ENVIRONMENTAL GEOSCIENCES

Prof. Prasoon Kumar Singh

Department of Environmental Science and Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Lecture-59

Geophysical Methods: Electrical Methods

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module eleven. Module eleven consists of geochemical classification of elements and geophysical methods. We have already completed lecture one to lecture four. Today we will discuss the lecture five that is the geophysical methods and within it we will discuss about the electrical methods.

The important concepts in this lecture will be covered like introduction to electrical methods, electrical properties associated with rocks, types of electrical methods, self-potential method, equipotential method, electromagnetic method, resistivity methods, Wenner method, Schlumberger method and applications of electrical methods. Let us start with the introduction to electrical methods. Electrical prospecting being more diversified than other geophysical methods and has been an integral part of exploration since its early stages. It relies on measuring electrical properties such as resistivity, conductivity and chargeability to investigate subsurface structures and helping in identifying mineral deposits, groundwater reservoirs, hydrocarbon-bearing formations and geological hazards. The effectiveness of these methods depends on factors like soil composition, moisture content and mineralization, making them crucial for resource exploration and hazard assessment.

Some techniques utilize naturally occurring electromagnetic fields, while others employ artificial sources to induce currents in subsurface materials. The variety of surface and airborne electromagnetic methods allows their application in diverse fields such as oil and gas prospecting, mining, geothermal exploration, groundwater studies, engineering geophysics, and waste disposal. Although primarily valuable for locating metallic mineral deposits, these methods also contribute to oil exploration, structural interpretation, and well logging. In many regions, the metallic sulfide ore deposits have been discovered by using the electromagnetic methods, which involve passing an alternating current through a loop of cable on the ground to induce currents in conductive ore bodies. The resulting induction currents are measured at the surface, providing insights into the ore body's location.

This induction method has now evolved into airborne electromagnetic surveys, enhancing large-scale exploration efficiency. In electrical well logging, continuous resistivity measurements are recorded and compared with adjacent boreholes to correlate encountered beds. Additionally, self-potential logging utilizes the natural potential of different subsurface layers where one electrode remains fixed at the borehole top while another is lowered to record continuous voltage differences, further aiding in subsurface characterization. Now let us understand the electrical properties associated with rocks. Electrical prospecting uses three phenomena by the properties associated with rocks.

First is the resistivity that is the reciprocal of the conductivity which governs the amount of current that passes through the rock when a specified potential difference is applied. Second is the electrochemical activity caused by electrolytes in the ground. It is the basis for magnetic self-potential and induced polarization methods. The third one is the dielectric constant gives information on the capacity of rock material to store electric charge and governs in part, the response of rock formations to high frequency alternating currents introduced into the earth by conductive or inductive means. Now first is the resistivity.

The resistivity of any material is defined as the electrical resistance of a cylinder with a cross section of unit area and unit length. Since minerals themselves act as insulators, the effective resistivity of a rock primarily depends on its pore liquid content. Rocks with higher liquid content in pore spaces exhibit lower resistivity and the presence of saline water further reduces the resistivity. As loose materials like gravels and sands contain more water and conduct electricity better than the underlying compact bedrock, resistivity surveys are particularly valuable for determining the thickness of sediment cover over the bedrock. Now, variations in electrical conductivity among rock types arise not only from their inherent properties but also from their position relative to the Earth's surface.

In most rocks, porosity and the chemical composition of the pore water play a more crucial role in governing resistivity than the conductivity of the mineral grains themselves. The salinity of water in pore spaces is a critical factor in determining resistivity. When porous rocks lie above the water table at shallow depths or exist at great depths where pore spaces are closed due to ambient pressure, current flow is maintained through electronic conduction within the mineral grains rather than through interstitial water, making resistivity dependent on intrinsic microscopic rock properties. There is no consistent difference between the resistivity ranges of many rock types, although metamorphic and igneous rocks generally exhibit higher resistivity than the sedimentary rocks. Certain rock materials, particularly those sought in mineral exploration, tend to have anomalously low resistivity, that is high conductivity, compared to surrounding rocks, making it possible to locate them by measuring resistivity anomalies at the surface.

Similarly, many geothermal systems are characterized by highly conductive rocks at depth. Resistivity contrast which can be significant among different rock types enables electromagnetic surface sensing to provide information about the geo-electrical structure at depth. Second is the electrochemical activity. Electrochemical activity in rocks depends on their chemical composition and on the composition and concentration of the electrolytes dissolved in the groundwater with which they are in contact. Such activity governs the magnitude and sign of the voltage developed when the rock material is in equilibrium with an electrolyte.

The electrochemical activity at depth is responsible for the self-potentials measured at the surface. And third is the dielectric constant. The dielectric constant is a measure of polarizability of a material in an electric field. The polarization or electrical moment per unit volume, is proportional to the impressed electrical field, and the proportionality constant is the electrical susceptibility. Now, types of electrical methods.

The electrical methods are used mainly for the exploration of metallic mineral deposits. The electrical survey methods are generally of four types. That is, first one is the self-potential method. Second is the equipotential method. Third is the electromagnetic method.

And fourth is the resistivity method. Self potential method. In this method, the electrical energy produced by the ore body itself is directly measured and no outside energizing force is required. Certain old bodies, particularly those containing sulfide minerals, when subjected to oxidation, produce electrical currents. These electrical currents are called telluric currents.

By measuring these currents, the presence of hidden ore body can be detected. Just in the adjacent figure you see it shows a sulphide ore body which is undergoing oxidation. So this one is the ore body which is undergoing oxidation. Its upper end which is in contact with the soil mantle. So this one is the soil mantle which is chemically more active than the lower part.

Hence, a potential difference is created and electric current flows down through the ore body and returns upward through the surrounding rock. You can see in the diagram also, the electric current is just going up. Hence a potential difference is created and electric current flows down through the ore body and return upward through the surrounding rock. Here you can see the water table is also here. Because the country rocks have high resistivity, the current spread out to great distances.

On the ground lying immediately above the ore body, the currents flow towards the negative center and that negative center is O, as shown in the figure. The center of the ore body can be located by constructing an equipotential diagram. So in this way, this figure shows self-potential currents of an ore body. Second method is the equipotential method. The equipotential method is best suited at shallow deposits in the regions which is not too wet. It can be used to locate ore bodies in the glacial drift and for determining the structure beneath the soil.

This method is also used to study the geological formations with steep or vertical contacts such as ignenous intrusions. In this method, the current is introduced into the ground by means of two-line electrodes. A line electrode is a bare copper wire which is pegged into the ground at intervals. The current flows between them through the ground because of the difference in potential. Here you can see the diagram of the equipotential method also.

If the intervening ground is of uniform conductivity, the lines of equal potential will be parallel to the line electrodes which is shown by the dotted lines that is a, b, c, d, e, f, g. On the other hand, if an ore body which is better conductor than the surrounding rock is present in the ground, the lines of equal potential will be distorted. And this is shown by the solid lines that is one, two, three, four, five, six, seven, eight. Hence, by noting the distortion in the equipotential lines, the hidden ore body can be demarcated. Next is the electromagnetic method. Electrical methods, the electromagnetic method is the most favored method for search of ore bodies.

It is more precise and gives greater information regarding shape, size and position of the hidden ore body. The electromagnetic method can be used for rocky ground, barren mountain region, dry sands and ice covered ground. When an alternating current is passed through a conductor, induced currents are produced around it. If a conductor such as an ore body, lies within the induced field, it sets up a secondary induced currents around it which can be measured. In this method, a rectangular loop of insulated cable is placed on or above the ground.

Then an alternating current is supplied to the loop. The loop sets up a primary magnetic field within the surrounding ground which diminishes with distance from the loop. If a conductor that is ore body is present within the ground, a secondary field is induced about the conductor. Because both the primary and secondary fields are present at the same place, the primary field gets distorted. The ore body is outlined by measuring the distortion by sensitive receivers.

In order to detect the distortion, traverse lines are laid normal to the longer axis of the loop and normal to the hidden ore body. These traverse lines are then surveyed by the receiver. If the ground is uniform, the readings of the field will decrease with distance. On the other hand, if an ore body is hidden in the ground, the readings will rise at the boundary of the ore body. Now next method is the resistivity method.

In resistivity surveys, the amount of resistance met by an electric current which is passed through a portion of the earth is measured. The measure of resistivity is presumed to be a measure of the fluid content and porosity of rocks. Therefore, the resistivity measurements help in making distinction between saturated and unsaturated rocks and also between rocks of different porosity. The resistivity surveys are very effective in the investigation of horizontal or gently dipping rocks. This method is generally used in detecting the thickness of overburden or depth to bedrock very accurately.

The resistivity surveys have been used in the exploration of the placer deposits and bedded deposits. The resistivity methods have been used widely for the exploration of the groundwater. In regions of gentle dips, the presence of aquifers can be determined. Fault zones may also be determined as they contain electrolyte in the solution. Resistivity surveys can be used for discovering the subsurface structure and the lithology.

The buried anticlines can be traced by determining depths to strata of greater or lesser resistivity. Hence, they are also used in the exploration of petroleum. There are two methods in resistivity surveys. First method is for the vertical variations and second method is related with the horizontal variations. Vertical variation method.

This method tells the gap between the electrodes can be regularly increased along a line around a fixed center. With the increase of the electrode separation, the current goes deeper and the resistivity for different levels can be ascertained. Therefore, by a routine calculation, the depth of a boundary surface can be obtained. Next is the horizontal variation method. In this method, the electrode separation remains constant.

So lateral differences in resistivity are determined consequently and the shape of a boundary surface can be ascertained. Now within it, remains the Wenner method and Schlumberger method. Wenner method we will discuss first. In resistivity surveying, various electrode arrangements are employed, but the arrangements of shown by the Wenner is widely used. In the Wenner method, the spacing between the electrodes are kept equal.

In the figure, the spacing is designated as d. So these are the spacing. The current is introduced into the ground by two current electrodes, that is c_1 and c_2. So these are the current electrodes, c_1 and c_2. And the potential difference between the inner electrodes, that is P_1 and P_2, is measured. All the four electrodes are placed in a line.

The resistivity of the ground is determined by the equation rho is equal to two pi d into V divided by I, where rho is the resistivity, d is the distance between electrodes, V is the difference in potential between inner electrodes, and I is the current flowing between the end electrodes. In this case, the depth of exploration is approximately equal to the electrode separation. By Wenner method, two types of resistivity surveys are carried out. First is the resistivity traversing and second is the resistivity sounding. Resistivity traversing, this method is also called resistivity trenching.

It is used to investigate variations of the rock beds in the horizontal direction at constant depth. The spacing of the electrodes are kept constant while they are moved along a traverse line. The resistivity measurements are made at various stations and from the data thus obtained the resistivity curves are drawn by plotting the distance of the stations on x-axis and resistivity values on y-axis. So on x-axis the distance will be there and resistivity value will be in the y-axis. An abrupt change in the curvature of the resistivity profile indicates a change in the nature of the underlying material.

You can see from the figure also, the resistivity profile showing change in the nature of the underlying material horizontally. So, here are two materials. One is the rock, another is the glacial till. And the curve also tells us a change in the nature of the underlying material. Second is the resistivity sounding.

This method is used to investigate the nature of Subsurface data at depth. In resistivity sounding, the resistivity is measured by increasing the electrode separation progressively about a central fixed point x. As the distance between the electrodes is increased, the depth of penetration of the current is also increased. In this way, the data on variation of resistivity with depth are obtained. You can see in the diagram also, then the resistivity depth curves are drawn by plotting resistivity values on x axis and electrode spacing on y axis. Next method is the Schlumberger method.

In the Schlumberger configuration, the operator expands the electrode spacing by increasing the distance between the current electrodes, typically on a logarithmic scale, during the course of a measurement. The potential electrode spacing is assumed to be infinitesimal and the observed values of potential can be adjusted accordingly. The schlumberger electrode arrangement is illustrated in the figure shown here. The apparent resistivity at the center of a schlumberger array is generally determined by this equation, where s is the half of the current electrode separation that is AB/2. This one is the AB/2 and a = MN.

ΔV is the potential difference between M and N and I is the current flowing to A and B. So by this equation we can find out the the apparent resistivity at a certain location. Now application of electrical methods. Electrical methods are used for different purposes like first in detecting ore bodies and conductive minerals like sulfides. In identifying aquifers, groundwater flow and contamination zones. In mapping hydrocarbon bearing formation and structural traps. In assessing soil contamination, landfill leachate and salinity levels. In evaluating subsurface conditions for construction projects.

In locating buried structures, artifacts and ancient settlements. In identifying landslide prone areas, fault zones and unstable ground. In mapping frozen ground layers for infrastructure planning in cold regions. In locating buried pipelines, cables and underground utilities and in identifying unmarked graves and buried evidence. Now let us conclude the module eleven. We have discussed first the goldsmith's geochemical classification in which we have discussed the elements are classified into lithophile that is rock loving, siderophile that is iron loving, chalcophile, sulfur loving and atmophile that is gas loving based on their chemical affinities and natural distribution in the earth. Then we have discussed the elemental distribution in earth layers.

Elements are unevenly distributed in the crust, mantle and core due to their chemical properties and geological formation processes influencing rock composition and mineral resources. Then we have discussed the geophysical exploration methods in which we have discussed the various geophysical techniques like gravity, magnetic and electrical methods which help us to study the subsurface structures and locate mineral and hydrocarbon deposits. Then we have discussed the role of geochemical cycles in which we have discussed that elements participate in biogeochemical cycles, for example, carbon, nitrogen and sulfur cycles and playing a crucial role in environmental and geological processes. And lastly, we have discussed the application in mineral resource exploration. Both geochemical classification and geophysical methods are essential for mineral exploration, petroleum prospecting, groundwater detection, and environmental assessments to identify valuable sources.

The references for the Model eleven has been taken from M. B. Dobrin, then Singh Parbin, Sen A. K., Bangar K. M., Lowrie and Telford W.M. and Jan Valenta. Thank you very much to all.