Kurdistan Region- Iraq
Ministry of Higher Education
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# NEAR SURFACE GEOPHYSICS

## Theory of ERM
## Resistivities of rocks and minerals

Earth sciences & petroleum department
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## Theory

In a homogeneous earth, current flows radially outward from the source to define a hemispherical surface. The current distribution is equal everywhere on this surface which is also called an equipotential surface (Fig. 1). Starting with Ohm’s law (*V* = *IR*) and defining the resistance *R* in terms of the resistivity *and* the area of the shell (equipotential surface), the potential difference across the shell is:

$$dV = i(R) = I\left(\rho\,\frac{L}{A}\right) = I\left(\rho\,\frac{dr}{2\pi r^2}\right)$$

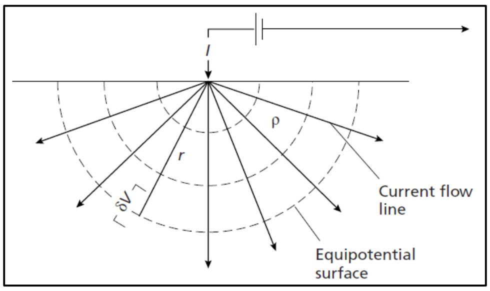


**Figure 1: Current flow from a single surface electrode.**

where *V* is the voltage (or electrical potential),
*I* is the current, ρ *is* the resistivity, and *r* is the radius of the equipotential surface.

Integrating the above equation and setting the potential at infinity to zero, the electric potential at a distance *R* from the source is given by:

$$V = \frac{\rho\ I}{2\pi\ R}$$

The *resistivity* of a material is defined as **ρ = *RA/L*** where *R* is the resistance of the material, *A* is the cross-sectional area through which current flows and *L* is the length on the material.

Resistivity has units of *ohm.m* and is not to be confused with *resistance* which has units of *ohms*.

The potential has been derived due to a single current source. The goal in resistivity surveying is to measure the potential different between two points due to the current from two current electrodes. The potential at each electrode is determined due to the current sources:

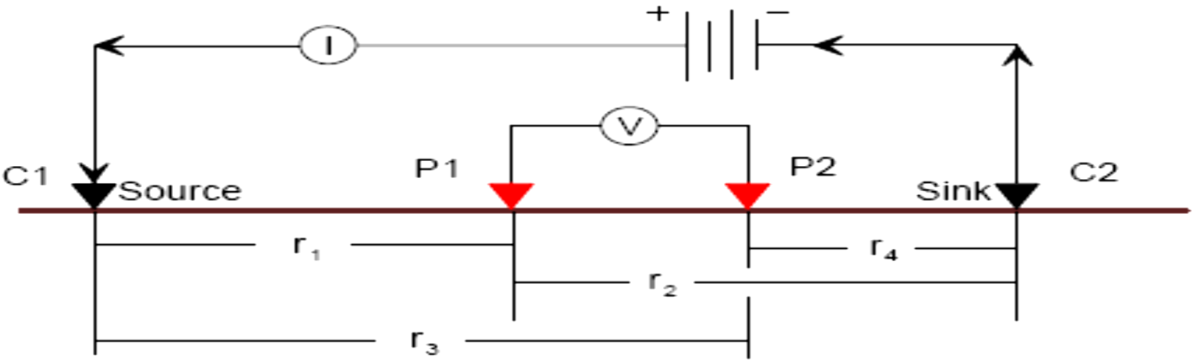
$$V_{P1} = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2}$$

$$V_{P2} = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4}$$

The potential difference V = $VP1 - VP2$ which simplifies to:

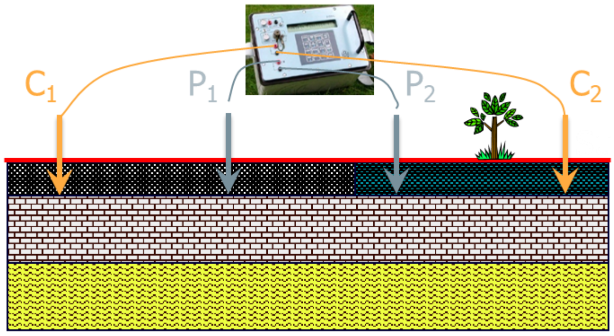
$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)$$

The above equation can then be solved for the resistivity. In a nonhomogeneous earth, the resistivity which is measured is not actually the true resistivity of the subsurface. For an earth with more than one layer, the *apparent resistivity* measured will be an average of the resistivities of the additional layers. The apparent resistivity data needs to be interpreted in terms of a subsurface model in order to determine the actual resistivities of the layers.

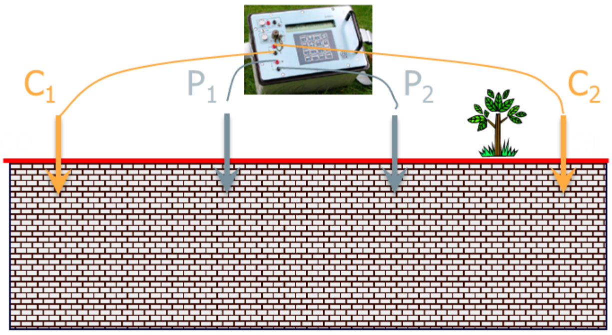


## Apparent resistivity

- If the resistivity in the ground is uniform, then the measured resistivity will be constant and independent of electrode spacing and surface location. If the resistivity in the ground is inhomogeneous, then the measured resistivity will vary with relative and absolute location of the electrodes. In this case, the measured resistivity is an ***apparent resistivity***, $\rho a$, which depends on the shape and size of anomalous regions, layering and relative values of resistivities in these regions.
- The apparent resistivity is similar to the equivalent resistivity of a circuit with resistors in parallel and series. In order to figure out how many resistors there are in the circuit and their individual resistivity, you would need to interrupt the circuit at various locations and measure the voltage. With several measurements you may be able to isolate the particular circuitry. Similarly, in the earth, by changing the relative spacing and location of the potential electrodes you can unravel where the resistors are below the surface.



**The reading represents apparent resistivity**

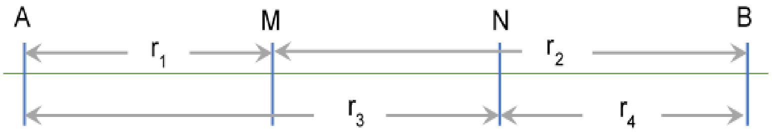


**The reading represents True resistivity**

**Calculation of Apparent Resistivity:** The most common problem encountered in resistivity sounding work is high contact resistances at the current electrodes. Whilst this does not directly affect the measured value of resistance, high contact resistances (>2kOhms) will reduce the maximum current that can be applied with the output voltage available from the meter (typically 300-400V). In order to overcome high resistances electrodes can be watered with a saturated salt solution or placed in hole filled with bentonite or clay slurry.

A, B: Are current electrodes

A, B: Are potential electrodes



After introducing current, the potential calculate by:

$$v = \frac{I\rho}{2\pi x}$$

The total potential at M and N are $V_M$ and $V_N$

The potential at M calculate by:

$$v_M = v_{r1} - v_{r2}$$

$$v_{r1} = \frac{I\rho}{2\pi r_1}, v_{r2} = \frac{I\rho}{2\pi r_2}$$

$$\therefore v_M = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2} = \frac{I\rho}{2\pi}(\frac{1}{r_1} - \frac{1}{r_2})$$

By the same way the potential at N calculate by:

$$v_N = v_{r3} - v_{r4}$$
$$v_{r3} = \frac{I\rho}{2\pi r_3}, v_{r4} = \frac{I\rho}{2\pi r_4}$$
$$\therefore v_N = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4} = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right)$$

Then the potential difference between M and N calculate by:

$$v = v_M - v_N$$
$$\therefore v = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)$$
$$\rho_a = \frac{2\pi v}{I}\left\{\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}}\right\}$$

$\rho_a$ : *is apparent resistivity*

**In homogenous area**

$$\rho_a = \rho_{true}$$

$The\ quantity\ \frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\ is\ called\ Geometrical\ Factor\ (G)$

$$\therefore \rho_a = 2\pi\ .\frac{v}{I}.G$$

**ρa= K . R**

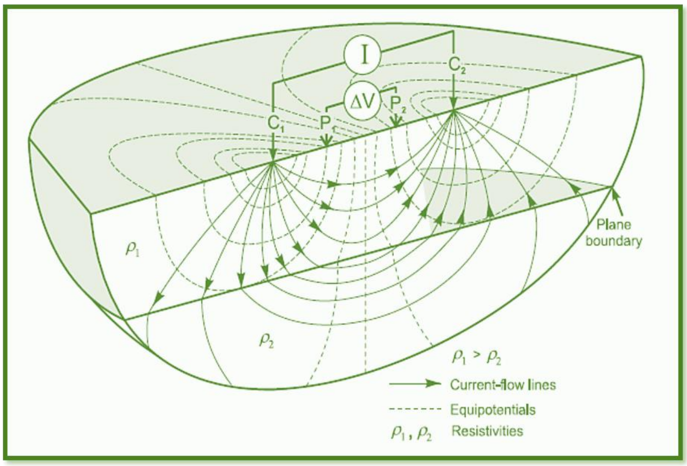


**Figure 2: Principle of resistivity measurement.**

## Conduction in the Earth

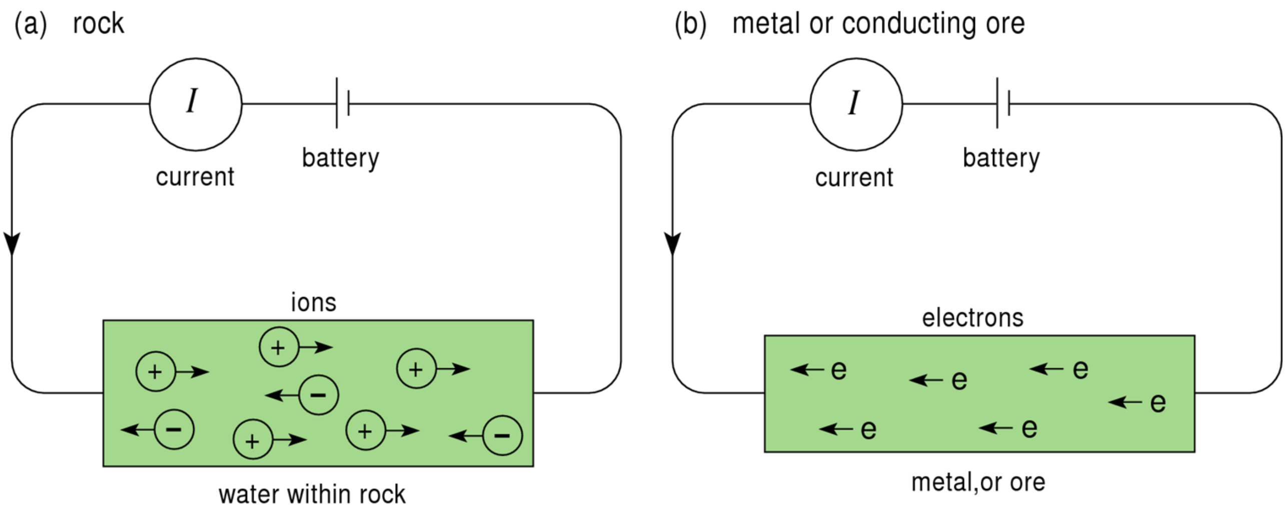
In rocks, two basic types of conduction occur:

- Electronic (**Metals allow electrons to flow freely**): Electrons are mobile in metallic ores and flow freely.

  \- Metals (wires) and some ore bodies.

- Electrolytic / Ionic (**Slow movement of ions in fluid**): Salts disassociate into ions in solution and move.

  -Involves motion of cations ($^+$) and anions ($^-$) in opposite directions.



## Resistivity of geological materials

Resistivity is one of the most variable of physical properties. Certain minerals such as native metals and graphite conduct electricity via the passage of electrons. Most rock-forming minerals are, however, insulators, and electrical current is carried through a rock mainly by the passage of ions in pore waters. Thus, most rocks conduct electricity by electrolytic rather than electronic processes. It follows that porosity is the major control of the resistivity of rocks, and that resistivity generally increases as porosity decreases. However, even crystalline rocks with negligible intergranular porosity are conductive along cracks and fissures. Figure 3 shows the range of resistivities expected for common rock types. It is apparent that there is considerable overlap between different rock types and, consequently, identification of a rock type is not possible solely on the basis of resistivity data (Fig. 3).

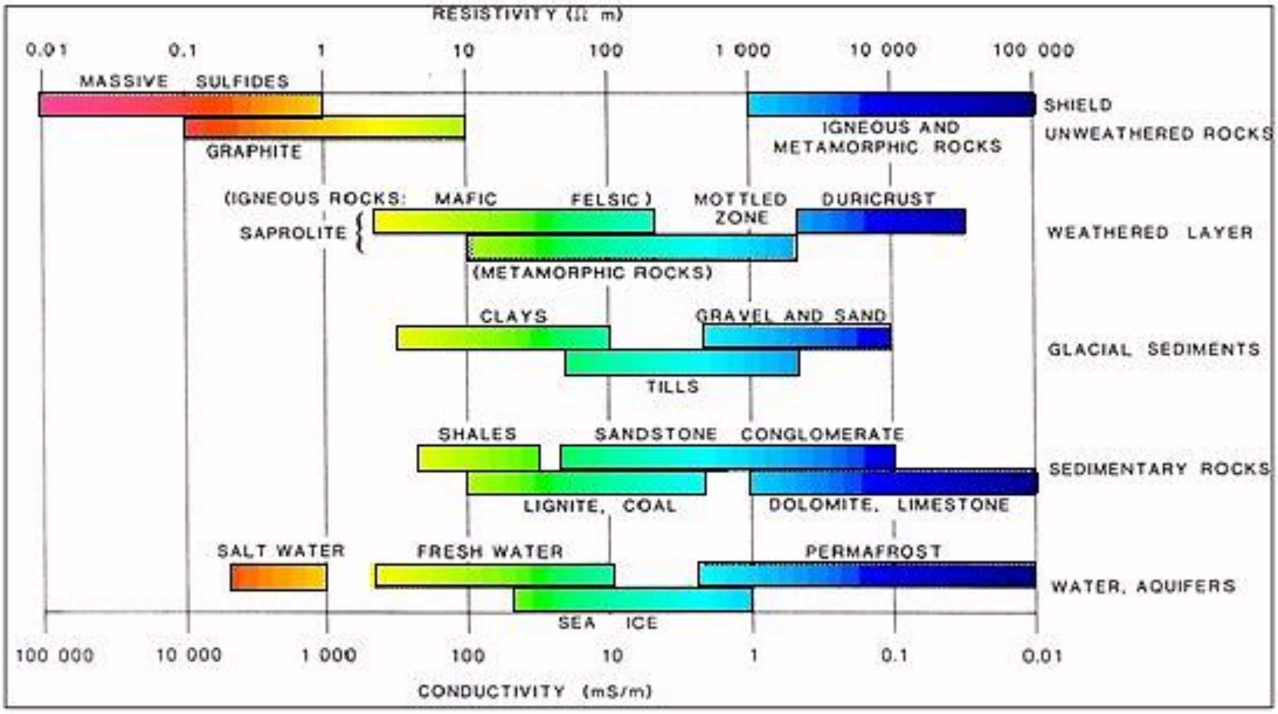


**Figure 3: Electrical resistivity and conductivity of Earth materials.**

Note that, in Figure 3, the resistivity ranges of different earth materials overlap. Thus, resistivity measurements cannot be directly related to the type of soil or rock in the subsurface without direct sampling or some other geophysical or geotechnical information. Porosity is the major controlling factor for changing resistivity because electricity flows in the near surface by the passage of ions through pore space in the subsurface materials. The porosity (amount of pore space), the permeability (connectivity of pores), the water (or other fluid) content of the pores, and the presence of salts all become contributing factors to changing resistivity. Because most minerals are insulators and rock composition tends to increase resistivity, it is easier to measure conductive anomalies than resistive ones in the subsurface. However, air, with a theoretical infinite resistivity, will produce large resistive anomalies when filling subsurface voids.

## Classification of Materials according to Resistivities Values

A) Materials which lack pore spaces will show high resistivity such as
- massive limestone
- most igneous and metamorphic (granite, basalt)

B) Materials whose pore space lacks water will show high resistivity such as:
- dry sand and gravel
- Ice.

C) Materials whose connate water is clean (free from salinity) will show high resistivity such as:

- clean sand or gravel, even if water saturated.

D) most other materials will show medium or low resistivity, especially if clay is present such as:

- clay soil
- weathered rock.

**The presence of clay minerals tends to decrease the Resistivity because:**

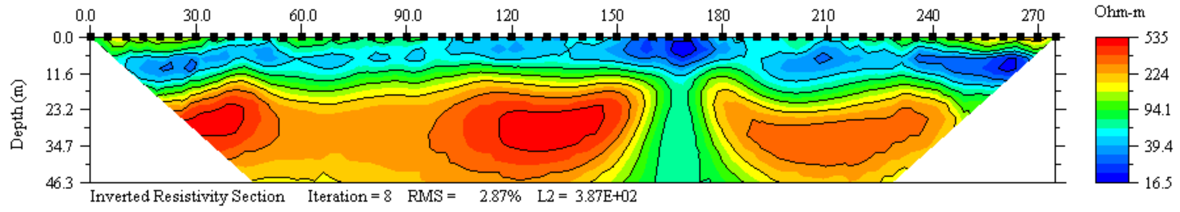
The clay minerals can combine with water.

1. The clay minerals can absorb cations in an exchangeable state on the surface.
2. The clay minerals tend to ionize and contribute to the supply of free ions.

**Factors which control the Resistivity**

1) Geologic Age
2) Salinity.
3) Free-ion content of the connate water.
4) Interconnection of the pore spaces (Permeability).
5) Temperature.
6) Porosity.
7) Pressure
8) Depth

In the shallow subsurface, the presence of water controls much of the conductivity variation. Measurement of resistivity (inverse of conductivity) is, in general, a measure of water saturation and connectivity of pore space. This is because water has a low resistivity and electric current will follow the path of least resistance. **Increasing saturation, increasing salinity of the underground water, increasing porosity of rock (water-filled voids) and increasing number of fractures (water-filled) all tend to *decrease* measured resistivity**. **Increasing compaction of soils or rock units will expel water and effectively increase resistivity**. Air, with naturally high resistivity, results in the opposite response compared to water when filling voids. Whereas the presence of water will reduce resistivity, **the presence of air in voids should increase subsurface resistivity.**



# Archie’s Law

Empirical relationship defining bulk resistivity of a saturated porous rock. In sedimentary rocks, resistivity of pore fluid is probably single most important factor controlling resistivity of whole rock.

**Archie (1942)** developed empirical formula for effective resistivity of rock:

$$\rho_t = a\rho_w\phi^{-m}s_w^{-n}$$

ρt = bulk rock resistivity
ρw = pore-water resistivity
a = empirical constant (0.6 < a < 1)
m = cementation factor (1.3 poor, unconsolidated) < m < 2.2 (good, cemented or crystalline)
φ = fractional porosity (vol liq. / vol rock)
Sw = volumetric saturation.
n = the saturation coefficient (1.5 < n < 2.5).