Geophysical Methods of Geological Investigation: Electrical Resistivity Method

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GEOPHYSICAL INVESTIGATIONS

- Geophysical methods involve simple methods of study made on the surface with the aim of ascertaining subsurface detail.
- This is achieved by measuring certain physical properties and interpreting them mainly in terms of subsurface geology.

IMPORTANCE OF GEOPHYSICAL INVESTIGATION

- Geophysical methods are gaining importance very rapidly because of their success in solving a vast variety of problems.
- This investigation are carried out quickly. This means large area can be investigated in a reasonable short period and hence time is saved.
- The geophysical instruments in the field are simple, portable and can be operated easily. This means field work is not laborious.
- Since the work is carried out quickly and only physical observations are made without the use of chemicals, it is economical too.
- Different interferences to suit different purposes can be drawn from the same field data. For example, electrical resistivity data can be interpreted for knowing subsurface of rock types, geological structures, groundwater conditions, ore deposits depth to the bed rock, etc. Hence the investigations are multipurpose.

APPLICATIONS OF GEOPHYSICAL INVESTIGATION

- Geophysical explorations are numerous, important and widely varied.
- Investigations aimed in solving problems of regional geology.
- Investigations aimed at locating and estimating economically important mineral deposits.
- Investigations aimed at locating and assessing groundwater potential and its quality.
- Investigations aimed at solving problems connected with geology.

CLASSIFICATION OF GEOPHYSICAL METHODS

- Geophysical methods can be classified as follows:
    1. Gravimetric Method
    2. Magnetic Method
    3. Electrical Resistivity Method
    4. Seismic Method
    5. Radiometric Method
    6. Geothermal Method
- In this assessment we will discuss about Electrical Resistivity Method.

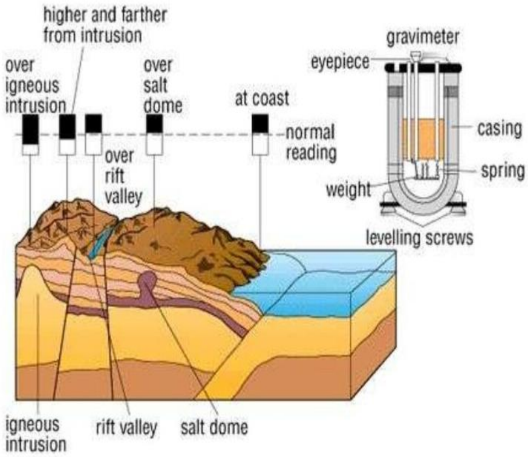

Figure 1: Gravimetric Method

Figure 2: Magnetic Method

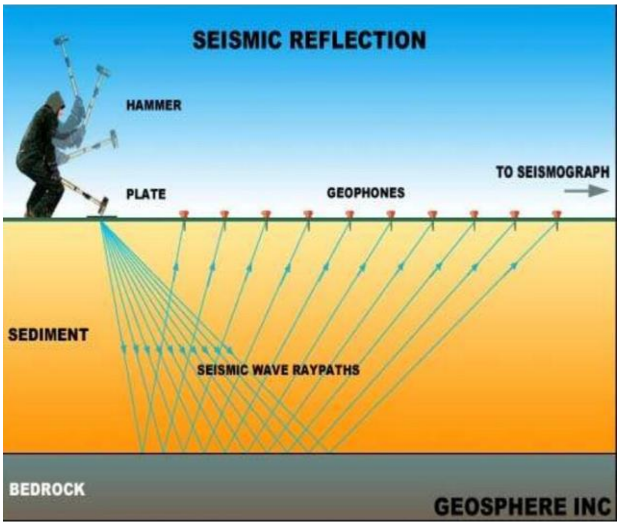

Figure 3: Seismic Method

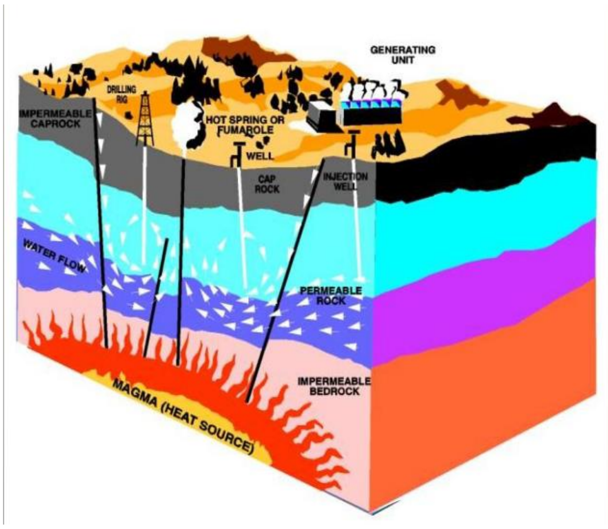

Figure 4: Geothermal Method

ELECTRICAL METHOD

- Among the methods different geophysical methods electrical method are numerous and more versatile. They are more popular because they are successful in dealing with a variety of problems like groundwater studies, subsurface structure, and many others.

Controlling Properties

- In electromagnetic methods, electrical conductivity, magnetic permeability and dielectric constant of subsurface bodies are the relevant properties.

Principle

- Electrical methods are based on the fact that the subsurface formation, structures, ore deposits, etc. posses different electrical properties. These differences are investigated suitably and exploited to draw the necessary conclusion.

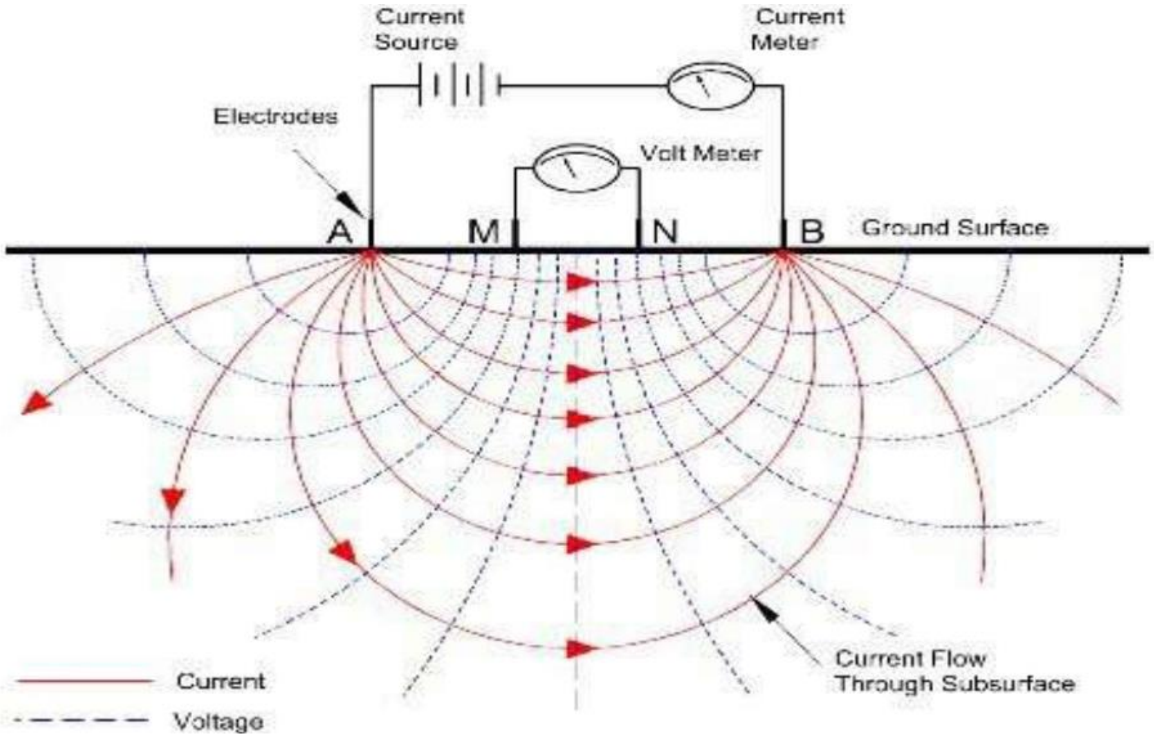

Figure 5: Diagram showing the process of electrical method

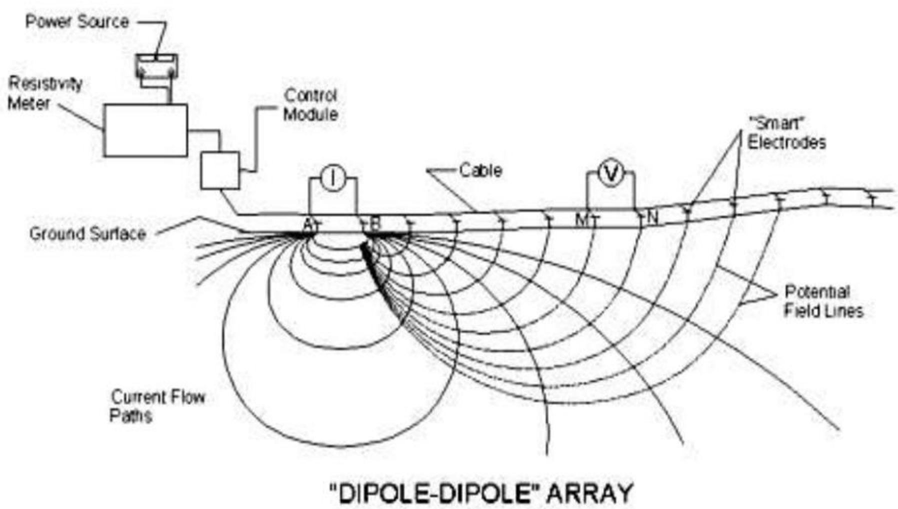

Figure 6: Dipole-Dipole Array

- We will discuss about Electrical Resistivity Method in this assessment.

ELECTRICAL RESISITIVITY METHOD

- The electrical resistivity method involves the measurement of the apparent resistivity of soils and rock as a function of depth or position.
- The resistivity of soils is a complicated function of porosity, permeability, ionic content of the pore fluids, and clay mineralization.
- The most common electrical methods used in hydrogeologic and environmental investigations are electrical soundings (resistivity soundings) and resistivity profiling.

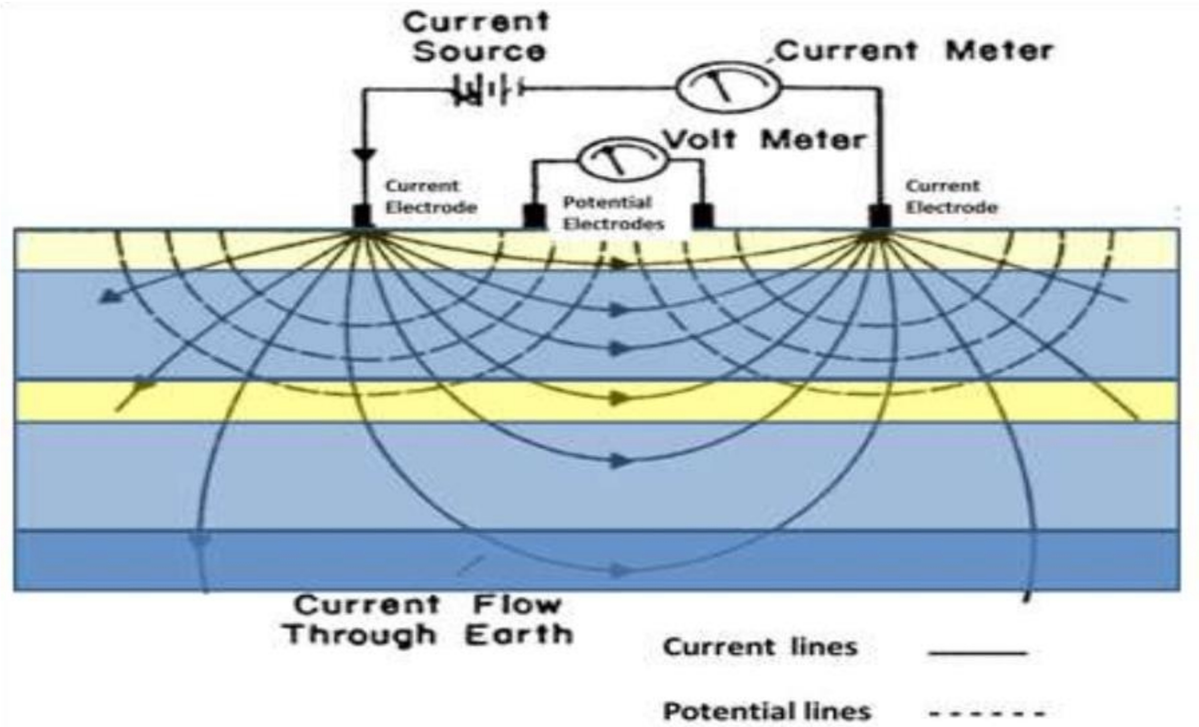

Figure 7: Process of Electrical Resistivity Method

- During resistivity surveys, current is injected into the earth through a pair of current electrodes, and the potential difference is measured between a pair of potential electrodes. The current and potential electrodes are generally arranged in a linear way.
- Common arrays include the dipole-dipole array, pole-pole array, Schlumberger array, and the Wenner array.

Schlumberger Array

- For this array (Fig 10(a)), in the limit as *a* approaches zero, the quantity V/*a* approaches the value of the potential gradient at the midpoint of the array. In practice, the sensitivity of the instruments limits the ratio of *s* to *a* and usually keeps it within the limits of about 3 to 30. Therefore, it is typical practice to use a finite electrode spacing and equation 2 to compute the geometric factor (Keller and Frischknecht, 1966). The apparent resistivity (r) is:

$$\rho_a = \pi\left[\frac{s^2}{a} - \frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2 - \frac{1}{4}\right]\frac{V}{I},$$

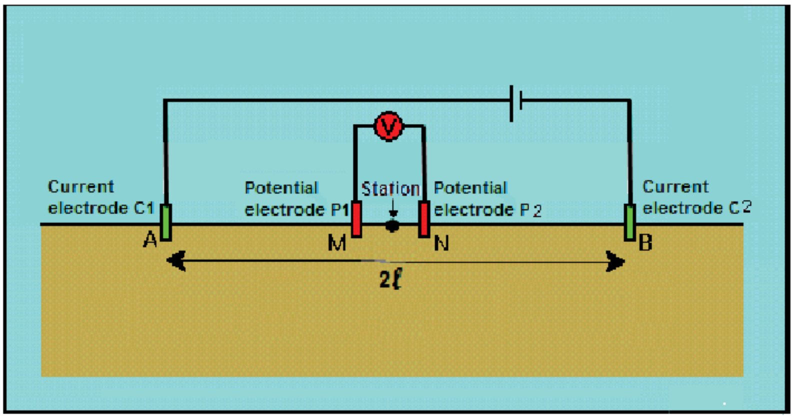

Figure 8: Schlumberger Array

- In usual field operations, the inner (potential) electrodes remain fixed, while the outer (current) electrodes are adjusted to vary the distance *s*. The spacing *a* is adjusted when it is needed because of decreasing sensitivity of measurement. The spacing *a* must never be larger than 0.4*s* or the potential gradient assumption is no longer valid. Also, the *a* spacing may sometimes be adjusted with *s* held constant in order to detect the presence of local inhomogeneities or lateral changes in the neighbourhood of the potential electrodes.

Wenner Array

- This array (Fig. 10(b)) consists of four electrodes in line, separated by equal intervals, denoted *a*. Applying equation 2, the user will find that the geometric factor K is equal to *a*, so the apparent resistivity is given by:

$$\rho_a = \pi\left[\frac{s^2}{a} - \frac{a}{4}\right]\frac{V}{I} = \pi a\left[\left(\frac{s}{a}\right)^2 - \frac{1}{4}\right]\frac{V}{I},$$

where, ρ_a= apparent resistivity, a= distance between electrodes, V= potential difference, I= current, s= electrode spacing

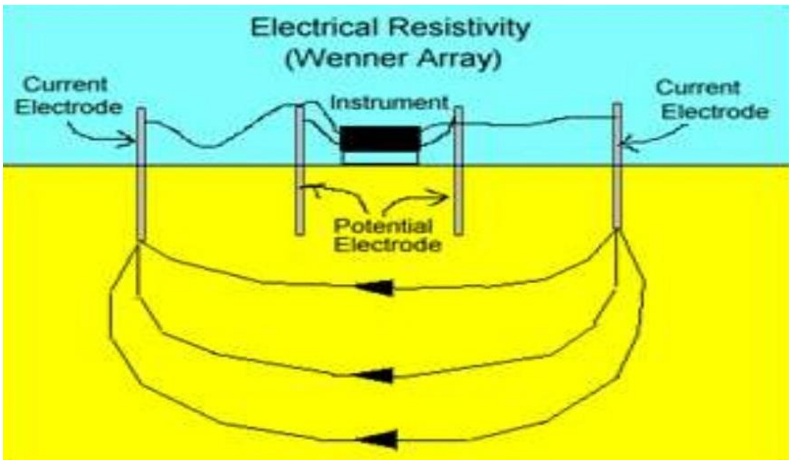

Figure 9: Wenner Array

Dipole-Dipole Array

- The dipole-dipole array (Fig. 10(c)) is one member of a family of arrays using dipoles (closely spaced electrode pairs) to measure the curvature of the potential field. If the separation between both pairs of electrodes is the same *a*, and the separation between the centres of the dipoles is restricted to *a(n+1)*, the apparent resistivity is given by:

$$\rho_a = \pi a n(n+1)(n+2)\frac{V}{I},$$

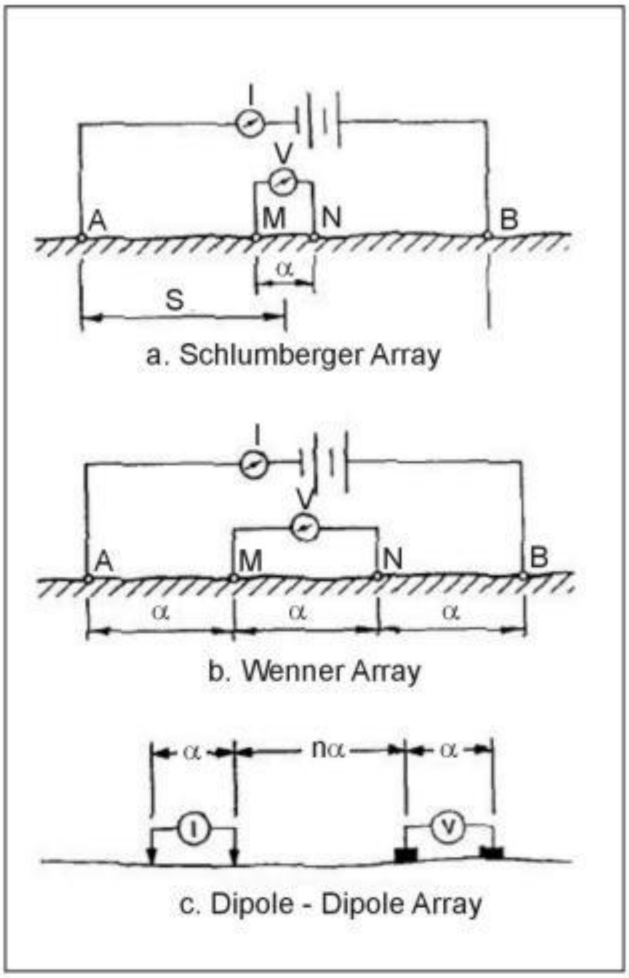

Figure 10: (a) Schlumberger Array, (b) Wenner Array, (c) Dipole-Dipole Array

Apparent Resistivity

- The apparent resistivity is the bulk average resistivity of all soils and rock influencing the current. It is calculated by dividing the measured potential difference by the input current and multiplying by a geometric factor specific to the array being used and electrode spacing.
- An electrode array with constant spacing is used to investigate lateral changes in apparent resistivity reflecting lateral geologic variability or localized anomalous

features. To investigate changes in resistivity with depth, the size of the electrode array is varied. The apparent resistivity is affected by material at increasingly greater depths (hence larger volume) as the electrode spacing is increased. Because of this effect, a plot of apparent resistivity against electrode spacing can be used to indicate vertical variations in resistivity.

In a **resistivity sounding**, the distance between the current electrodes and the potential electrodes is systematically increased, thereby yielding information on subsurface resistivity from successively greater depths. The variation of resistivity with depth is modelled using forward and inverse modelling computer software. This technique is applied to:

- Characterize subsurface hydrogeology
    1. Determine depth to bedrock/overburden thickness
    2. Determine depth to groundwater
    3. Map stratigraphy
    4. Map clay aquitards
    5. Map salt-water intrusion
- Map vertical extent of certain types of soil and groundwater contamination.
- Estimate landfill thickness.

In **resistivity profiling**, the electrode spacing is fixed, and measurements are taken at successive intervals along a profile. Data are generally presented as profiles or contour maps and interpreted qualitatively. This technique is applied to:

- Map faults
- Map lateral extent of conductive contaminant plumes
- Locate voids and karsts
- Map heavy metals soil contamination
- Delineate disposal areas
- Map paleo-channels
- Explore for sand and gravel
- Map archaeological sites

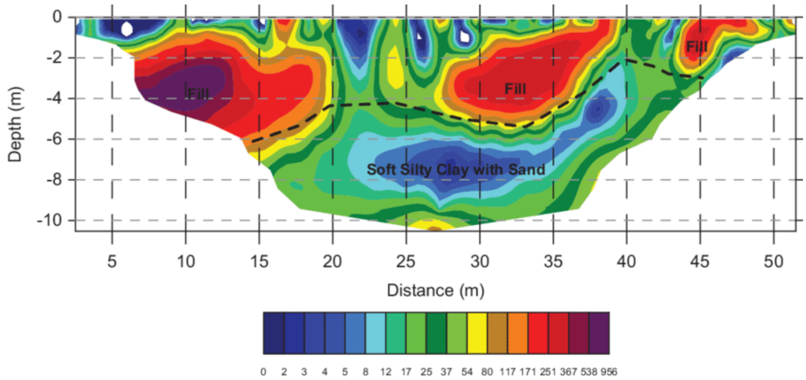

Figure 11: Electrical Resistivity imaging inversion model

- When information on both the lateral and vertical extent of a subsurface feature is desired, it is common to combine the sounding and profiling techniques. The recent advent of automated data acquisition systems has made it possible to very efficiently gather 2-D resistivity data. With these systems it is possible to lay out a large portion of the line, connect the electrodes to the data acquisition system using multi-core cable or intelligent nodes, and have the resistivity system automatically gather all of measurements using pre- programmed arrays. The resistivity data is then downloaded to a computer and modelled using 2-D forward and inverse modelling software.

ELECTRICAL RESISTIVITY METHOD FOR GROUNDWATER INVESTIGATION

- Electrical resistivity methods of geophysical prospecting are well established and the most important method for groundwater investigations. Groundwater through the various dissolved salts it contains, is ionically conductive and enables electric currents to flow into the ground. Consequently, measuring the ground resistivity gives the possibility to identify the presence of water, taking in consideration the following properties:
    1. A hard rock without pores or fracture and a dry sand without water or clay are very resistive
    2. A porous or fractured rock bearing free water has a resistivity which depends on the resistivity of the water and on the porosity of the rock
    3. An impermeable clay layer, which has bound water, has low resistivity
    4. Mineral ore bodies have very low resistivities due to their electronic conduction
- To identify the presence of groundwater from resistivity measurements, one can look to the absolute value of the ground resistivity, through the Archie law: for a practical range of fresh water resistivity of 10 to 100 ohm-m, a usual target for aquifer resistivity can be between 50 and 2000 ohm-m. Most of the time it is the relative value of the ground resistivity which is considered for detecting groundwater in a hard rock environment, a low resistivity anomaly will be the target, while in a clayey or salty environment, it is a high resistivity anomaly which will most probably correspond to fresh water. In sedimentary layers, the product of the aquifer resistivity by its thickness can be considered as representative of the interest of the aquifer. However, electrical methods cannot give an estimation of the permeability but only of the porosity. The contrast of resistivity between a fresh water and a salted is high and the depth of the water wedge is usually well determined with electrical methods.

APPLICATIONS OF ELECTRICAL METHOD

- In Prospecting: The electrical methods have been successfully employed in delineation of ore bodies occurring at shallower depths. For such surveys at great depths, these are not of much help.
  In table given below some typical value-ranges of resistivity are given. As may be seen, rocks exhibit a great variation ranging from as high resistivity as $>10^5$ ohms-meters in igneous rocks to as low as less than 1 ohm-m for clayey marls.
- In civil engineering: Resistivity methods have been widely used in engineering investigation for determination of:

1. Depth to the bed rock: As for instance, in important projects like dams, buildings and bridge foundations, where it would be desirable that the structure should rest on sound hard rocks rather than on overburden or soil.
2. Location of geological structures: Like folds, buried valleys, crushed and fractured zones due to shearing and faulting.
3. Location of Aquifers: and other water bearing zones which could be easily interpreted on the basis of known resistivity values of moisture rich rocks and dry rocks.

Table 1: Resistivity of different materials

Material	Resistivity(Ω-cm)
Massive Rock	**>400**
Shale and Clay	**1.0**
Seawater	**0.3**
Wet to moist clayey soils	**1.5-3.0**

Advantages of Electrical Resistivity Method

- It is a very rapid and economical method.
- It is a non-destructive method.
- The instrumentation of this method is very simple.
- Shallow investigations are rapid.

Disadvantages of Electrical Resistivity Method

- It can only detect absolutely different strata like rock and water.
- It provides no information about the sample.
- Cultural problems cause interference, e.g, power lines, pipelines, buried casings, fences.
- Data acquisition can be slow compared to other geophysical methods, although that difference is disappearing with the very latest techniques.

REFERENCE

1. Gangopadhyay, S., 2013. *Engineering Geology*. 1st ed. New Delhi: Oxford University Press, pp.198-207, 210-212.
2. *Geovision*- geophysical services a division of Blackhawk GeoServices