil fields. Some deceleration of the decay of induced polarization inside the contour could be connected with presence of electronconducting minerals . This is most efficient use for this purpose of the speed of the decay, taking into account the change of potential difference of IP on the large times of observation after the switching-off the polarization current.

Brodovoiy et al (1975a) p. 63-70

Kirichek, M.A., Z.A. Korkh,
E.I. Ratner, V.S. Khar'kovskaia

"Geoelectric model of gas and oil deposits"

Evaluation of the possibilities of different modifications of electroexploration prospecting for oil and gas, important rules come from the knowledge of characteristics of the geoelectric section of in-situ oil and gas fields, specified by direct deposits, and accompanying them secondary and surrounding species.

The characteristics of different anomaly-building factors also depends on the appearance and intensity of anomalies in the deposit region, method of observations and experimental data interpretations. Because of this, for direct prospecting for oil and gas, a very important role is the question of physical-geological basis of electric research in specific oil and gas fields.

Side by side with that in VNII Geofizika, mass-statistical analysis of materials of electrologging in several oil and gas provinces was done with the intention to obtain a general idea about the geoelectrical model of deposits in various physical and geological surroundings and for various types of deposits. Materials from Ust'iurt, west Turkmenia, south Mangyshlak, Bucharo-Chivinsk depression, north-east part of Sakhalin, west Siberia and other regions were studied. The above mentioned oil and gas provinces in the sections have widespread terrigenous (sand-clay) deposits; thick covering layers are usually absent, i.e., geoelectrical conditions appears relatively simple.

Together with the deposit types, their depth; tectonic characteristics, and hydrogeological conditions and other features, these provinces considerably differ. In each of the provinces five to six sections were picked out: the larger (unique) gas and oil deposits, the most widespread industrial oil and gas deposits, and one or two non-prospective ("barren") structures.

On each section there was found to be predominant increase of resistivity of the layers - collectors in connection with their oil and gas saturation. For this reason usually all available data of VKZ was analysed. Afterwards by means of treatment of diagrams KS of standard gradient-probe the variation of resistivity of enlarged electrical horizons, appearing on the curves of electrical sounding was studied. First of all the change of resistivities in the horizons, connected with the productive thickness (sequence) was investigated. Furthermore the characteristics of the change of resistivity of higher layering horizon, were apparent associated with the top part of the productive section (excluding the very top ones 300-500m, for which information often is absent).

As a result the comparison of standard gradient-sound (probe) diagrams and VKZ was established that in the conditions of terrigenous sections the relative errors in determination of enlarged electric horizons on the gradient-sound usually does not exceed ± 15 to 30% (2). Observed anomalies, as a rule, essentially exceed these errors. For decrease of relative errors in each individual sections KS diagrams have been analysed, obtained from holes with identical diameter and identical (or mildly) changing in interval ± 20-30%) resistivity of drilling mud. The processing of logging diagrams was done by combined (KI - Z) and functional (IF-2) integrators in the "building of calculation" using technique VDNX, also by planimeter and sometimes by hand (if knowledge of ρ_l and ρ_m was needed). Using already known formulae transverse was calculated, and seldom longitudinal ρ_l and mean square ρ_m resistivity of electric horizons. On the well drilled sections the logging diagrams of many tens of holes in the dome and beyond the contour of the oil and gas deposit (on the periphery of structure) were treated, but on the explored sections - all the rest of logging core diagrams. By these results graphs and maps of resistivity changes of individual oil/gas bed and enlarged electric horizons were designed, i.e., the spacial distribution of resistivities on the oil/gas and non-productive sections was studied.

To find out about tendencies of resistivity change in (by) different intervals of the section, average values of parameters were used in all inner and outside holes of the contour, their relationship also different variation curves. Altogether KS diagrams of more than 500 holes in depth from 1500 to 3000 m were treated on the Gazlinsk rise 83, on the west Turkmenia 60, on Ust'iurt 16. west Siberia 60, on Sakhalin 150, on Mangyshlak 70, on Prikaspiisk Depression (Kenkiiak region) 27.

Fig. 1 shows characteristic of schematic geolelectric sections of different deposits and non-prospective sections using data of electric logging of inner and outside holes. Evidently, in the interval of depositioning of productive layers can be noticed significant resistivity increase of rocks: On the Gazli gas field in horizon 9 & 10 from 5 to 50 Ohm-m, on Kotur-Tepinsk oil field-from 5 to 18 Ohm-m, on Ust Balyksk oilfield from 5 to 30 Ohm-m, on Punginsk gas field - from 10 Ohm-m up to four hundred, on Okarensk - from 3 to 10 Ohm-m. In this way, the resistivity of productive intervals increases not less than 5 times.

On the unique Gazli gas field, the cover of which (Turon clays) is relatively thin, there was noticed some gas overflow into the chalk and in recent sediments, forming non-industrial deposits, the increase of resistivity was observed even higher (on the top) of base deposits. It is significantly lower than for exploitating deposits and increases from 3-6 to 10-20 Ohm-m, i.e., not less than 3 times.

On the fields Kotur-Tepe, Okarem and Ust'-Balyk in penetratable deposits on the top of the productive thickness, above the cover also the increase of resistivity was observed, as a rule, up to 20-30%. However, those changes involve significant intervals of the section about 400 m in Kotur-Tepinsk field and (300-400 m) on Okaremskom and Ust'-Balyksk field. On the Punginsk gas field above the productive layer (thickness) the section inthe contour and beyond it was the same.

On non-prospective section of the profile and on the periphery no changes (Kara-kyr, Komsomol'sk) were observed. The relative change of resistivities ρ_{otn} of productive horizons, deposited above it, for different oil/gas provinces the general characteristics were planned and also individual differences (ρ_{otn} of individual horizons appeared as a ratio (relation?) of the average values of ρ_m or ρ_ℓ , received no less than from every five holes correspondingly in the contour and beyond the contour of deposits). So in all oil/gas provinces with unique and large deposits of oil/gas with total effective capacity of oil/gas saturated rocks (h_{ef} more than 50 m) resisitivity of the productive stratum increases more than 1.5 - 2 times (sometimes up to 4.5). In cases of more distributed deposits (h_{ef} = 20-50 m) resistivity increases to 30-50% during which more effect was noticed on the gasfields and minimal on the mixed - oil/gas fields (Fig. 2). On the nonprospective sections resistivity of the productive stratum from periphery to the dome, as a rule, is steady or decreases (1-0.8). Some increases of it observed at the presence of non-productive oil/gas appearances (Alambek, At-Baktor).

In the horizons which cover the productive layer, on the deposits of Middle Asia to the province of contour associated the significant increase of resistivity - 30-80% (Gazli, Shakhpakhty, Okarem), but in some cases up to 250% (Nebit-Dag).

Figure 3

On the layers (deposits) of west Siberia and Sakhalin such cases did not appear. In these regions resistivity of rocks, layering above deposits, normally decreases towards the arch (dome) (Berezovsk-Deminsk, Syskon'syn'insk, Tungorsk, Kolendinsk et al.) or stays constant (Punginsk).

Only in some cases is there significant increase of resistivity (Pokhromsk and Ust'-Balyksk). One could assume the reason for such changes of resistivity of rocks above deposits in various regions. It is know that in conditions of terrigenous sections for general vertical migration of hydrocarbons and for the corresponding modifications of physical characteristics of higher laying rocks in first place could contribute such factors as characteristics of the cover and intensity of development of breaking infractions, i.e., the level of enclosure of structures-traps also hydrogeological conditions.

In the most studied regions (except west Siberia) the covers are comparatively thin, specially on Sakhalin and Gazli, the breaking infractions were developed in recent oil/gas prospective provinces - on Sakhalin and west Turkmenia. In this way, these factors seems not to be taken as determining factors in connection with observed characteristics of the resistivity changes above the deposits. Together with that, investigated regions of middle Asia and western part of U.S.S.R. are in different climatic and also hydrogeological zones. The first ones are related to the arid zone, characteristic of which is predominant evaporation of underground waters above infiltration, and therefore the increased durable circulation of water occuring below the petroleum layer in vertical direction, owing to the capillarity phenomenon, is possible. This must assist in the general migration of hydrocarbons upward through the section. West Siberia and Sakhalin are in overmoistened zone and of intensive infiltration of atmospheric precipitation, which could work against the similar motion of hydrocarbons and could weaken them sharply. Further studies on geological/geophysical materials for more proved explanation of reasons which cause the aureole (halo) changes of physical characteristics of rocks.

On basis of that said above one can have the first knowledge about quantitative and qualitative changes of the geoelectric sections on oil/gas fields. The possible models of ore bodies of sheet-like (layer-like) arch-like (anticline-like) are shown in Fig. 3 in form of graphs of relative change of resistivity for different layers (stratum) of four-layer sections. On this basis, a quantitative indicator is very useful, is differentiating:

(i) <u>the larger</u> (with total effective capacity of oil/gas saturated rocks h_{ef} not less than 100 m) deposits

(ii) <u>the large</u> ones (h_{ef} = 50-100 m) and

(iii) <u>more distributed ones</u> (h_{ef} up to 50 m).

On the first ones (Fig. 3, a, b) quite often can be noticed effects of increase of resistivities in productive stratum much higher than in case of large and in more distributed one (Fig. 3 c, d).

An important qualitative indicator is the presence or absence of aureole phenomenon, most of which expressed on the larger deposits (i) Beside, it is quite important to have some knowledge about geoelectric section changes in case of non-productive oil/gas occurrences and of the more distributed (iii) ones since they can be similar (Fig. 3, d, e).

As a results of all studies one can make a conclusion that for the solving of direct and inverse problems of electro-prospecting with purpose to evaluate the possibilities of use to modifications VEZ, DEZ, ZS, ChZ at the prognosis of oil/gas content it is necessary to dispose the concrete data about geoelectric model of deposits, characteristic for the given region. Probably further on the basis of spatial detailed studies of the resistivities change will be obtained significantly more complicated ideas about the geoelectric model of deposits as a specific geological object, which will allow to increase the effectiveness of search for oil/gas.

Fig. 1 P. 66

1. Geoelectric sections on some oil and gas fields and non-prospective sections.

1 - schematic graph KS in the contour of oil/gas field (dome of structure).

2 - schematic graph KS in the contour of oil/gas field (periphery of structure);

3 - terrigenous deposits of sedimentary covering;

4 - crystalline metamorphic rocks of Palaeozoic base.

Fig. 2, Page 67

Graphs of relative change of resistivity of electric horizons on exploration and explored sections.

a) West Turkmenia
b) Ust'iurt
c) Gazlinsk rise
d) west Siberia
e) north-east region of Sakhalin
f) general graph

(abscissa is name of section and type of deposit)

1 - relative change of resistivity of electric horizons, to which large oil/gas deposits have been assigned

2 - the same, for large oil deposits

3 - the same, for large oil/gas deposits

4 - the same, for most widespread gas deposits

5 - the same, for most widespread oil deposits

6 - the same, for most widespread oil/gas deposits

7 - the same, for barren deposits

8 - electric horizon, encompassing deposits of productive mass

9 - electric horizon, encompassing deposits of mass above the productive one

10 - the second electric horizon, separated by cut in the overlying productive laying mass.

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(18) Gorelov, D.A., A.I. Koriavko: On the influence of buried relief of main ores on the results of detailed high-precision gravimetric exploration and purpose of its registration P.105

(19) Lukachenko, P.I., V.F. Demchenko, O.G. Astashenkov: Improvement of amortization system of Kardan suspension for sea-bottom gravimeter. P.116

(20) Stepanov, V.P., V.V. Dorofeev, G.A. Bakhtizen: Calculation of depth of crystalline basement using magnetic anomalies on EVM integral-correlation method. P.118

Page 84 (Abstract)

Described principle of work of piezoseismoreceiver with increased sensitivity, which was achieved through original construction, using a selection of plane-parallel piezoplates (slabs, sheets), separated (divided) by dielectric separators (gasket, pad, filler) displaced on the edges and in the centre.

Page 93 (Abstract)

The surveyors plane (table) is described consisting of 2-layer curve sounding by buildup field (ZS) in form (shape) of graphics if f(u) permitting to create united system of image of the theoretical curves ZS for two modifications of sounding: in near and distant zone.

Page 118 (Abstract)

Determination of depth of deposits with crystallic foundation using correlative relationship between the depth of its deposition and of the upper edges the depth of upper edges deposit of magneto-active objects, which are calculated using Simonenko formula for two-dimensional case. The practical use of this method is given.

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SUMMARY

This book summarizes the field and research results and useful findings of the use of low frequency inductive methods of electrical prospecting for locating magnetic ores.

Inductive methods give more information of geological nature than magnetic anomalies found in the process of magnetic surveys. In some cases they can help as they can be used as an independent method of prospecting.

In the process of research of magnetic anomalies with intensity greater than 1000 to 2000 gammas it is possible to use normal field serial apparatus and quite ordinary (a little bit improved) electrical field methods. This makes it easier to use inductive methods in practice.

All practical work should be directed for developing apparatus and methods which could help to obtain high frequency measurements of low signal EM fields with errors of no more than 0.1 to 0.2%.

If this job is done it is possible to use inductive methods for discovery of weak magnetic anomalies, in connection with deep lying magnetic ores or weak magnetic ores. As described, methods are useful for the vector of remanent magnetization, and it may be possible to use low frequency inductive methods for palaeomagnetic investigations.

Page 7

For a uniform sphere of radius a, σ, μ, situated in an infinite uniform host with parameters σ_2, μ_2, in which there is harmonically varying magnetic field H_z = Hzo exp $(-i\omega t)$; a spherical coordinate system can be useful for radial Hz and azimuthal H_θ components of fields.

Gol'dberg, I.S., Ivanova, A.V., Ryss, Yu. S., Veiher, A.A., Bakhtin, Yu. G., Alekseev, S.G., Iakovlev, A.F., 1978. INVESTIGATIONS AND RESEARCH OF THE METHOD OF ChIM IN ORE DEPOSITS (Yu. I. Ryss, Ed), VITR, Leningrad, 75 pp.

ABSTRACT

These recommendations describe the method and technique of field investigations using method of partial extraction of metals (ChIM). A short description of the physical chemical grounds of the new method and detailed description the method of field work, apparatus and methods of analysis of the extracted metals are given. Special attention was paid to the safety during the process of extraction, also to the planning, documentation and report of investigations.

The method has been used for exploration of deep lying polymetallic, copper-nickel, gold-bearing and other ores covered by sediments of 100 m and more (areal variant) and for investigation of ores to determine the intervals (of ores) in the hole made without core taking, or with unlimited output of core (logging method).

CONTENTS

(Gol'dberg, I.S., Ivanova, A.V., Ryss, Yu. S., Veiher, A.A., con't)

Isaev, G.A., and Rempel, G.G., (Ed.) 1974. INTERPRETATION OF SOUNDING WITH METHOD OF TRANSIENT SOUNDING (MPP) IN PROSPECTING FOR POLYMETALLIC FLAT LYING DEPOSITS. SNIIGGIMS, Novosibirsk, 88 pp.

CONTENTS

INTRODUCTION

Recently, scientific research has resulted in a new method of electrical prospecting - the method of transient processes, in the search for polymetallic ore deposits. The work was done in the research laboratory SNIIGGIMS. Initial work was done in the laboratory, then applied to field problems.

Recommendations are given for new equipment which was developed in conjunction with the Acad. of Sciences of USSR. Developed for ore geophysics. The apparatus description is given by G.A. Isaev, and data interpretation by G.G. Rempel. Work done in conjunction with laboratory A.G.E. Z.S.T.U.

Thanks to B.E. Rabinovich, D.E. Kunin, B.F. Alexenko, E.P. Lembitskii, V.K. Bochkarev.

Kamenetskii, F.M., Timofeev, V.M., and Mamaev, V.A., 1978. AIRBORNE SURVEYING WITH THE METHOD OF TRANSIENT PROCESSES. "Nedra", Moscow, 64 pp.

ABSTRACT

The method of transient processes (MPP) is very valuable in prospecting for sulphide ores with high electrical conductivity. This method enables prospecting in areas with poor accessibility, and in a faster time. This book contains the theory, description of the multichannel airborne version AMPP-2, method of survey, interpretation and field examples.

The book is for geophysicists and geologists who interpret airborne surveys, scientists and students in geophysics.

CONTENTS

Kulikov, A.B., and Shemiakin, E.A., 1978. ELECTRICAL PROSPECTING USING PHASE METHOD OF INDUCED POLARISATION. "Nedra", Moscow, 157 pp.

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Kulikov et al., 1978 - p.124-131

Use of the method in oil fields

The use of VP (IP) method in electroprospecting for oil was demonstrated by VNII Geophysics, and Spetsgeofizika trest (office) (22.) (VNII = Vsesoiuznyi Nauchno-Issledovatel'-skii Institut).

Recent thoughts about the origin of IP anomalies above oil fields are connected with the presence of a halo of epigenetic pyritization of ores caused by the presence of the oil deposits.

The characteristics of using IP in oil fields appears to be connected with the high electric conductivity of the geoelectric section and it is necessary to use large installations to find more effective ways of separating polarizing and inductive phenomena in observed electromagnetic fields.

As it was shown in ch.III the transfer to measurements with orthogonal installation in combination with measurements to very low frequencies (or large times) significantly widens the possibilities of the IP method in conditions of low resistance geoelectric sections. It has been confirmed by examples of INFAZ VP method used above some oil and petroleum fields, given by VNII Geofizika (shown below) (34, 41).

Oil field in Asfal'toyaia gora (mountain) Krasnodarskii kraii

This formation belongs to Khodughensk group of oil deposits which is associated with the zone of western kuban' Deflection and anticlinorium of Main Caucasus.

The geological conditions were favourable for oil (traps) formation of litho-stratigraphic type. Chalk type deposits are the oldest in this region, appearing on the surface towards the south of Asfalt Mountain. The appearance is rhythmically overlain with lime, sand, marl and clay. The top monoclinic deposits of palaeogene-neogene time provide the basis for the clay sequence. Industrial oil deposits are associated with Maikop sequence ($P_3 + N'_1$). Characteristics of this deposit change with the changing facies in the area. The oil deposits were formed in sand blocks situated in clays.

Productive sediments differ by having a complicated structure with thickness changes by significant amounts. In the oil field deposits of two horizons with effective thickness of 4 and 17 m were exploited. One of the deposits in the southern part appears on the surface, the second one dips gently away from it beginning from a depth of 700 m.

Exploration using INFAZ VP method was done along the meridian line of prospecting and exploring holes in the intersection of the trend of the deposit-bearing rocks. Measurements were done by model apparatus which was constructed by VNII Geofizika. The apparatus was constructed on the automobile and profile was done in a rugged and forested country, measurement points were allocated irregularly taking into account the possibility of access to them by automobile. In these conditions the use of the orthogonal installation was preferable. Taking into account that the oil deposit was not deeply situated the spacing of the installation was 500 m. The length of the transmitting line perpendicular to the profile was 500 m; receiving line 100 m. The measurements of installation were chosen to be optimal for solution of the geological problem, and allowed to conduct accurate measurements of the background of very strong electric interference source of which was near Caucasus main railway line.

Measurements were done in range of frequencies 0.038-19 Hz. Accuracy of phase measurements was in range of $\pm$ 0.1°. The parameter ϕVP_k was calculated following data in lower range of frequencies up to 0.15 Hz by the formula for measurement of dual (2) frequencies (III.20). Measured graphs ϕVP_k and ρ_k are shown in Fig. 44.a.

The minimal value of ϕVP_k = 0.4 to 0.6° was registered on the southern part of profile above chalk species, and species of palaeocene (PK0-PK 10), which corresponds with usual background value of characteristic weak polarisation. The magnitude of P_k in this interval of profile was accordingly high - 20-25 ohm-m. Above the species of Maikop sequence, which contains oil deposits, the value of ϕVP_k sharply rises up to the magnitude (-2 to -3°). Such a high level maintains for a further length of profile, just insignificantly falling at its northern part. This fall is in connection with higher level of pyrite in the bodies of the surface part of Mai'kop sequence. The graph ρ_k shows that resistivity of bodies in the northern direction decreases down to 1-2 Ohm.m. Fig. 44.b shown ϕ ChX, taken from three points of the profile. Their right branches have various forms and differ in level and sign of phase shift. On the lower frequencies ϕ Ch X, received from above the deposit (PK 25 and PK 35) come out on the horizontal asymptote in the region of negative angles.

(Fig. 44 Results of work using INFAZ VP on oil field Asfal't Mountain

a - geological section and graphs ϕ_{VPk} and ρ_k;

b - ϕ ChX;

b - dependence ϕ_{VPk} from the distribution of installation r on Pk30.
Oil deposits are shaded.

The dependence of the parameter ϕVP_k from the distribution of installation on PK30 (Fig. 44, b) is an evidence that spacing of installation for profiling was chosen correctly. The size of the parameter ϕVP_k. increases with spacing up to 300 m.

<u>Oil deposits of western Primugod-zharia</u>

Work was done on oil fields of Kenkiak, Kokzhide & Kumsai', which are on the eastern part of Ural-Embiisk salt-dome region. Before, work was done by Spetsgeofizika using VEZ VP method with impulse excitation of the field. Deposits of Kenkiak are associated with the salt-dome rise deposits of Kokzhide & Kumsai' - to the interdome rise. The depth of salt in the dome arrangement is 500 m, the dimensions of the dome 8.5 x 3 km. Above the salt deposits there are two structural levels. The low level contains bodies of terrigenous-sulphate thickness of Kungur stage Upper Permian and Lower Triassic series.

The upper structural level contains sand-clay deposits of Jurassic and Cretaceous systems. In the above salt deposits there are 9 productive oil horizons. The oil horizons of the upper level are joined to the arched part of the oil horizon of the lower level - to the flanks of the eastern part of the dome.

The thickness of oil saturated bodies of productive horizons changes from 1 to 44 m.

Kumsai deposits lay in boundaries of positive structure, which were emplaced in Upper Permian complex of bodies and has measurements of 20 x 10 km. The structure is asymmetric, the southern flank gently sloping. In the top laying deposits the structure becomes more even. Oil deposits have thicknesses of 4 to 20 m emplaced in the Upper Jurassic deposits at a depth of 230-250 m.

Kokzhide deposits are associated with the gentle rise, which was emplaced in Upper Permian complex of deposits. Oil deposits are associated with the Jurassic deposits and measure 6 x 2 km.

Characteristically the deposits of salt in the region have specific resistivity of 20 to 40 Ohm-m. Above the salt sediments have specific resistivity 3 to 10 Ohm-m. Above all of the oil deposits distinctive anomalies were observed in VEZ VP data. The INFAZ VP method was used on the same points of observations as measurements using method VEZ VP. The distance between these points in average is 500 to 1000 m. Almost everywhere the observations were made in the range of frequencies from 0.3 to 0.5, to 75 to 312 Hz.

Testing of installation of the middle gradient with cable, placed in half-loop form, and of axial installation showed that inductive phase displacement significantly exceeds phase displacement of VP field even on the very low frequencies. In the orthogonal installations influence of induction considerably decreased. Also in this case on ϕ ChX was not possible to obtain the asymptote independent of frequency which indicates the considerable influence on thickness of the section and its horizontal heterogeneity.

(Fig. 45 Results using method INFAZ VP and VEZ VP
Oil deposits: a - Kenkiak & Kokznide
b - Kumsai
1 - rock salt
2 - oil deposits
3 - tectonic disruptions
For graphs ϕ_{VPk} AB = 500 m; r = 500 m; for graph
η_k AB/2 = 500 m
tzar = 2 min.
tizm = 0.5 s (after Spetsgeofizika data).)

For measurements the orthogonal installation was chosen, with a transmitted line of 500 m, perpendicular to the profile and receiving line of 100 m, placed along profile. On the base of distance soundings the optimal distance between Tx and receiving lines at the time of profiling was 500 m. At these distances values of ϕVP_k practically reached their asymptotic value but inductive phase displacements still were small.

The chosen separation guaranteed necessary depth of investigation which was confirmed by measurements using method VEZ VP, where the best results were received during the spacing of AB/2 - 350 to 500 m.

The parameter ϕVP_k was determined by results of phase measurements in low frequency range up to 4 Hz. Experience showed that the spacing up to 500 m gave reliable results were given calculations using formula of dual frequency measurements (III.20).

Fig. 45 represents graphs of ϕVP_k and η_k above oil deposits on Kenkiak and Kokzhide deposits with quite satisfactory repeats. Anomalies in the region PK0-PK(-20) are associated with the deposits of Kokzhide. Here the value ϕVP_k rises up to 0.7°, and η_k is 6-7%. In the central part of the profile, where there are no oil deposits, the values of ϕVP_k decreases down to (-0.3) to (-0.4°), but η_k goes down to 2 to 2.5%.

Above the deposits of Kepkiak deposit (PK30-PK80) on graphs ϕVP_k and η_k there appears an anomaly of complicated form with 2 maxima. Near the southern region of the top deposit on Pk 40 a local maximum was observed, the value ϕVP_k reaches -4° and η_k is -11%. The second, much wider maximum is associated with the other side of the deposit and appears outside of its boundaries. Maximum value here of ϕVP_k is 0.9°, but η_k is 4%. Analogue results were received on oil field of Kumsai (Fig. 45b). Using data of the VEZ VP method it was found that above the field there is an increase of values of η_k up to 5-6, 4% on the background 2.5 to 3.5%.

The comparison of given graphs η_k and ϕVP_k shows, that, if on the graphs η_k values of anomalies up to 5% and on the background 2.5-3%, in that case on graphs ϕVP_k values of anomalies reach 1° and on the background 0.1-0.3°. Both anomalies in their length surpass the dimensions of the deposit but maximum values ϕVP_k and η_k are obtained directly above the ore.

Kzyloisk deposit (northern Ust'iurt)

The deposit is associated with the Kzyloisk anticline, which is part of the Akkulkovskoe Rise. Industrial accumulation of oil was found in Akkulkovskoe sequence of Lower Oligocene. The sequence contains clays.

In the base of the sequence sometimes could be found the layer of siltstone in thickness up to 10 m, which is the most oil saturated layer of the field. Higher situated deposits of Middle Oligocene are represented by sands, sandstone (gritstone) and siltstone.

Upper and Lower Oligocene formations are structured from sand and clay bodies. Middle and Upper Miocene deposits of Neogene are represented by quartz sands with intersections of marl, limestone and clays. Lower Pliocene structures as limestone are contained under a thin layer of continental Quaternary formations.

Bed (seam) displayed on the depth of 450 and 500 m.

(Fig. 46: Results of work using method of INFAZ VP and VEZ VP on oil field Kzyloi.

Value of ϕVP_k calculated:

1 - on two (dual) frequencies f = 0.076 and 0.15 Hz;

2 - on three frequencies f = 0.076, 0.153 and 0.305 Hz

3 - on four frequencies f - 0.076; 0.153; 0.305; 0.61 Hz

4 - oil deposits)

The resistivity of bodies of upper parts of the section containing limestones, changes from 20 to 30 Ohm-m. Deposits of Middle and Lower Oligocene have resistance 3-15 Ohm-m. Lower laying thickness of sand and clay bodies characterized by very low resistance - from 0.9 to 1.30 ohm-m.

Works using method INFAZ VP were put on the profile where Spefsgeofizika was working before using VEZ VP. Investigations were conducted in range of frequencies 0.038-312 Hz. Because of the low resistance characteristics of the profile, the orthogonal installation was used. At the end of the distant soundings was determined, that by the depth of search, the optimal separation at 1000 m. The length of Tx line of orthogonal installation was 2000 m; length of receiving line - 200 m.

Accurate results of the magnitude of parameter ϕVP_k were obtained on the basis of measurements on 3-4 frequencies of lower range (margin) up to 1 Hz. From Fig. 46, graphs of ϕVP_k are given, calculated at 2, 3 & 4 frequences. One can see that values of parameter ϕVP_k, received as a result of measurements on 3 and 4 frequencies, give well coinciding results. That is evidence that graphs of ϕVP_k are correct and that there is possibility of treatment of phase measurement data on several frequencies which much more effectively allows inductive influence on the parameter ϕVP_k to be eliminated.

Graphs of ϕVP_k and η_k (Fig. 46) show that anomalies are identical by form and by relative apparatus in spite of that that both graphs obtained are basically by different installations - four electrode installation for η_k, orthogonal for ϕVP_k. It is interesting that the form of anomaly consists of two maxima of polarization above the edges of the deposit and deep minimum above its centre. Similar results were obtained on the neighbouring deposit - Bazaisk oil field, situated in an analogous geoelectric condition. One can see it on Fig. 47, for results of areas surveys by INFAZ VP are given. On the plan the zone of anomaly ϕVP_k has a narrow range of rise of negative values which follows the contour of gas deposit.

(Fig. 47: Plan of isolines ϕVP_k (in degrees) on Bazaisk gas field -

1 - profiles

2 - contour of gas field).

Lebedkin, L.V. (Ed.), 1973. METHOD AND TECHNIQUE OF BOREHOLE INDUCTIVE ELECTRO-PROSPECTING. VITR Methods and Techniques of Prosp., No. 85, 49 pp.

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Lebedkin, L.V., (Ed.), 1977. THREE-COMPONENT INDUCTIVE ELECTROPROSPECTING OF BOREHOLES. VITR Methods and Techniques of Prosp., No. 116, 49 pp.

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Lebedkin, L.V., Popov, N.I., Maksimova, T.M., 1978. INTERBOREHOLE DIPOLE ELECTROMAGNETIC PROFILING. (L.V. Lebedkin, Ed.), VITR, Leningrad. 63 pp.

CONTENTS

(Lebedkin, L.V., Popov, K.I., Maksimova, T.M., 1978., con't)

ABSTRACT

This book describes the physical basis of interborehole inductive multifrequency electrical investigations, method of handling apparatus, methods of data processing and interpretation of results of investigations. Also given are examples of practical applications of interborehole inductive method on KOLCHEDAN ores.

Page 32 (Chapter 3.1)

Apparatus

The block diagram of switching on the apparatus ASMI-40M at interborehole dipole electromagnetic profiling is analogous to using it with a loop. But the current of working frequency from the generator flows not in the loop laying on the ground but in the loop which is in the frame of generator in the interborehole.

The signal received by the loop frame through the cable of the winch of the hoist I, goes to the measuring and indicating block. Between hoists I and II two-way telephone-connection is useful

Using for interborehole inductive investigation ASMI-40 apparatus instead of ground measuring and indicator blocks the surface measuring console has to be switched on. But instead of semiconductive generator we now use generator GN Ch-2. If interborehole inductive investigations are worked out

(Lebedkin, L.V., Popov, N.I., Maksimova, T.M., 1978., con't)

with the help of the series of frames, the distance between interboreholes no higher than 100-120 m. To increase it up to 250-300 m requires special more effective generator frames, each one of them has to be adjusted to one of the working frequencies (Table 2).

(Table 2: The quantity of turns in the coils and the amount of capacity of frames of generator).

The core of each frame is from transformer steel E340 and made up with 2 components 450 mm in length each. Electrical scheme of connections of such generator frame is shown in Fig. 25.

If the distance between interboreholes in 150-180 mm, then only 1 generator frame has been used. From the bottom this frame is sealed by special screw cap which helps to short-circuit the outlet lead 1 and 2.

If the distance between interboreholes is higher than 150-180 m then in series from the first generator frame is connected the second one (the same) frame of generator.

This joining is accomplished through the transformer, made from the cable KTO-I in length 1.5 m.

During the work on serial generator frames for increasing the distance of investigations up to 120-150 m it is possible to connect 2 frames one after another of the same frequency, before that the transformer of the first frame has to be switched off. The low end of the second generator frame is shut up -tight with steel screw cap, which is included in equipment (apparatus).

Page 34 (Ch. 3.21)

Compensation of the original shift of apparatus

The phase shift of the transverse (cross) frames and direction of their movement must be determined before the beginning of the operation with apparatus and must be repeated 1-2 times a year. These operations are done in a controlled field, free from the influence of the conductive objects (especially on the field in the absence of low-resistance unconsolidated deposits) on each one of the operating frequencies.

Generator and reception frames are positioned on the bottom, at 75 m distance from each other. The coils of the frames are displayed in the way so that axis of their winding would be on one line, but receiving frames at the same time are in condition of maximum of the receiving. The frame axis is orientated coaxial with that of the generator. Determine the quantity and sign of the signal: Applying to the interborehole investigations, received data of the moment of the receiver frame must be changed to the opposite one. In correspondence with formula (3) the magnitude of the signal at the coaxial location of the installation (single hole (well) DEMIS) is twice as much as at parallel (interborehole DEMP).

For determination of the moment of the direction of the cross frame, its equipment, ready for measuring of horizontal component, is placed horizontal on the bottom and perpendicular to the axis of the generator frame.

For measuring the vertical component it (i.e. equipment) has been set in the vertical plane, passing through the axis of generator frame. Keeping of records of size, magnitude of the signal of the cross frame: In the data book, after compensation of the phase shift has been fixed, the value of signal, its sign, and situation of the dial of phaseshifter of the measuring block, at which the compensation was achieved (FK). On the basis of these measurements for each working frequency the coefficient must be calculated, equal (even) to the sensitivity (response) of the axial and cross frames (Kotn).

Neishtadt, N.M., 1970. USE OF SEISMOELECTRIC AND PIEZOELECTRIC EFFECTS IN EXPLORATION GEOPHYSICS. "Nedra", Leningrad, 78 pp.

ABSTRACT. Short analysis is given on study of seismo-electric and piezoelectric phenomena. Experimental data is given on its regularities and the characteristics of its origin are explained. On the basis of research, an estimation is given on the possible use of this phenomenon in exploration geophysics. The main characteristics of new piezoelectric research method is given for the ground variant, developed in VITR; also description of serial produced apparatus.

Method of procedure has been worked out and experience of piezo-method for use in the ground variant and for interhole piezoelectric probing on different mine-quartz (crystalline) and pegmatite deposits of the Soviet Union.

For geophysicists in research institutes and industrial organisations.

CONTENTS

Postelnikov, A.F., and Piatnitskiy, B.I. (Eds), 1978. GEOPHYSICAL METHODS OF EXPLORATION FOR POLYMETALLIC AND NOBLE METALS. Trans. TSNIGRI, No. 137, Moscow, 94 pp.

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(Postelnikov, A.F., and Piatnitskiy, B.I. (Eds), 1978. con't)

CONTENTS (contd)

Prikhoda, A.G., 1974. THE BASIS OF THE METHOD OF GRAVIMETRICAL SURVEYING IN GEODETIC METHODS. "Nedra", Moscow, 161 pp.

CONTENTS

Prikhoda, A.G., and Rabinovich, B.I. (Ed.), 1979. GEOPHYSICAL AND GEODETIC METHODS AND FACILITIES IN INVESTIGATIONS OF SIBERIA. SNIIGGIMS and Sib. Res. Inst. of Acad. Sciences USSR. Collective Scientific Works, v.267, Novosibirsk, 142 pp.

ABSTRACT

This volume contains results of details of new geophysical and geodetic methods and aids for investigations of Siberia. Questions of the improving of methods of the structural seismoprospecting and electro-prospecting are examined and also of the measuring apparatus requirements.

Also, the results of investigations of the new digital radio-telemetrical seismical apparatus for areas where radio investigation is possible is discussed. Some articles deal with questions about seismical complex "Vibrolocator".

In recent years the technique of applying and tracing water-saturated collectors on the Siberian platform has been established. This requires for its realisation characteristic with high levels of accuracy. One of possibilities is using of multi-component measurements, e.g. registration not only of vertical but also horizontal component of the magnetic field. In this volume is given description of the new soviet cryogenic magnetometer and of inductive transmitter, allowing to realise similar investigations; also given are the results of their field tests. A lot of attention is given to the problem of developing new digital electrical investigation apparatus. There is description of the improved apparatus "Tsikl 2", portative apparatus "Impul's - Ts", the carborne version of electroinvestigating instrumental set-up.

Some articles deal with navigational and geodetic guarantee of geophysical survey. Results are given on developing and testing of radio-geodetic system "MIR-3" with supplementary electronic noise-reducing which was produced in series of experiments and applied in the industrial organizations; analysis is given on recent situation of instruments for hydrostatic leveling, based on measurements of the pressure of liquid; the possibility of the development of geodetic instruments using laser techniques is shown.

The volume was prepared by Siberian Inst. of Scient. Research on Geol. Geophysics and Mineral Resources, together with Inst. of Geol. & Geoph. of Acad. of Science of USSR for geophysicists and geodesists.

CONTENTS

(Prikhoda, A.G., and Rabinovich, B.I. (Ed.) cont.)

(Prikhoda, A.G., and Rabinovich, B.I. (Ed.) cont.)

Page 69, Tsypliashehuk et al.

Automobile Variant of MPP

One of the major task for today's mining geophysics is searching for deeply buried ores in regions with a well developed mining industry. For this there is a procedure of soundings using method of transient processes (ЗMPP). Disadvantages of this method are the low field work efficiency, weak mechanization of auxiliary processes (reeling, unwinding of generator and measuring loops).

In this article, description is given of apparatus which allows the increase of the level of field work mechanization using MPP soundings in conditions of tundra and steppe. It consists of gen/groups registrator, transmitter and measuring, positioned on two automobiles with trailers. Measurements EDS of transient process are conducted during short stoppages on the projective points of the profile.

To choose the optimal size of installation some investigations were done on double-measuring models of sheet type ore bodies (following the conditions of electromagnetic similarity). Parameters of medium and installation as following:

H = 2.5 ; 5 cm; hp = 0.3 cm $\rho_p = 0.17 \times 10^{-7}$ ohm-m

m = 5 cm ϕ = 0; 30; 60° Z = 2; 4; 8 cm where hp; ρp; m; H; Φ - accordingly the thickness, specific resistivity, width, depth and angle of slope of ore body model.

Measurements were taken by dipole device in which electromagnetic field was excitated by vertical magnetic dipole and measurements were taken by horizontal and vertical inductive transmitters. Measurements refer to the middle of the installation.

Illus. 1 (a, b, c (v) shows samples of graphs ε/I. nr nu (nr.nu- the number of coils (turns) of generator and measuring (circuits) loops), investigations of profile which is orientated across to the strike of ore body model.

Their analysis shows:

(1) By increasing the size of installation the amplitude decreases and its characteristics change. Positive anomaly of transient field above low-resistance non-uniformity is present when the generator measuring of the loop is located in the boundaries of ore body model. If measurement of installation higher than dimensions of low-resistance of sheet (τ>m) the sign of the anomaly EDS changes. In this case observed, local positive anomalies of peripheral parts of profile E/I.nr. nu relative to situation, at which one of the transmitters is situated in epicentre of conductive object. The distance between magnitude (E/I. nr nu)max is equal approximately to the size of the installation.

(2) The amplitude of anomaly EDS, measured by horizontal dipole decreases the quantity (E/I. nr nu) max, registered by horizontal frame.

(3) If the size of installation is commensurable with the transverse dimensions of the model of the ore body, the amplitude of anomaly $\dot{B}_\tau$ is bigger than $\dot{B}_z$. So, for example, at τ/m = 0.8 then $\dot{B}_\tau/\dot{B}_z$ equals 1.84. The decrease of value τ results in the increase of the vertical of the magnetic field component, but the horizontal one decreases. So, at Z/M=0.4 value of $\dot{B}_\tau/\dot{B}_z$ equals 0.79. The requirements to the amplitude of current in the generator loop was worked out keeping in mind a few preconditions :

a) maximum power (capacity) of source current 25 kV (at amplitude of current 500A);

b) maximum admissible currents for quick-acting thyristors - 400 A at admissible voltage 1500 V;

c) Excessive strain at current disconnection in inductive loading is 1500 V at the duration of the front of switching-off current in generator loop is 0.8 ms .

d) Generator's loop must be dismountable.

All those above mentioned preconditions can be implemented with a 10-turn generator loop. The loop towing automobile must be at least 3 m from it and quite sure that the compensation of influence of conductive mass on measuring signal proceeds successfully. The measuring loop together with pre-amplifier forms one united construction and situated a distance from the automobile.

For industrial regions where interference is quite strong the moment of the measuring loop needed is Mu = 10^3 m^2; for non-industrial Mu = 10^4 m^2. The power of the installation of automoveable apparatus is situated on the automobile ZIL-IZI with trailer. Generator GSO-300 serves as the source of current. It is connected to the automobile engine to be fed. The moment of generator loop is 2.10^5 A. m^2.

Thyristor commutator of bipolar impulse current which permits the accumulated inductive loading energy to be used for switch-on of power thyristors. Reliability of the current impulses of the commutator is insured by installation of logical protection (shielding) chosen on optron (?) which excludes cross-cuts of scheme of control and possibility of short-circuit of thyristor's outputs.'

As a result of the use of multiturn generators the front of switch-off current of 300-400A reaches 1- 1.5 ms. And, so some distortion of measured signal on early times is registered.

The influence of the front of switch-off current on the measured signal was switched off by the choice of the beginning of reading of the time of measuring. We can see it from the sample of linear front I(t) switching current in generator loop. At the registration of an exponential signal (V(τ) the analytical term (expression) would be:

$$V_1(t) = \int_0^t V(\tau) \frac{dI(t+\tau)}{dt} d\tau$$

where $V(\tau) = e^{-ct}$, $I(t) = t/T$

$V(t)$ = useful signal

$I(t)$ = front of switching-off current in generator's loop.

For time interval $t \geqslant T$ the solution is:

$$V_1(t) = \frac{1}{cT}(1-e^{-ct}).$$

Analyses of signals of rectangle and trapezoidal impulses show that the last signal was displaced accordingly to the true quantity t, which equals T/2. Thus, the choice of the beginning of readings is the moment when the current of switching-off is equal to half of the set value fully allows the avoidance of errors of apparatus inertia.

Characteristics of measurement by small-sized loops appears as influence of the field of eddy currents, induced in the conductive mass of the apparatus on the final results of measurements. Compensation of eddy currents in the body of the automobile of the trailers was carried out by a short-circuited coil situated in a manner such that the eddy currents produced in it would have reverse polarity.

The table (p.73) shows a sample of compensation of parasitic signal. The level of compensation corresponds to the level of external error, while parasitic signal compensates by 200-300 times.

t, ms	$\frac{\epsilon V}{I}$, μV/A		
	Factual	Corrected	Measured

To investigate the possibilities of a moveable electroresearch station for solving field problems, practical and methodical procedures were carried out in one of the ores of Altai region, which was explored using well advanced drilling and geophysical methods.

Drilling was used to determine contours of ore body of the geological structure of the rocks. In this way, the work with model of the moveable autoelectro research apparatus was done on the spot, and so it was possible to check the reliability of measurements and effectiveness of usage of given modification MPP. The presence of low-resistance unconsolidated deposits (ρ_τ = 3 - 50 m) with thickness 70 - 130 m covering the ore body, allows one to determine the possibilities of the equipment in complicated geological conditions.

100 soundings with installations τ=50 and τ=80 m were done. The level of industrial disturbance (50 Hz) contained some millivolts. Interpretation of curves was provided on ZVM BESM - 4 (Fig. 1, 2).

Using field measurement results the scheme was completed of total longitudinal conductivity of isolines.

Isolines repeat the contours of ore body, enlargement of value S appears near stations 25-26 (S = 26 S) where the depth of low-resistive deposits is minimal.

Beyond the margins of ore body's contours the size of total longitudinal conductivity is 14-15 S.

An interpretation example of sounding MPP on one of the profiles and also drilling results are given in Figure 2:

Figure 2: Results of works with apparatus "Tsikl-auto" (ore body Rubtsovskoe, profile 4).

1 - curves

2 - value (measuring) of depth H, obtained by MPP

3 - graph of longitudinal conductivity S

4 - contours of ore body

5 - loose sediments.

The value of the total longitudinal conductivity S increases above ore body (Stn 25-26) and on the stn 20, near which the ore body is situated.

The values H plotted also on the profile as tiny bars coincide with the base of loose deposits or with the top of ore bed.

These findings lead to a conclusion about the effectiveness of use of mobile variant ZMPP even in conditions with high industrial disturbances and complicated geoelectric structures.

Literature: (1) Method of interpretation of soundings MPP at search of polymetallic ores in the form of layer, by G.A. Isaev (comp.) et al. Novosibirsk, 1974, SNIIGGIMS.

(2) Methodical recommendations for use MPP in search of deep-lying iron ores, by G.A. Isaev (comp.) et al. 1977, SNIIGGIMS, Novosibirsk.

Rempel, G.G., Isaev, G.A., Itskovich, G.B., Poletaeva, N.G., (Ed.) 1977. METHODOLOGICAL RECOMMENDATIONS FOR USING TRANSIENT PROCESSES IN PROSPECTING FOR DEEP-LYING IRON ORES. SNIIGGIMS, Novosibirsk, 78 pp.

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ABSTRACT One of the current directions in developing geophysics in the next 10 years is increased research and exploration. It is very important for regions with highly developed industrial mining, where the problem is how to develop deep lying minerals.

Among electrical research methods used in Siberia for exploration of highly conductive ores like magnetite ores, special attention is given to the method of transient processes. There are new developed methods for field work using transient processes apparatus.

"Tsikl", enables the use of strong currents with advanced electronic signal averaging.

This book includes methodical recommendations and general results of exploration (page 19) method of sounding (MPP) used in exploration of iron ores, highly conducting ores; results were worked out in laboratory of SNIIGGIMS.

Priority is given to non-stationary electromagnetic fields in horizontal-non-uniform medium (sphere?), analysis of depth sounding and checking the method using model and field results.

A method of calculation of transient fields above the sphere, covered by surface S, has been used (F.M. Kamenetskii) (p.14).

For calculation of the electromagnetic field above the disc V.A. Sidorov's development was used (p.23, 24).

Calculation of the electromagnetic field above an inclined plate was worked out by G.A. Isaev, above the thin conductive disc-G. B. Itskovich, above spherical cylindrical inhomogeneities - N.G. Poletaeva.

Modelling work of horizontal cylinder, covered by thin low-resistance plate has been provided by Novosibirsk State University (I.P. Titov and I.F. Iziumov).

For the inclined plate in work of the Altai region the geophysical expedition chief was B.F. Alexenko. The main ideas of methods of field work and interpretation of sounding with MPP by G.A. Isaev. Results, theory, modelling mainly by G.B. Itskovich and N.G. Poleteva.

Field work done by MPP in iron mines done on Gornoi Shori were done by Central Geophysical Expedition (TSGE), ZSGU; interpretation of field data was done by G.A. Isaev, N.C. Paleteva (SNIIGGIMS) & N.A. Venger, V.P. Piatkovskii, Ya. Z. Sheraizin (TSGE ZSGU).

Discussion about results of field work mainly by MSc candidate G.G. Rempel, means of interpretation by G.M. Trigubovich.

Ryss, Yu, I., Bakhtan, Yu. G., Popov, Yu. V., Korostin, V.P., 1978. PROSPECTING AND INVESTIGATION OF ORES USING KSPK. (Yu. I. Ryss, (Ed.) VITR, Leningrad, 87 pp.

ABSTRACT

Described are methods and techniques of field investigations obtained using the contact method of polarizated curves (KSPK). Experience in managing field work in different regions of the country is shown. Details are given of the methods of field measurements, instruments and methods of determination of grade (size, dimension), contents and reserves of useful metals.

Special attention is paid to the projection, documentation and reporting of results.

The application of the method in different stages of estimation of ore development for exploration of copper, copper-nickel, polymetallic, lead-zinc, manganese (pyrolusite) and other ore deposits.

CONTENTS

(Ryss, Yu, I., Bakhtan, Yu. G., Popov, Yu. V., Korostin, V.P., 1978.,con't)

SNIIGGIMS, 1976. SOUNDING IN THE NEAR ZONE BY THE METHOD OF FIELD BUILDUP. Siberian Scientific Research Institute of Geology, Geophysics and Mineral Resources. Moscow, "Nedra", 102 pp.

ABSTRACT

Methodical problems of electromagnetic field sounding measurements by the field buildup in the near zone (ZSBZ) and construction of electrical apparatus are discussed. Material for this book shows the experience of using the method of sounding by field buildup in the near zone on the Siberian platform. Investigation of problems and apparatus is very important for the development and application of the method. Analysis of technical conditions of the apparatus construction allows the formulation of the requirements of the form of current, the range of registration, the range of transmission frequency, and examination of basic types of interference and methods of their suppression - this all allows to choose the optimal scheme for the processing of numerical electroprospecting station Tsikl 2.

This book is for geophysicists in NII, and also for specialists on method ZSBZ.

CONTENTS

Contents.

(Translators Note: ZSBZ = Zondirovanie Stanovleniem polia v Blizhned Zone, or Sounding (field) Buildup Near Zone)

Surkov, V.S., and Matizen, E.V. (Eds), 1977. SUPERCONDUCTIVITY APPLICATION IN GEO-ELECTRICAL PROSPECTING. "Nauka", Novosibirsk, 222 pp.

Authors: D.S. Mirinskii, B.I. Rabinovich, V.N. Shakhtarin, A.I. Arenshtam, A.I. Benenson, V.G. Novitskii, E.V. Kholopov, Ia. I. Gitarts, M.M. Gol'dman, G.A. Isaev, S.A. Mezentsev, B.M. Rogachevskii, A.A. Shpunt.

ABSTRACT

Described is the possibility of application of super conducting systems for construction of geophysical apparatus used for searching for deep laying ores and oil and gas deposits with electrical, prospecting method. Analysis of sources of current for generator installations is given; emphasis is given to the superiority of unipolar generator with liquid metallic current collection and superconducting winding, of excitation. Magnetometers on the basis of superconductive modulators and quantum measure of magnetic current are described. Analysed are possibilities of a new method of electric prospecting, based on the use of superconductive magnetic systems. Attention has been paid to cryogenic technique and its exploitation in field conditions, to superconductive magnetic systems, to methods of their calculation and to the ways of stabilization. Ecological and medico-biological aspects of application of powerful generating installations are studied.

Useful for specialists in the field of production of geophysical apparatus, also for wide range of people using superconductivity in other fields.

CONTENTS

Detailed contents-

(Surkov, V.Z., and Matizen, E.V. (Eds), 1977. cont.)

Svetov, B.S., Mizuk, L.Y., Podzhariy, V.M., 1969. MINING ELECTRICAL PROSPECTING BY THE METHOD OF ELLIPTICALLY POLARIZED FIELD. "Nedra" Moscow, 136 pp.

CONTENTS

Tabarovskiy, L.A., 1975. USE OF THE INTEGRAL EQUATION METHOD IN PROBLEMS OF GEOELECTRICITY (M.M. Lavrent'ev, Ed.). Acad. Sciences USSR. "Nauka", Novosibirst, 140 pp.

ABSTRACT. The book has been devoted to the solution of theoretical and application problems using the integral equation method, esp. for problems of geoelectrical characteristics.

Discussed is the method of auxiliary sources for building-up the system of integral equation in problems of diffraction of harmonical fields or non-uniformities. Investigation has been made on auxiliary fields of point, linear and circular sources in horizontal-bedded media. Method of calculation of source fields in horizontal-bedded medium, based on the ways of deformation in complex plane of integration variable has been developed. Situation location of space spectrum poles of field components has been worked out. The theory has been laid out about electromagnetic fields in quasi-three-dimensional models (source-arbitrary). The book is written for specialists in electromagnetic methods for geophysical investigations.

CONTENTS

Tabarovskiy, L.A., 1977a

Characteristics of potentials of a simple (flat-lying) layer in anisotropic medium.

Geologia i Geofizika, Academy of Sciences of USSR, No. 4, 1977. p. 84-92.

ABSTRACT

The behaviour of electric field components is studied for the system of point current source distributed with equidensity over a flat-lying surface of arbitrary shape. The relationship obtained is made the basis for constructing the theory of potentials and integral equations for anisotropic media. The latter problem is very actual owing to the requirements of d.c. electrologging used for ore prospecting.

Tabarovskiy, L.A., 1977b. Integral equation solution in an anisotropic environment (continuation of article by same author in Geol. & Geophys. No. 4, 1977). Geol. & Geophys. No. 5, p. 81-88.

SUMMARY

The theory of potential for the ordinary layer in anisotropic media is postulated. Based on the theory are integral equations for the d.c. problems. The integration region in equations is the inhomogeneity surface. The obtained results were mainly those reported in the earlier paper of the author.

Tabarovskiy, L.A., and Gol'dman, M.M., 1978. THE USE OF FINITE DIFFERENCE METHODS FOR SOLVING NON-STATIONARY FIELDS IN ELECTRICAL PROSPECTING AND SOME PROBLEMS IN DEEP SOUNDING USING THE METHOD OF FIELD BUILDUP. SNIIGGIMS, Novosibirsk, 34 pp.

CONTENTS

Tabarovskiy, L.A., and Krivopotskii, V.S., 1978. Solving the problem of build-up of the elctromagnetic field (ZSB) in axial-symmetric models using the grid method (finite differences). Geol. & Geophys. No. 7, p. 64-72.

SUMMARY

The solution of the problem of electromagnetic field formation by applying various schemes is given. The model medium is a halfspace containing inclusion in the form of finite-thin disc. The upper halfspace conductivity is zero. The conditions for the bottom surface conjugation are changed for the integral-differential equation which permits to exclude the upper halfspace leaving formulation of the problem for the lower halfspace alone. The calculations made indicate a fair agreement and stability of the differentiation scheme.