Telluric Current

Related terms:

Electromagnetism, Electrode, Photoelectric Emission, Geomagnetism, Corrosion

View all Topics

Magnetotelluric Studies in Russia: Regional-Scale Surveys and Hydrocarbon Exploration

Mark N. Berdichevsky, ... Denis Yakovlev, in Electromagnetic Sounding of the Earth's Interior (Second Edition), 2015

13.1 Introduction

Electromagnetic (EM) geophysical methods (telluric current method, magnetotelluric (MT) sounding, frequency sounding, transient sounding) have been used in the USSR to study a deep structure of sedimentary basins and consolidated crust since 1950s. Tectonic schemes of the major sedimentary basins of the USSR were constructed and several large hydrocarbon deposits, for example, the Urengoy gas field, were discovered using telluric currents method and MT soundings, in combination with other geophysical methods. A review of major results obtained up to 1990s is presented in (Berdichevsky, 1994), indicating substantial progress in this field.

In 1990s, because of economic difficulties, the rate of EM exploration dropped dramatically. However, a rapid expansion began in 2000, caused by the depletion of established resources and by hydrocarbon (and other mineral resources) price growth.

Nowadays, electromagnetic methods, used for subsurface conductivity imaging are widely applied in Russia in three areas: regional exploration; oil and gas prospecting; and solid mineral prospecting. Regional onshore geophysical surveys are performed along single profiles that are from a few hundred to several thousand kilometers in length and run through deep boreholes. Joint application of a variety of geophysical methods is characteristic for regional surveys. The combination includes common depth point (CDP) seismic, EM, gravity and magnetic prospecting, and other methods; such as geochemical. Seismic prospecting plays the leading role, in most cases it determines the location of geological boundaries rather precisely. Other methods, in particular EM, supplement this data with information about the physical properties of rocks, characterizing their lithology, fluid content, rheological state, etc.

This chapter represents an essential revision of the material published by Bubnov et al. (2007). In the subsequent sections, we briefly cover some results of recent regional-scale surveys, with primary target being Earth crust large-scale structure, and then consider a number of case studies, aimed at hydrocarbon prospecting.

> Read full chapter

Geophysical Exploration

S.M. Gandhi, B.C. Sarkar, in Essentials of Mineral Exploration and Evaluation, 2016

5.18.1 Magnetotelluric Technique

The MT technique is a development of the telluric method which exploits certain natural earth currents (telluric currents) that propagate as sheets over vast areas on the earth. Their cause is attributed to several factors like the rotation of the earth, ionospheric currents, tropical storms, etc. These currents are interrupted and modified by large-scale natural electrical discontinuities like major geological contacts, folds, faults, shear zones, etc. MT has become one of the most important tools in deep Earth research. MT method can resolve geoelectric structure from depths of tens of meters to depths of tens of kilometers depending upon signal frequency and resistivity of material being studied. Hence, depth interpretation based on MT data is much more definitive than that based on gravity or magnetic data (Vozoff, 1972).

The low frequencies employed in MT enable larger depth penetration of several kilometers and also the resistivity of the ground obtained will be close to DC resistivity. With the fast development of technology of low noise sensors and signal processing acquisition of data up to 500 Hz is now possible. Hence its use in exploration of deep-seated mineral deposits becomes viable as well as attractive. MT has been found by many operators to be a cost-effective way to enhance an exploration program.

5.18.1.1 Controlled Source Magnetotelluric (CSMT)

An electrical dipole (an artificial source) connecting directly to the ground at a certain distance from the receivers is used in CSMT. This creates a situation similar to an EM plane wave traveling downward from the sky, in which the measurements at a certain frequency are related to the skin depth of the EM field (www.detectation.com). Natural electromagnetic waves that are generated in the earth's atmosphere by a range of physical mechanisms are being measured in CSMT. Natural electromagnetic waves decay at a rate dependent upon their wavelengths, as they travel into earth's interior (Yamashita, 1984) (www.geoservices.co.id). CSMT allows rapid reconnaissance of areas while detecting conductive zones up to 2000 m deeper. MT surveys are also employed for large area target potential evaluation and shallow crustal as well as deep crustal regional scale structural mapping (data inverse modeled to even 25 km depth). For locating future mineral deposits, combined use of 3D geophysical inversion and 3D geological models is essential.

5.18.1.2 Audio Magnetotelluric (AMT)

Instead of expensive traditional diamond drilling and borehole geophysics, AMT, a shallow penetrating EM technique, can be used as an alternative. In searching for new deposits of both brownfield and greenfield exploration, MT and AMT are being used increasingly by major and junior companies. This technique has logistic simplicity (portable by backpack to anywhere) which reduces cost and increases productivity. The installation of this system is environmentally benign and the technique is practical anywhere. Unlike seismic and IP survey methods, meaningful profiles could be constructed due to flexible site location and offline sensitivity. The direction and relative strength of offline rigid grid of conductors are indicated by "induction vectors" and are useful especially where the surface is resistive or frozen. The great advantage of MT/AMT survey is that it can penetrate zones of thick conductive clay that covers many prospective sites. Other airborne or surface technique cannot penetrate thick conductive clay zones (Quantec Geoscience, 2011).

5.18.1.3 Deep Rapid Reconnaissance and Detailed Follow-up

MT allows rapid reconnaissance of large areas, while detecting conductive zones from near surface down to 2000 m and more. Continuous picture of subsurface resistivity structure and high lateral resolution data may be redundant by placing close-spaced stations along lines. In order to keep the cost minimum, a "two-pass" methodology can be followed wherein station and line spacing are as wide as possible in the "first pass." A "second pass" with more stations at closer spacing can be done to increase resolution, once the areas of interest have been identified. This way, cost-effective identification of conductive mineralized zones could be done rapidly and accurately. This trend of two AMT sites adopted by INCO in Sudbury, Ontario, Canada, sensed a 1750-m-deep nickel deposit. Following similar method, Falconbridge also could locate two Ni–Cu mineralization zones (at ~800 and ~1350 m) (www.phoenix-geophysics.com).

5.18.1.4 Advantages of MT Surveys

MT surveys have many advantages, viz., (1) suitable for both Greenfield and Brownfield exploration; (2) exploration from surface to kilometers deep (better than other surface or airborne techniques); (3) practical over geological composition from highly resistive to highly conductive cover areas; (4) light weight portable equipment with negligible environmental impact; and (5) exploration in any season.

In various countries in the world (Canada, United States, Australia, Chile, Argentina, PNG, Russia, Mexico, etc.) MT/AMT surveys are used for base metals exploration. In many parts, exploration for precious metals and diamond (kimberlite mapping) is also done. Titan 24 magnetotelluric survey carried out in Half Mile Zn, Cu Deposit, NB, Canada, and Kidd Creek deposit area, Ontario, Canada, are shown in Fig. 5.8. In shield areas, significant MT surveys have also been done. Surveys that can be done using this technique are (1) advanced deep penetrating Titan 24 technology for MT and IP and (2) Spartan MT surveys for regional and terrain scale exploration to depths of 30 km. MT surveys have been successful in locating deep metallic mineral deposits and elusive kimberlite pipes undetectable with other EM methods. MT survey (Titan 24) carried out in Pur-Banera Prospect, Rajasthan, India, sensed the buried copper ore bodies, which were drill-proved later (Kavdia et al., 2015). The Titan 24 survey MT section and delineation of buried ore bodies along with the drill section are given in Figs. 5.9 and 5.10.

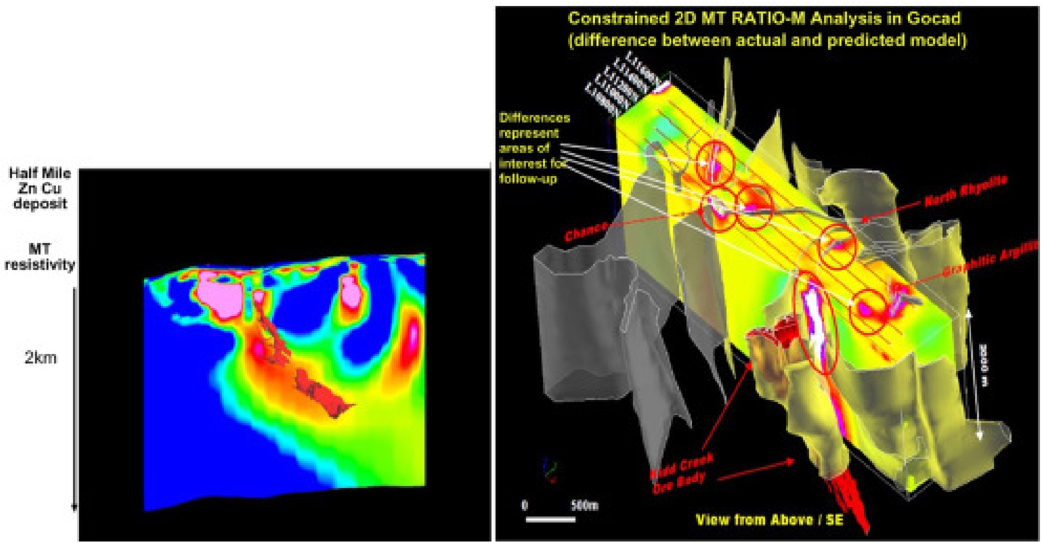

Figure 5.8. Titan 24 Magnetotelluric survey: (left) Half Mile Zn, Cu Deposit, NB, Canada and (right) Kidd Creek deposit area, Ontario, Canada.

Source: From Hollyer (2012).

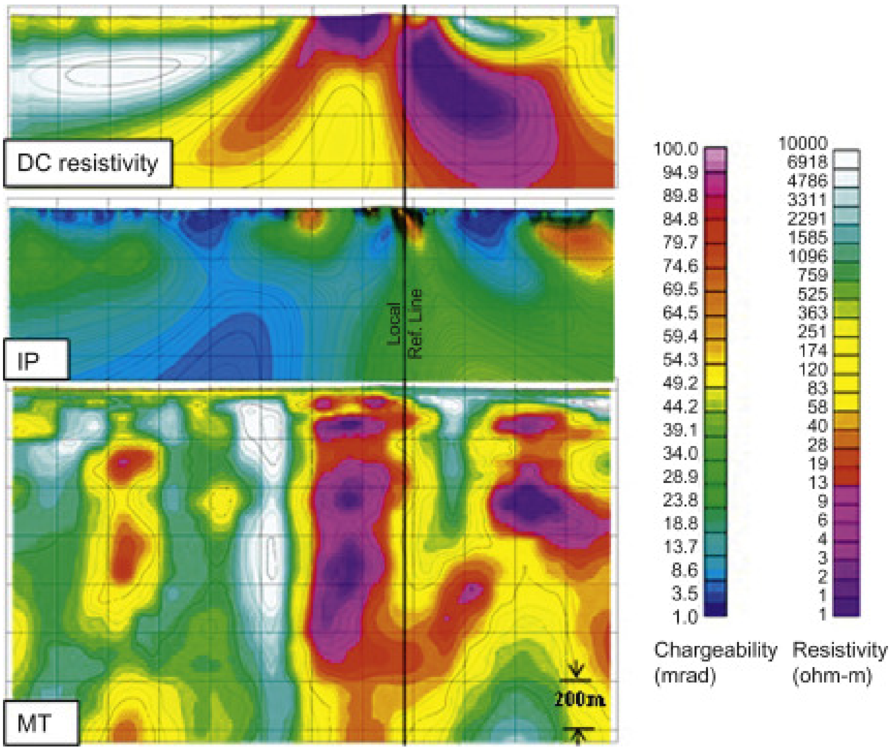

Figure 5.9. Inverted sections of DC resistivity, IP and MT along Line-5 in Pur-Dariba area (Titan 24 Survey, MT Section), Rajasthan, India.

Source: From Kavdia et al. (2015).

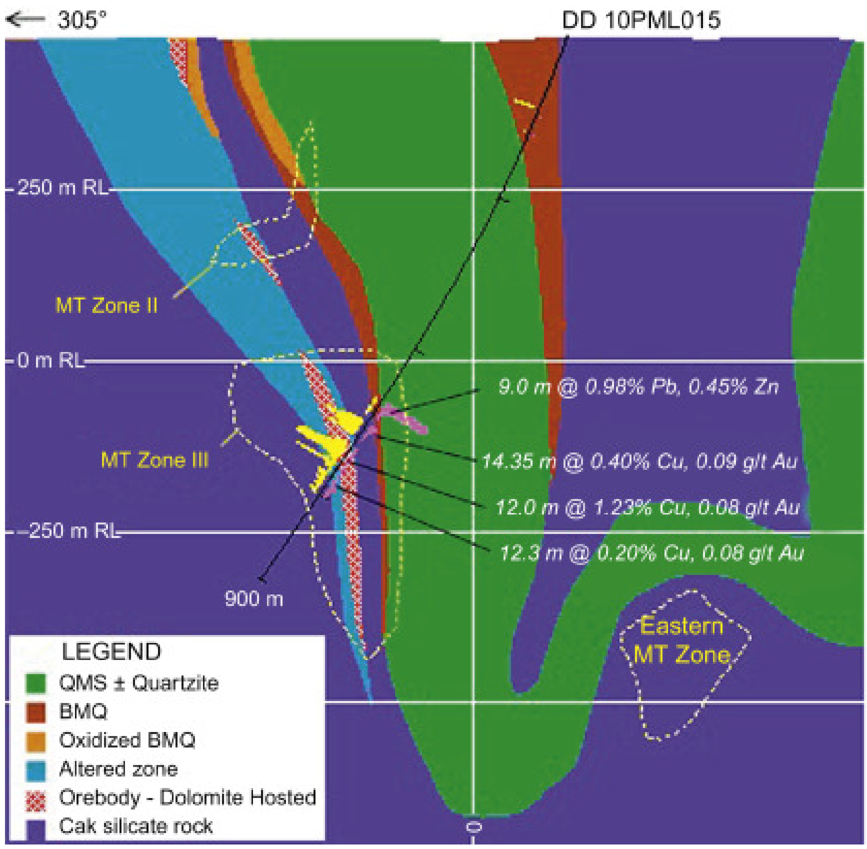

Figure 5.10. Interpreted Geological Section along Line 4 showing conductive MT zones and drill hole through Zone III, Pur-Dariba prospect, Rajasthan Histoplots: Yellow—Cu (Au) and Magenta—Pb+Zn.

Source: From Kavdia et al. (2015).

Titan 24 IP & MT surveys look deep, map mineralization, alteration, structure and lithologies in three dimensions, enable explorationists to aim their drilling programs more effectively, and find the big one early. These surveys aid in deep crustal studies (deep transect over 300 km traverse, basin and range setting, northwest Nevada; Soundings distributed at 3–4 km intervals; Data inverse modeled to 25 km depth; Basin and range geological setting). Titan 24, EM/electrical system provides DC resistivity and IP chargeability sections up to a depth of 750 m. Titan 24 is a deep earth imaging system, maps the depth, and focuses on drill programs. Titan 24 IP & MT and Spartan MT surveys are effective in the discovery of VMS-NiS, Porphyry Cu, U, and Au deposits and enable explorationists to aim their drilling program more effectively. These deep penetrating surveys help for regional and terrain scale exploration up to depths of 30 km and also enable exploration to detect positive targets at depth and let you find the big one early.

Recent innovations in airborne and downhole EM, use of AMT, adoption of 3D-Seismics are the steps in this direction. AMT and 3D-Seismic systems are being increasingly used for locating deep-seated conductive mineralized bodies (+500 m depth) in already explored and developed mining districts. Recently, 3D Seismic system located a 15-Mt massive sulfide deposit at a depth of 1100 m in New Brunswick.

> Read full chapter

Magnetotelluric Field Transformations and Their Application in Interpretation

Viacheslav V. Spichak, in Electromagnetic Sounding of the Earth's Interior (Second Edition), 2015

11.4.2 Local and Regional Anomalies

Another important problem successfully solved in terms of point field transforms is the determination of the regional strike of a structure and identification of a local disturbance against its background. To this end, Banks and Beamish (1984) took the frequency dependence of the azimuths of real inductive vectors at various points of the surface. In this way, ranges of periods (and, accordingly, of space coordinates) were established over which currents induced in the Earth are determined by the local and regional patterns of conductivity.

Menvielle and Tarits (1986) examining the Rhine–Graben conductivity model had virtually to decide upon one of the two explanations of the magnetic field anomaly by local induction in a 2-D structure or by static deviation of telluric currents by poorly conducting crystalline masses (regional structure). To find the answer to these questions, the authors resorted to the notion of adjustment distance of the inductive mechanism: for 20 (where and S is the cross-sectional area of the anomaly) they decide on the second mechanism, while for they tend to the first one. Their theoretical considerations have been confirmed experimentally: the curves for the moduli and the phases of induction vector at two different points at $T > 1000$ s coincide up to a constant factor.

Zhang et al. (1987), Bahr (1988), Groom and Bailey (1991) studied the properties of the impedance Z in a long-wave approximation, using for this purpose a model consisting of a near-surface local inhomogeneity and a regional structure.

Zhang et al. (1987) claim that the regional strike is characterized by the direction at which the elements of the columns of are proportional and their ratios and are real and independent of the period. The local strike is noted for the direction at which the impedance diagonal elements are proportional and the parameter is real, negative, and independent of the period T.

To separate the effects of local disturbance and regional induction, Bahr (1988) has elaborated a method of telluric vectors. It relies on the information about the impedance phases elements. Figure 11.11 plots phases of all the impedance tensor elements versus the coordinate system chosen. At , the phases $\square_{xy}$ and $\square_{xx}$ corresponding to the unit vector $\mathbf{e}_y$, are close, whereas the other two are not. When , the phases corresponding to $\mathbf{e}_x$ are identical. This circumstance underlies a method of determining the regional strike. Within this method, a system of coordinates is chosen to correspond to $\square_1$, and instead of four impedance phases one employs two phases of telluric currents,

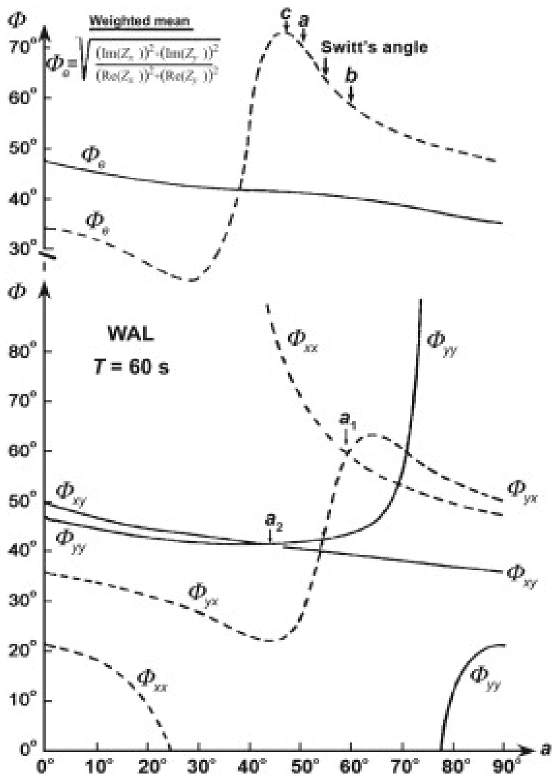

Figure 11.11. Phases of the elements of the impedance tensor (bottom) and phases of the "telluric vectors" of site WAL, $T = 1$ min, at a stepwise coordinate transformation (after Bahr, 1988).

(11.20)

which are subsequently examined.

Under the same model, when the frequency is low enough that the inductive response can be neglected, Groom and Bailey (1989) decompose the data to obtain 7 parameters per frequency: regional strike, two parameters describing the effects of the local electric field distortion (twist and shear) and two complex regional impedances.

> Read full chapter

Messages from the Earth's Crust

Leonid F. Khilyuk, ... Bernard Endres, in Gas Migration, 2000

Electrical Phenomena Associated with Rock Strain

There is some evidence that electrical rock properties change when the stresses applied to the rock are altered. There are two phenomena of interest:

1. Changes in the electrical resistivity as a result of the rock stress alteration.

2. Generation of electrical fields by piezoelectric effect.

Rocks and sediments conduct electric current in varying degrees, and appreciable changes in conductivity from one bed to another are quite common. For example, resistivity (reciprocal of conductivity) for shales varies from 1 to 100 ohm-m, whereas that of sandstones varies from 10 to 10^5 ohm-m. The conductivity is primarily a function of the electrolyte content of interstitial water and texture of the sediment (for example, tortuosity). The electrical properties of various minerals and rocks are given by Guyod (1944, p. 5).

There are many sources of potential difference in the ground and the principal ones include: (1) electrochemical action, (2) contact of dissimilar substances, and (3) electromagnetic induction (Chilingar et al., 1966). Any dissimilarity existing between two substances, which are in contact with each other, results in a potential difference between them. It is not necessary, however, for a current to flow between substances having potential differences. If there is a potential difference in a homogeneous substance, there must be a current flowing through it somewhere. Current will only flow in a closed circuit; otherwise a battery or a capacitor situation is present.

In addition to telluric currents, there appears to be a steady vertical electric current in the earth's crust having a density of 1–100 amp/km (R. Ambronn, 1926; in Guyod, 1944, p. 97).

Streaming potential (electromotive force) is generated across a porous membrane when an electrolyte is forced (by pressure) through the porous medium. On the other hand, application of direct current to a porous medium filled with solutions results in steady movement of positively charged ions toward the negative electrode (Chilingar et al., 1965, 1970).

The change in resistivity is a function of changes in the porosity, fluid saturation, and chemistry of interstitial fluids. Therefore, measurements of electrical resistivity can provide information on porosity that can be altered as a result of variations in stresses. The changes in permeability, in turn, change the migration rates of gases to the surface. This presents one possible explanation for the radon gas migration to, and changes of its concentration in, the near-surface layers (radon anomalies) on the eve of major seismic events.

It is difficult to explain the generation of strong electric fields (usually DC fields) in the ground. The existence of these fields may explain the lights in the atmosphere on the eve of strong earthquakes. These fields may be generated by the piezoelectric effect, which manifests itself in pronounced redistribution of electrical charges in some minerals when strong pressure is applied. They can be developed and maintained *if* the resistivity of rocks is of an order of 10^9 ohm/meter (the resistivity of quartz) and the mineral crystals are statistically oriented over several kilometers (which seems to be highly improbable). Because the realistic values of resistivity are in the range of 10 to 10^4 ohm/meter, Morrison (1976) stated that it is difficult to expect the development of significant DC fields in the ground.

The piezoelectric fields associated with high-frequency components of seismic waves may form AC fields. This does not apply to shallow quakes, for which seismic waves and associated changes in stresses would decay very quickly and could not be registered at the surface. It is necessary to note that these fields can be generated by seismic waves at the time an earthquake occurs or as a result of foreshocks and, for this reason, cannot serve as premonitory events.

> Read full chapter

Magnetotelluric and magnetovariational methods

Michael S. Zhdanov, in Methods in Geochemistry and Geophysics, 2009

13.4 Magnetotelluric fields in horizontally inhomogeneous media

Up to this point, we have organized our analysis only for a simple geoelectric model, that of a horizontally stratified medium. But, the real earth is inhomogeneous both horizontally and vertically. To construct a complete model for the magnetotelluric methods, we must consider the basic features of the propagation of the MT field in inhomogeneous conducting media (that is, for two-dimensional and three-dimensional models, as well as one-dimensional models).

13.4.1 Concepts of external and internal, normal and anomalous parts of an electromagnetic field

We will examine a model in which a conducting earth is bounded at $z = 0$ by a uniform insulating half-space (Figure 13.17). The distribution of electrical conductivity in the earth will be represented in the form:

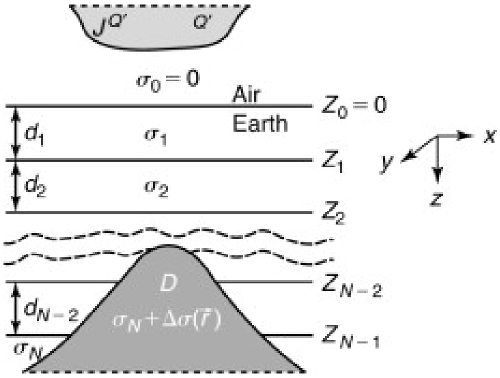

Figure 13.17. Model used in developing the concepts of internal, external,normal, and anomalous parts of an electromagnetic field. In contrast to the model in Figure 13.16, this model includes a region, *D*, with a resistivity distribution that differs from a one-dimensional resistivity profile.

(13.61)

where $\sigma_n(z)$ is the normal distribution of electrical conductivity, characteristic of an *N*-layered horizontally stratified earth, $\Delta\sigma$ is the anomalous (disturbing) electrical conductivity, defined as the deviation of resistivity in an inhomogeneous region *D* from that of the normal section,

(13.62)

The field in this model is excited by the flow of currents with a density $\mathbf{j}_Q$ in a region *Q* in the upper half-space (Figure 13.17).

The distinction between internal and external fields is of great importance in the theory of electromagnetic induction in the earth.

Definition 1. The field excited by the magnetospheric-ionospheric currents $\mathbf{j}_Q$ in the absence of a conducting earth is called the *external field*. It is designated with the symbols $\mathbf{H}_e$ and $\mathbf{E}_e$.

Definition 2. The part of the total field excited by telluric currents induced in a conducting earth is called the *internal field*, and is designated by the symbols $\mathbf{H}_i$ and $\mathbf{E}_i$.

With these definitions, the total electromagnetic field in the model will be the sum of the internal and external fields:

(13.63)

In these equations, the external fields take the form

(13.64)

To describe the electromagnetic field in the model we are considering, in addition to the terms in equation (13.63), we can also represent the total fields as the sum of normal $\mathbf{H}_n$ and $\mathbf{E}_n$ and anomalous $\mathbf{H}_a$ and $\mathbf{E}_a$ fields:

(13.65)

Definition 3. The field excited by the magnetospheric-ionospheric currents $\mathbf{j}_Q$ in normal, horizontally stratified earth, □*n* (*z*), is called the *normal field*.

Definition 4. The part of the total field contributed by the distortion of current flow, $\mathbf{j}_D$ = Δ□**E**, in the inhomogeneous region *D* is called the *anomalous field*.

The normal field satisfies the equations:

(13.66)

13.4.2 Anomalous electromagnetic fields and their classification

Anomalous electromagnetic fields, or electromagnetic anomalies, reflect the effect of horizontal geoelectric inhomogeneities. Depending on the depth to the geoelectric inhomogeneity, electromagnetic anomalies can be divided into two classes:

- *near-surface anomalies*, indicating inhomogeneities in the shallow layers forming the sedimentary complex and ocean basins; and
- *deep-seated anomalies*, related to inhomogeneities in earth's crystalline crust and upper mantle.

If near-surface and deep-seated anomalies are coincident in location, the distinction between the two is difficult. Anomalous fields from shallow-seated structures affect current flow in deep-seated regions, while anomalous fields from the deep-seated regions excite effects in the near surface. The two forms of anomaly can interact in such a way that the combined effect is not merely the sum of a deep anomaly and a shallow anomaly. Such anomalies can often be distinguished on the basis of the distribution of deviant currents.

Broad anomalies which extend for hundreds or even thousands of kilometers over the surface of the earth, are called *regional anomalies*. Regional anomalies are found over major geological structures, such as depressionsin the crystalline basement surface filled with conductive sedimentary rocks, or zones of enhanced conductivity in the upper mantle. Anomalies associated with coastal effects and the ocean basins are also regional in character.

Against a background of regional anomalies, one finds local anomalies which have dimensions of tens of kilometers. These local anomalies are often associated with lateral changes in the character of sedimentary rocks, deep faults and displacements, hydrothermal action, and many other factors which will affect the conductivity of rocks locally. The form of an electromagnetic anomaly will depend on the geometry of the geoelectric inhomogeneity. In electrical prospecting, we talk of two-dimensional and three-dimensional inhomogeneities. Two-dimensional inhomogeneities might be considered to be mathematical abstractions, existing only in theory. However, if the real inhomogeneity has a length which is considerably greater than its width, there is considerable merit in treating it as two-dimensional, that is, independent of one coordinate. We might call such anomalies *quasi two-dimensional*. Structures which cannot be called two dimensional by any stretch of the imagination are considered to be *three-dimensional*.

13.4.3 Fields in two-dimensionallyinhomogeneous media and the concepts of *E* and *H* polarization

In order to simplify or discussion of two-dimensional structures, we will always use coordinate systems in which the long extent of the two-dimensional structure lies along the *y* axis (Figure 13.17). We will also assume that the current density in the magnetosphere and ionosphere will not vary along the *y* direction. Therefore, the electromagnetic field in a given model will also be two-dimensional; that is, it will not vary along the *y* axis.

For such two-dimensional models, we can simplify Maxwell's equations,

as follows. Considering that all derivatives with respect to *y* are zero, the scalar expressions for Maxwell's equations can be written as

(13.67)

(13.68)

(13.69)

(13.70)

(13.71)

(13.72)

where = (*x*, *z*) is the conductivity as a function of location in the *xz* plane.

We find that only the field components E_x, H_y, and E_z are present in equations (13.67), (13.69), and (13.71), while only the components H_x, E_y, and H_z are present in equations (13.68), (13.70), and (13.72). The advantage of using two-dimensional models lies largely in the fact that Maxwell's equations separate naturally into two independent systems:

(13.73)

(13.74)

(13.75)

and

(13.76)

(13.77)

(13.78)

At this point, we introduce a standard notation:

(13.79)

(13.80)

The field $\mathbf{E}_H$, $\mathbf{H}_H$ is called an *H-polarized field* because the magnetic field has only a single component, H_y, which is nonzero (that is, the magnetic field is polarized to lie always on the long axis of the structure). Likewise, the field $\mathbf{E}_E$, $\mathbf{H}_E$ is called an *E-polarized field* because only the single component E_y of the electric field is nonzero (the electric field is polarized to lie always on the long axis of the structure). Equations (13.73) to (13.75) characterize the behavior of the *H*polarized field, and equations (13.76) to (13.78) characterize the behavior of the *E*-polarized field. Because these two sets of equations are independent of one another, we conclude that when the earth is structured in only two dimensions, the total electromagnetic field reduces to the sum of *Hand E*-polarized fields which propagate in the earth independently of one another:

The problem of studying the interaction of an electromagnetic field with a two-dimensionally structured earth reduces to the solution of two far simpler problems, the solution of problems for *E*-polarized and *H*-polarized fields separately. The simplicity lies in the fact that when *E*-polarized or *H*-polarized fields are considered, Maxwell's vector equations reduce to scalar differential equations.

Initially, let us examine a case with *E* polarization (equations (13.68), (13.70), and (13.72)). Substituting equations (13.70) and (13.72) into (13.68), we obtain

(13.81)

where is a two-dimensional Laplace operator, $\partial^2/\partial x^2 + \partial^2/\partial z^2$, and $k^2 = k^2(x, z) = i\omega\mu_0\sigma(x, z)$.

Thus, the y component of the electric field for E polarization satisfies a twodimensional Helmholtz equation with the variable wave number, $k(x, z)$. The magnetic components of the field in this case are found simply by differentiating E_y according to equations (13.70) and (13.72).

In the case of H polarization, by substituting equations (13.73) and (13.75) into equation (13.74), we find

(13.82)

In summary, two-dimensional models permit a great reduction in the amount of computation necessary for the solution of forward or inverse geoelectric problems. Because of this, such models are widely used in most forms of electrical exploration.

> Read full chapter

Magnetotelluric and Magnetovariational Methods

Michael S. Zhdanov, in Foundations of Geophysical Electromagnetic Theory and Methods (Second Edition), 2018

13.4 Magnetotelluric Fields in Horizontally Inhomogeneous Media

Up to this point, we have organized our analysis only for a simple geoelectric model, that of a horizontally stratified medium. But, the real earth is inhomogeneous both horizontally and vertically. To construct a complete model for the magnetotelluric methods, we must consider the basic features of the propagation of the MT field in inhomogeneous conducting media (that is, for two-dimensional and three-dimensional models, as well as one-dimensional models).

13.4.1 Concepts of External and Internal, Normal and Anomalous Parts of an Electromagnetic Field

We will examine a model in which a conducting earth is bounded at by a uniform insulating half-space (Fig. 13.17). The distribution of electrical conductivity in the earth will be represented in the form:

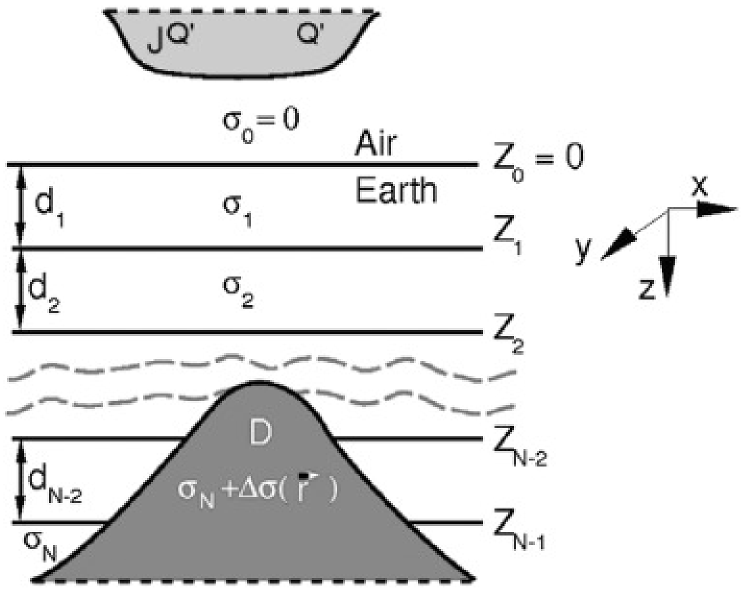

Figure 13.17. Model used in developing the concepts of internal, external, normal, and anomalous parts of an electromagnetic field. In contrast to the model in Fig. 13.16, this model includes a region, *D*, with a resistivity distribution that differs from a one-dimensional resistivity profile.

(13.61)

where is the normal distribution of electrical conductivity, characteristic of an *N*-layered horizontally stratified earth, Δ is the anomalous (disturbing) electrical conductivity, defined as the deviation of resistivity in an inhomogeneous region *D* from that of the normal section,

(13.62)

The field in this model is excited by the flow of currents with a density in a region *Q* in the upper half-space (Fig. 13.17).

The distinction between internal and external fields is of great importance in the theory of electromagnetic induction in the earth.

Definition 1

The field excited by the magnetospheric-ionospheric currents in the absence of a conducting earth is called the *external field*. It is designated with the symbols and .

Definition 2

The part of the total field excited by telluric currents induced in a conducting earth is called the *internal field*, and is designated by the symbols and .

With these definitions, the total electromagnetic field in the model will be the sum of the internal and external fields:

(13.63)

In these equations, the external fields take the form

(13.64)

To describe the electromagnetic field in the model we are considering, in addition to the terms in Eq. (13.63), we can also represent the total fields as the sum of normal and and anomalous and fields:

(13.65)

Definition 3

The field excited by the magnetospheric-ionospheric currents in normal, horizontally stratified earth, , is called the *normal field*.

Definition 4

The part of the total field contributed by the distortion of current flow, , in the inhomogeneous region *D* is called the *anomalous field*.

The normal field satisfies the equations:

(13.66)

13.4.2 Anomalous Electromagnetic Fields and Their Classification

Anomalous electromagnetic fields, or electromagnetic anomalies, reflect the effect of horizontal geoelectric inhomogeneities. Depending on the depth to the geoelectric inhomogeneity, electromagnetic anomalies can be divided into two classes:

- a) *near-surface anomalies*, indicating inhomogeneities in the shallow layers forming the sedimentary complex and ocean basins; and
- b) *deep-seated anomalies*, related to inhomogeneities in earth's crystalline crust and upper mantle.

If near-surface and deep-seated anomalies are coincident in location, the distinction between the two is difficult. Anomalous fields from shallow-seated structures affect current flow in deep-seated regions, while anomalous fields from the deep-seated regions excite effects in the near surface. The two forms of anomaly can interact in such a way that the combined effect is not merely the sum of a deep anomaly and a shallow anomaly. Such anomalies can often be distinguished on the basis of the distribution of deviant currents.

Broad anomalies which extend for hundreds or even thousands of kilometers over the surface of the earth, are called *regional anomalies*. Regional anomalies are found over major geological structures, such as depressions in the crystalline basement surface filled with conductive sedimentary rocks, or zones of enhanced conductivity in the upper mantle. Anomalies associated with coastal effects and the ocean basins are also regional in character.

Against a background of regional anomalies, one finds local anomalies which have dimensions of tens of kilometers. These local anomalies are often associated with lateral changes in the character of sedimentary rocks, deep faults and displacements, hydrothermal action, and many other factors which will affect the conductivity of rocks locally. The form of an electromagnetic anomaly will depend on the geometry of the geoelectric inhomogeneity. In electrical prospecting, we talk of two-dimensional and three-dimensional inhomogeneities. Two-dimensional inhomogeneities might be considered to be mathematical abstractions, existing only in theory. However, if the real inhomogeneity has a length which is considerably greater than its width, there is considerable merit in treating it as two-dimensional, that is, independent of one coordinate. We might call such anomalies *quasi two-dimensional*. Structures which cannot be called two dimensional by any stretch of the imagination are considered to be *three-dimensional*.

13.4.3 Fields in Two-Dimensionally Inhomogeneous Media and the Concepts of E and H Polarization

In order to simplify or discussion of two-dimensional structures, we will always use coordinate systems in which the long extent of the two-dimensional structure lies along the y axis (Fig. 13.17). We will also assume that the current density in the magnetosphere and ionosphere will not vary along the y direction. Therefore, the electromagnetic field in a given model will also be two-dimensional; that is, it will not vary along the y axis.

For such two-dimensional models, we can simplify Maxwell's equations,

as follows. Considering that all derivatives with respect to y are zero, the scalar expressions for Maxwell's equations can be written as

(13.67)

(13.68)

(13.69)

(13.70)

(13.71)

(13.72)

where is the conductivity as a function of location in the *xz* plane.

We find that only the field components , , and are present in Eqs. (13.67), (13.69), and (13.71), while only the components , , and are present in Eqs. (13.68), (13.70), and (13.72). The advantage of using two-dimensional models lies largely in the fact that Maxwell's equations separate naturally into two independent systems:

(13.73)

(13.74)

(13.75)

and

(13.76)

(13.77)

(13.78)

At this point, we introduce a standard notation:

(13.79)

(13.80)

The field is called an *H-polarized field* because the magnetic field has only a single component, , which is nonzero (that is, the magnetic field is polarized to lie always on the long axis of the structure). Likewise, the field is called an *E-polarized field* because only the single component of the electric field is nonzero (the electric field is polarized to lie always on the long axis of the structure). Eqs. (13.73) to (13.75) characterize the behavior of the *H*-polarized field, and Eqs. (13.76) to (13.78) characterize the behavior of the *E*-polarized field. Because these two sets of equations are independent of one another, we conclude that when the earth is structured in only two dimensions, the total electromagnetic field reduces to the sum of *H*- and *E*-polarized fields which propagate in the earth independently of one another:

The problem of studying the interaction of an electromagnetic field with a two-dimensionally structured earth reduces to the solution of two far simpler problems, the solution of problems for *E*-polarized and *H*-polarized fields separately. The simplicity lies in the fact that when *E*-polarized or *H*-polarized fields are considered, Maxwell's vector equations reduce to scalar differential equations.

Initially, let us examine a case with *E* polarization (Eqs. (13.68), (13.70), and (13.72)). Substituting Eqs. (13.70) and (13.72) into (13.68), we obtain

(13.81)

where is a two-dimensional Laplace operator, , and .

Thus, the *y* component of the electric field for *E* polarization satisfies a two-dimensional Helmholtz equation with the variable wave number, . The magnetic components of the field in this case are found simply by differentiating according to Eqs. (13.70) and (13.72).

In the case of *H* polarization, by substituting Eqs. (13.73) and (13.75) into Eq. (13.74), we find

(13.82)

In summary, two-dimensional models permit a great reduction in the amount of computation necessary for the solution of forward or inverse geoelectric problems. Because of this, such models are widely used in most forms of electrical exploration.

> Read full chapter