

GEOPHYSICAL METHODS

FUNDAMENTALS, APPLICATIONS, AND CASE STUDIES

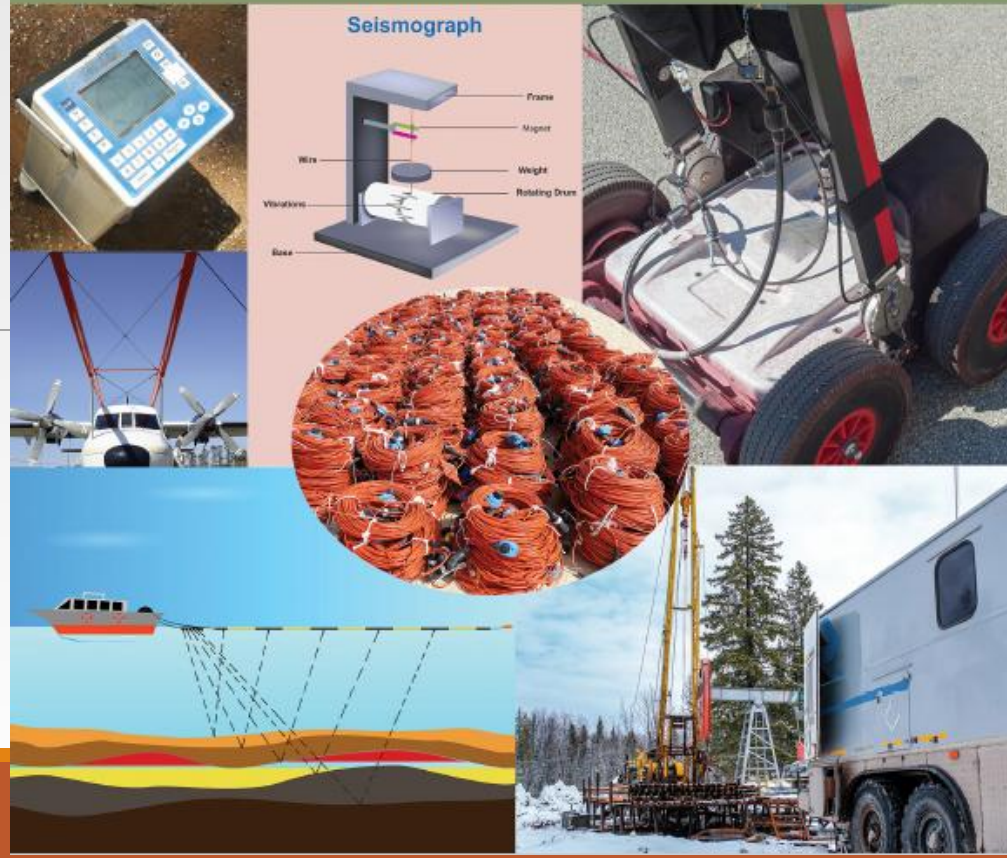
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Geophysical Exploration G405

Lecture-4

Resistivity Method

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Direct Current (DC) Resistivity Method

Electrical Principles

The DC resistivity method is based on **Coulomb's Law**, which describes the force between two charged spheres. This force is proportional to the product of their charges and inversely proportional to the square of the distance between them.

$$F = k \frac{q_1 q_2}{r^2}$$

where q_1, q_2 are charges, r is their separation, and k is a constant.

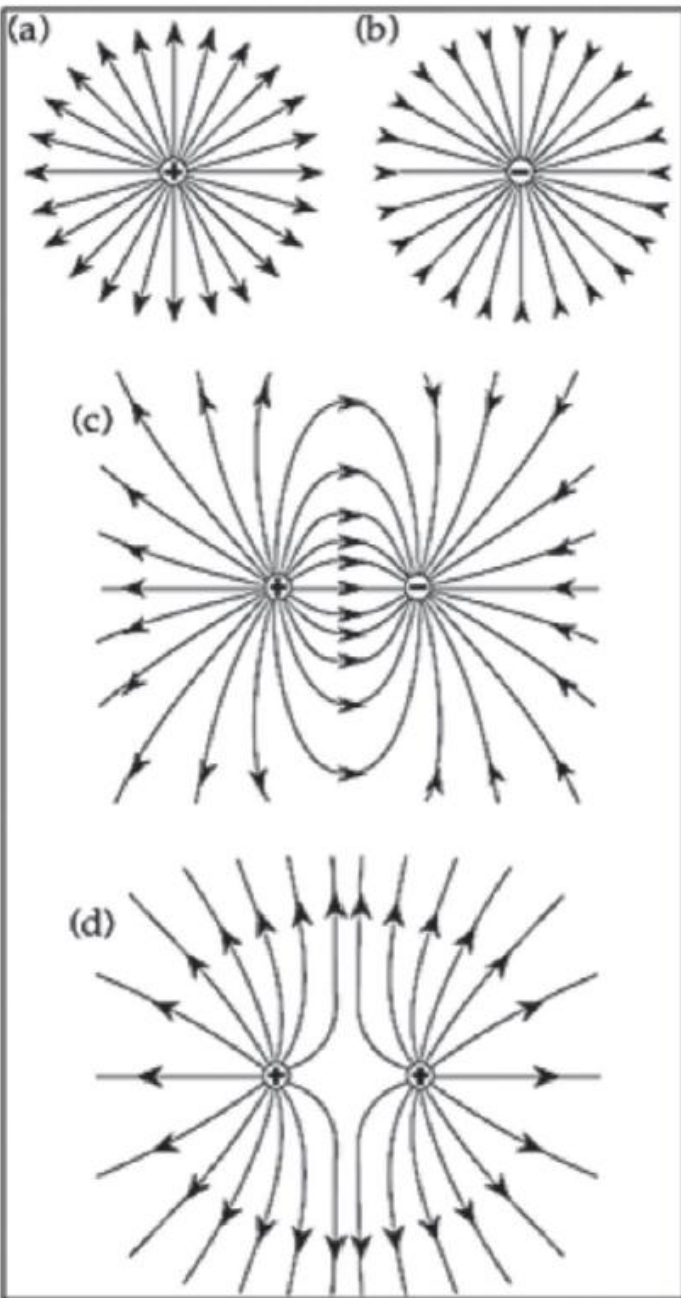
Electric field (E) is the force exerted on a unit charge and is defined by the equation Below. The electric field strength is visually represented by the concentration of field lines; the closer the lines, the stronger the field. Work is required to move a charged particle within this field, which contributes to the system's potential energy. This potential energy per unit charge is known as the:

$$E = \frac{q}{4\pi\epsilon_0 r^2}$$

(The electric field (E) at a distance r from a charge q)

Electric potential (U), is the work needed to move a unit charge in the field. In geophysics, potential differences (voltage) are measured to infer subsurface resistivity. U is measured in joules per coulomb, or volts (V). Electric current flows from a higher potential to a lower potential.

$$U = \frac{q}{4\pi\epsilon_0 r}$$



Planar cross sections of electric field lines around point charges: (a) single positive, (b) single negative, (c) two equal and opposite, and (d) two equal positive charges.

Ohm's Law

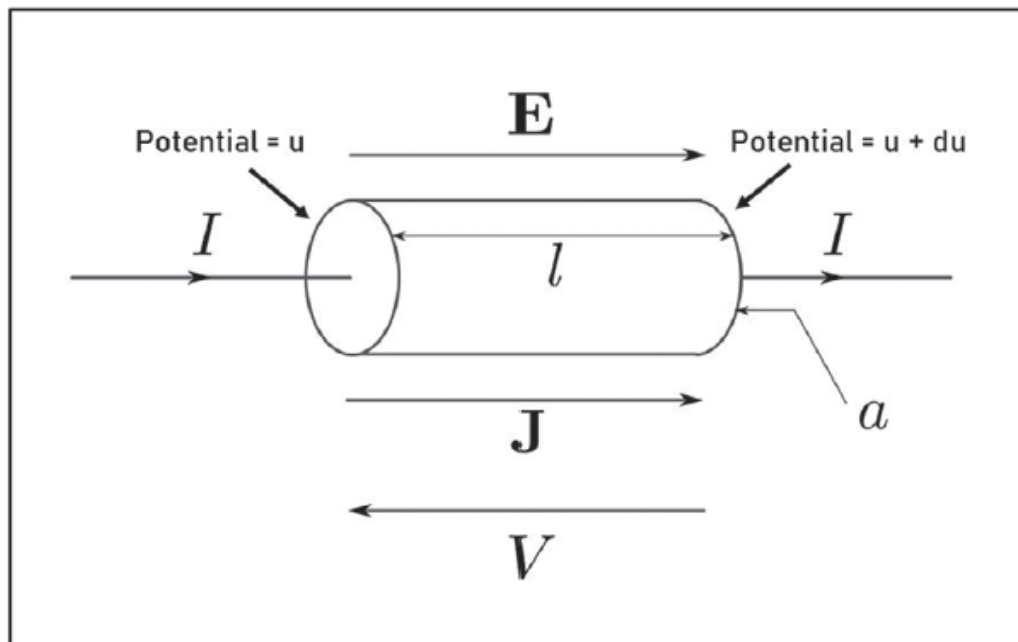
It is a key principle, stating that the electric current (I) in a conductor is proportional to the potential difference (V) across it, expressed as $V = IR$, where R is the resistance. Resistance (R) is directly proportional to the length (L) and inversely proportional to the cross-sectional area (A) of the conductor.

For a conductor of length L , cross-sectional area A , and resistivity ρ :

$$R = \rho \frac{L}{A}$$

Current density (J) and electric field (E) are related by:

$$E = \rho J$$



Electrical Conduction in the Earth and Equipotential

Unlike wires, electrical current in the Earth is not confined to a single path but flows in three dimensions. When a current is introduced into a homogeneous, isotropic medium (e.g., the Earth), the current flows radially outward from the point of injection. The surfaces on which the voltage drop is constant are called **Equipotential**.

In a homogeneous medium, these equipotential form hemispherical surfaces centered on the current electrode. The current flow lines are always orthogonal to the equipotential surfaces.

Two main types of electrical conduction in rocks:

- Electronic (ohmic) conduction:** Occurs in metals and metallic ores where electrons are mobile and flow freely (metals, graphite)
- Electrolytic/ionic conduction:** Occurs in liquids where salts dissociate into mobile cations (+) and anions (-). This is the primary mode of conduction in most rocks, where resistivity is more influenced by the interstitial fluid's porosity, water content, and water quality than the rock matrix itself. (groundwater, porous rocks)

In addition to Dielectric: Insulators with no free charges (e.g., dry quartz).

Archie's Law

An empirical model used to define the formation resistivity of porous, water-bearing rocks and sediments, which are considered ionic conductors.

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

Empirical formula for resistivity in porous, water-bearing rocks:

where:

- ρ_t = rock resistivity,
- ρ_w = water resistivity,
- ϕ = porosity,
- S_w = water saturation,
- a, m, n = empirical constants (e.g., $m \approx 1.3$ for unconsolidated sediments).

Rock Resistivities

Rock and mineral resistivity values have an exceptionally wide range, from as low as $10^{-8} \Omega\text{-m}$ for native silver to over $10^{16} \Omega\text{-m}$ for pure sulfur. This wide range makes resistivity a valuable property for geophysical surveys.

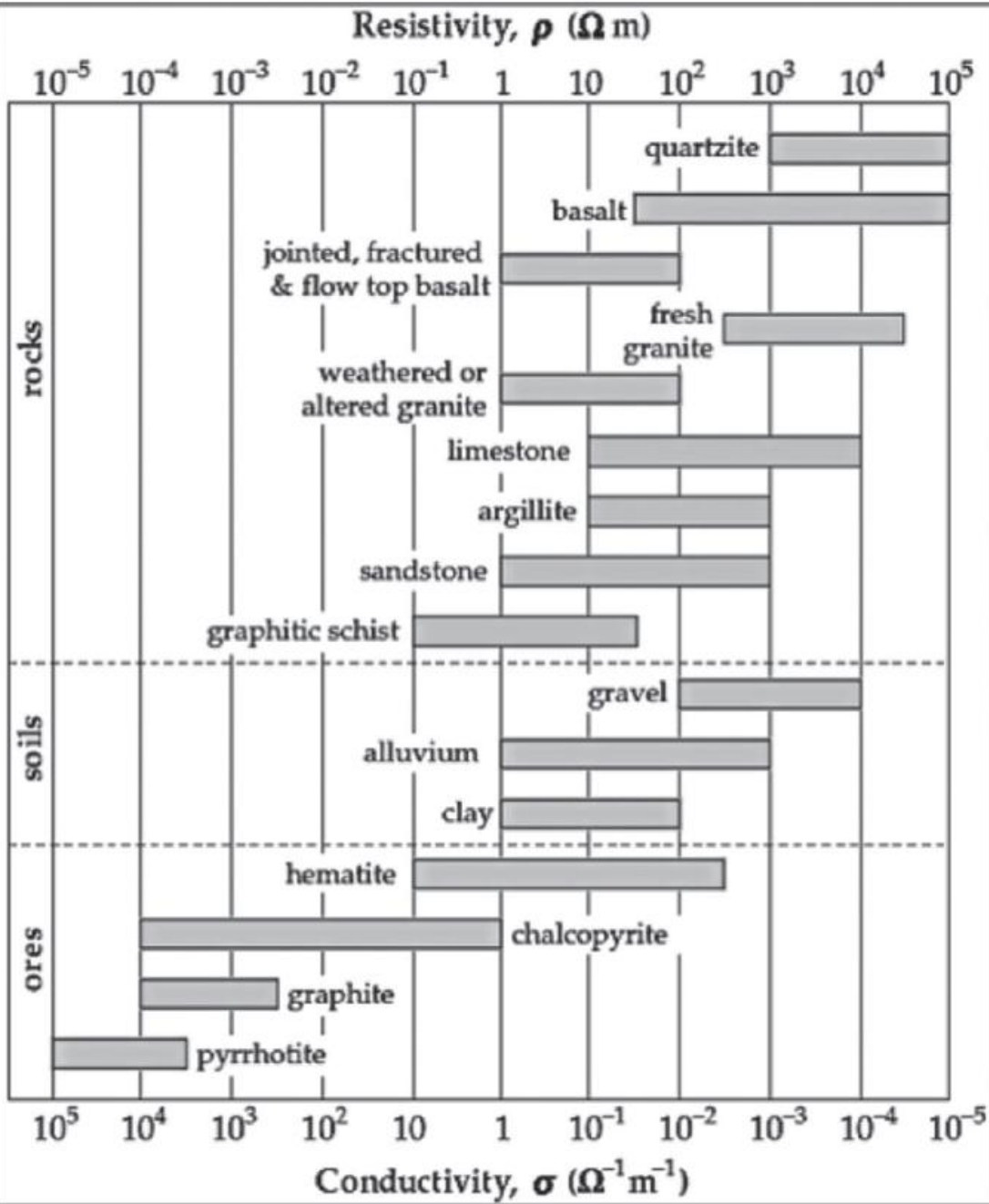
- ❖ **Low resistivity:** Clays, saline water ($1\text{--}100 \Omega\text{m}$).
- ❖ **Intermediate:** Sandstone, limestone ($50\text{--}10^3 \Omega\text{m}$).
- ❖ **High resistivity:** Granite, dry basalt ($10^3\text{--}10^6 \Omega\text{m}$).

General Rules:

Highest resistivity: Found in igneous rocks (due to a minor component of pore water) and older rocks (where fractures and pore spaces have had more time to fill in).

Intermediate resistivity: Found in metamorphic rocks (which contain hydrous minerals and fabrics).

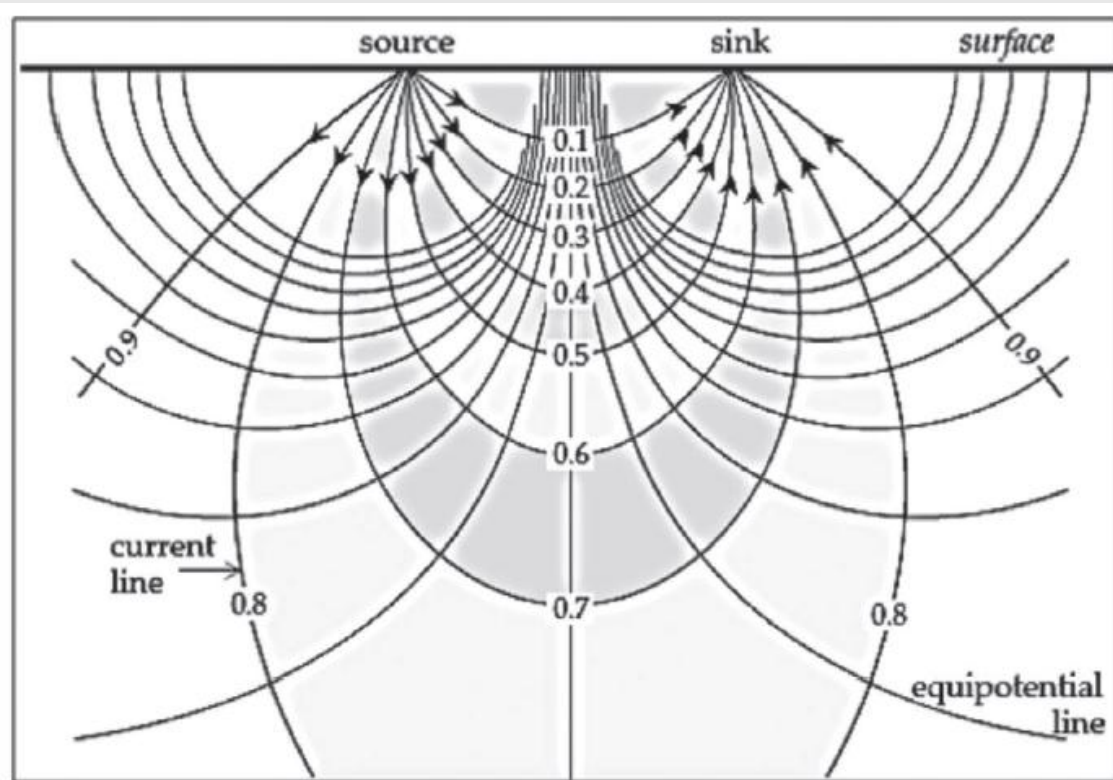
Lowest resistivity: Found in sedimentary rocks (due to abundant pore space and fluids) and younger rocks (which have abundant fractures and/or pore space). Clay minerals, in particular, can exhibit very low resistivity.



Ranges of electrical resistivity for some common rocks, soils, and ores.

Current Distribution

- Current flows radially from electrodes, penetrating deeper with wider spacing.
- Depth of Investigation: ~30% of current reaches depth $AB/2$ (half electrode spacing).



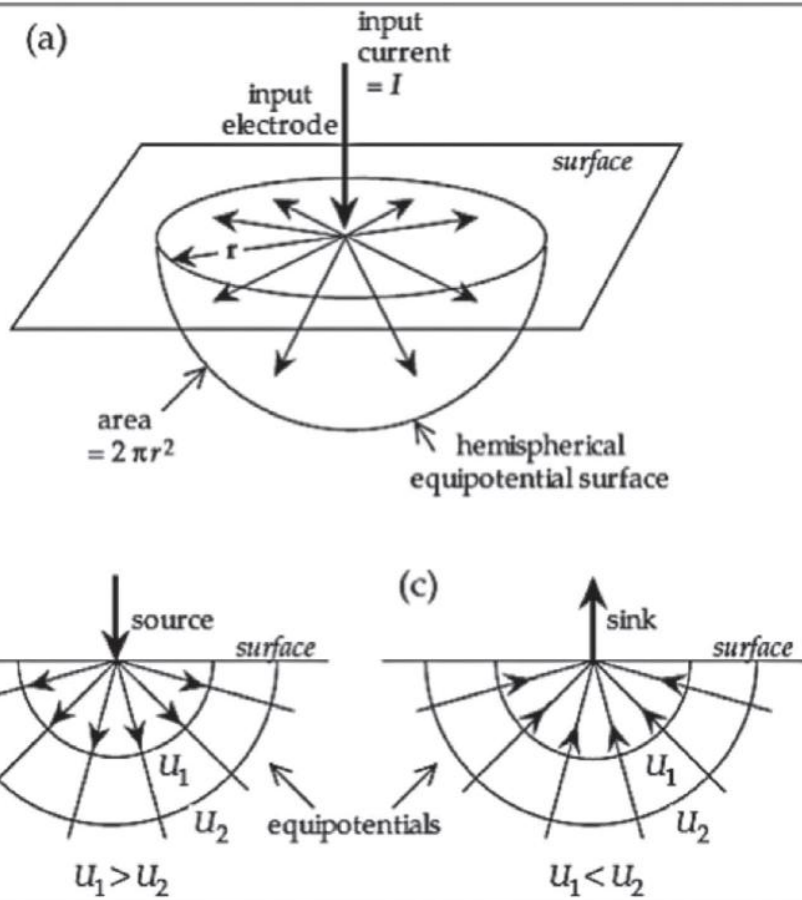
Cross section of current 'tubes' and equipotential surfaces between a source and sink. Numbers on the current lines indicate the fraction of current flowing above the line.

Principles of Resistivity Method

Four-electrode arrays (two current, two potential) measure apparent resistivity (ρ_a)

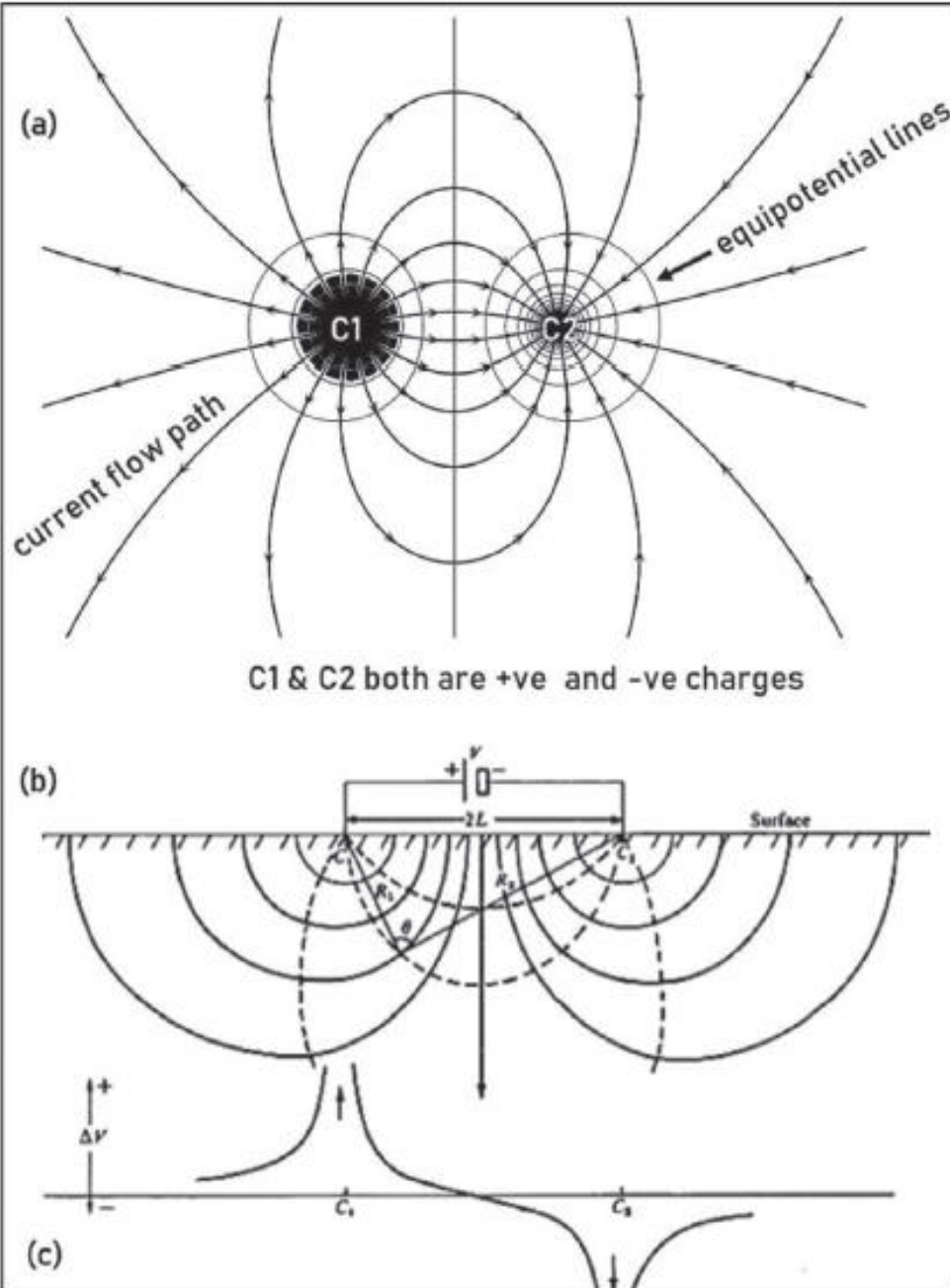
$$\rho_a = K \frac{\Delta V}{I}$$

Where, K is a geometric factor dependent on electrode spacing.



Electric field lines and equipotential surfaces around a single electrode at the surface of a uniform half-space:

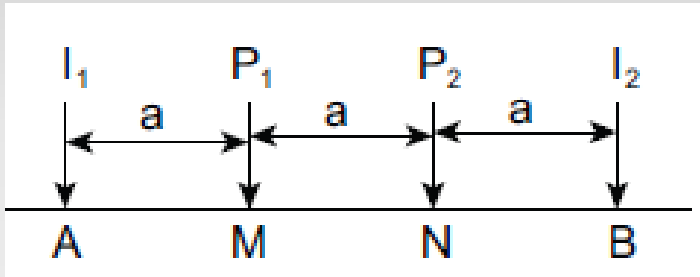
- (a) hemispherical equipotential surfaces,
- (b) radially outward field lines around a source.
- (c) radially inward field lines around a sink.



Equipotentials and current flow lines (paths) for two point sources of current on the surface of a homogeneous ground:
 (a) plan view,
 (b) vertical section,
 (c) potential variation at the surface along a straight line through the point sources.

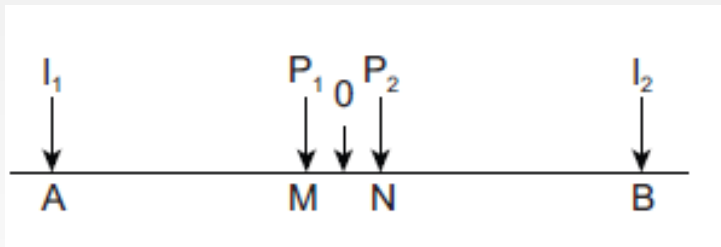
Electrode Configurations

1. Wenner Array: Equal spacing aa between electrodes. Used for profiling (e.g., fault mapping).



$$\rho_a = 2\pi a \frac{\Delta V}{I}$$

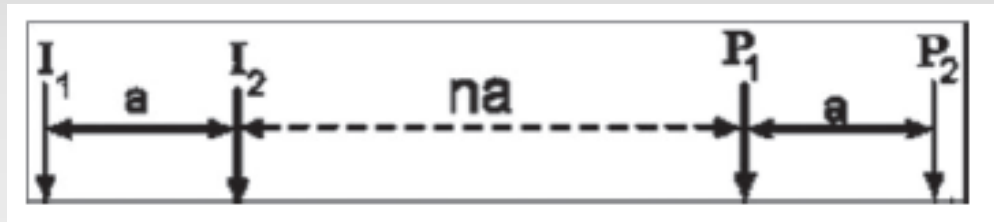
2. Schlumberger Array: Potential electrodes close ($MN \ll AB$). Preferred for vertical electrical sounding (VES).



$$\rho_a = \pi \frac{(AB/2)^2}{MN} \frac{\Delta V}{I}$$

3. Dipole-Dipole Array:

High resolution for lateral variations. Used in 2D/3D imaging.



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

Electrical Sounding and Profiling in DC Resistivity Surveys

1. **Electrical Sounding (Vertical Electrical Sounding – VES):** Determines how resistivity changes with depth at a single location (1D subsurface model). Uses the Schlumberger array (most common) or Wenner array. Current electrode spacing ($AB/2$) is progressively increased to send current deeper. Measures potential difference (ΔV) at each spacing to calculate apparent resistivity (ρ_a).

Plots ρ_a vs. $AB/2$ on logarithmic scales to generate a sounding curve. Curve shapes indicate layer resistivity contrasts (e.g., H-type for conductive middle layer). Matched with theoretical models or inverted for layer thickness/resistivity.

•Applications:

- Groundwater exploration (aquifer depth/thickness).
- Bedrock mapping.
- Geothermal studies.

Electrical Sounding and Profiling in DC Resistivity Surveys

2. Electrical Profiling (Constant Separation Traversing – CST): Maps lateral resistivity variations along a line or grid (2D/3D subsurface model). Electrode spacing (e.g., Wenner "a" or dipole-dipole "n") remains fixed while the entire array is moved along a traverse. Measures ρ_a at each station to detect horizontal anomalies (e.g., faults, ore bodies).

Contour maps or pseudosections show resistivity variations. High ρ_a : Dry sand, bedrock. Low ρ_a : Clays, saline water.

•Applications:

- Fault/dyke delineation.
- Archaeological site mapping.
- Contaminant plume tracking.

In both survey types a practical considerations must be taken:

Sounding requires homogeneous subsurface laterally; **profiling** assumes minimal vertical variation. Combined approaches (e.g., **2D ERT**) integrate both principles for detailed imaging.

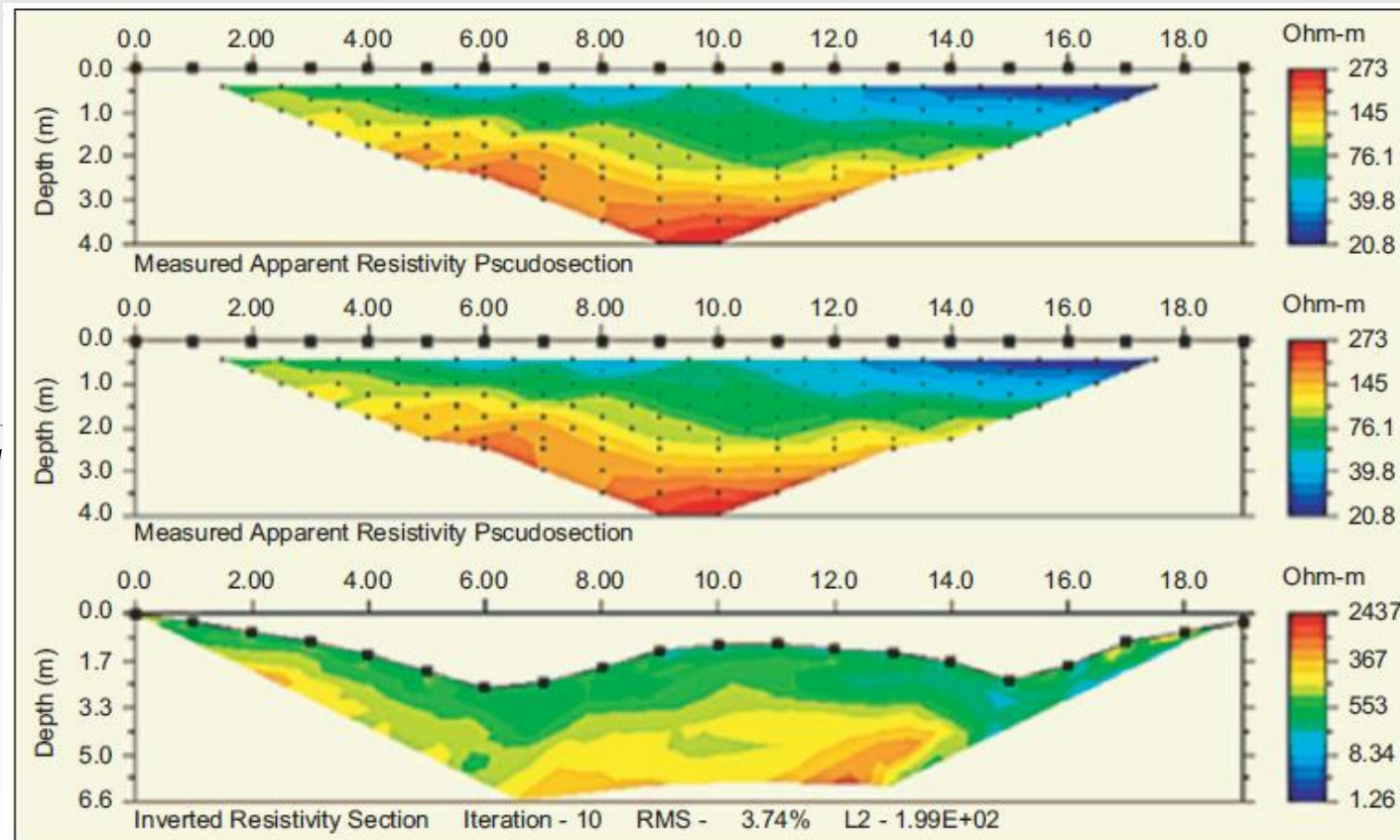
- Ambiguities:** Thin layers or anisotropy may require complementary methods (e.g., seismic).

A final note: Sounding probes vertical resistivity changes with depth while Profiling reveals horizontal contrasts (i.e., lateral extent). Together, they provide comprehensive subsurface characterization for hydrogeological, mining, and engineering applications.

2D and 3D Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography (ERT) is an advanced geophysical method that produces 2D or 3D subsurface resistivity models by combining multiple resistivity measurements along profiles or grids. Unlike traditional Vertical Electrical Sounding (VES) or profiling, ERT provides high-resolution imaging of complex subsurface structures.

Examples of measured apparent resistivity, calculated apparent resistivity, and inverted resistivity sections.



2D ERT (Two-Dimensional Imaging)

Electrode Layout: Multiple electrodes (e.g., 48–96) are placed in a straight line at fixed spacing (e.g., 1–10 m). **Data Acquisition:** Automated systems (e.g., ABEM Terrameter) switch current and potential electrode pairs. Measures **apparent resistivity** (ρ_a) for many combinations (e.g., Wenner-Schlumberger, dipole-dipole).

• **Inversion:** Data are inverted using software (e.g., RES2DINV) to generate a **2D resistivity cross-section**. **Pseudosections** (raw data) are converted into **true resistivity models** with depth.

Applications:

- ✓ **Geotechnical:** Landslide studies, bedrock mapping.
- ✓ **Environmental:** Contaminant plume tracking.
- ✓ **Hydrogeology:** Aquifer delineation, saltwater intrusion.

Example:

A **2D ERT survey** across a fault reveals a low-resistivity zone (clay/water) juxtaposed against high-resistivity bedrock.

3D ERT (Three-Dimensional Imaging)

Electrode Layout: Electrodes are arranged in a grid (e.g., 10×10) with equal spacing in X and Y directions. **Data Acquisition,** Measures resistivity in multiple directions (e.g., parallel, perpendicular, diagonal). Combines cross-line and in-line dipole configurations.

Inversion: Software (e.g., RES3DINV) reconstructs a 3D resistivity volume. Outputs include horizontal slices (depth slices) and vertical sections.

Applications:

- ✓ Mining: Ore body delineation (e.g., sulphides, kimberlites).
- ✓ Archaeology: Buried structure mapping.
- ✓ Civil Engineering: Void detection (e.g., tunnels, sinkholes).

Example:

A 3D ERT survey of a landfill identifies zones of leachate (low ρ) and undisturbed soil (high ρ).