**Chapter IV:** Electrical methods

### II.3 Electrical methods

Electrical prospecting is one of the geophysical methods applied in subsurface exploration, by vertical probing or profiling (search for conductors). The depth of investigation ranges from a few centimetres to several hundred meters, so its spectrum of use is very broad: in sub-surface exploration, mining, agriculture, land use planning, building construction, bridges and roads, railroads, archaeological research, as well as aquifer research in hydrogeology. It is used in sub-surface applications, where multi-electrode techniques enable us to monitor the surface of the ground with great precision.

#### 1/ Current propagation in the subsoil (1 electrode)

Ohm's law enables us to predict the path of current currents in a homogeneous, isotropic medium. Let's consider a homogeneous, isotropic terrain of resistivity ρ bounded by a flat surface on the air side. Let's send a direct current through a point electrode C1. The current will flow in straight lines radiating around C1, producing potential variations in the soil due to its ohmic resistance. The potential distribution can be represented by half-spheres centered on A.

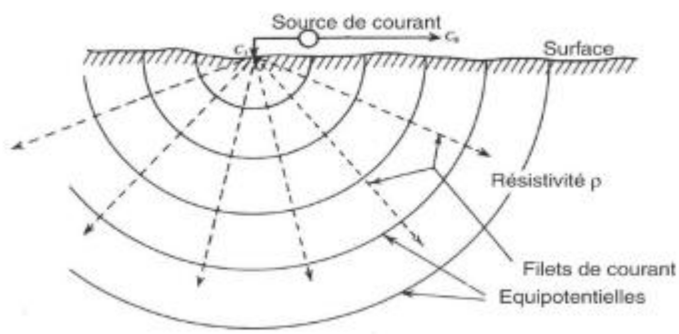



Figure: Equipotential currents and current nets

#### 2/ Current propagation underground (2 electrodes)

In practice, there are two emission electrodes. The current sent by A (+) will be collected by B (-), but according to the superposition theorem, the potential at a point M will be the same if we independently send a +I current by A or a -I current by B. Furthermore, the laws governing the propagation of electrical phenomena are linear, which means that we can algebraically add up the potentials created by different sources. The total potential at a point is Vtot = V1 + V2 for two current-sending poles:

Translated with DeepL.com (free version)

$$V = \frac{\rho I}{2\pi r}\left(\frac{1}{r1} \pm \frac{1}{r2}\right)$$

**Where**

**V** = potentiel [V]

$\mathbf{r_1}$ et $\mathbf{r_2}$ = rayons [m]

$\rho$ = résistivité du milieu [ohm.m]

**I** = intensité du courant [A].

The curves in the figure above show the evolution of the potential and its gradient, the E field. The V and E fields are substantially uniform in the central third of AB, while most of the potential drop from electrodes A (+) and B (-) comes from the immediate vicinity of the A and B sockets.

**2.1 / Potential distribution**

Current flows underground from one current electrode to the next. Current density is higher near the surface than at depth. The depth of investigation depends on the maximum spacing between electrodes. The greater the spacing, the greater the depth of investigation.

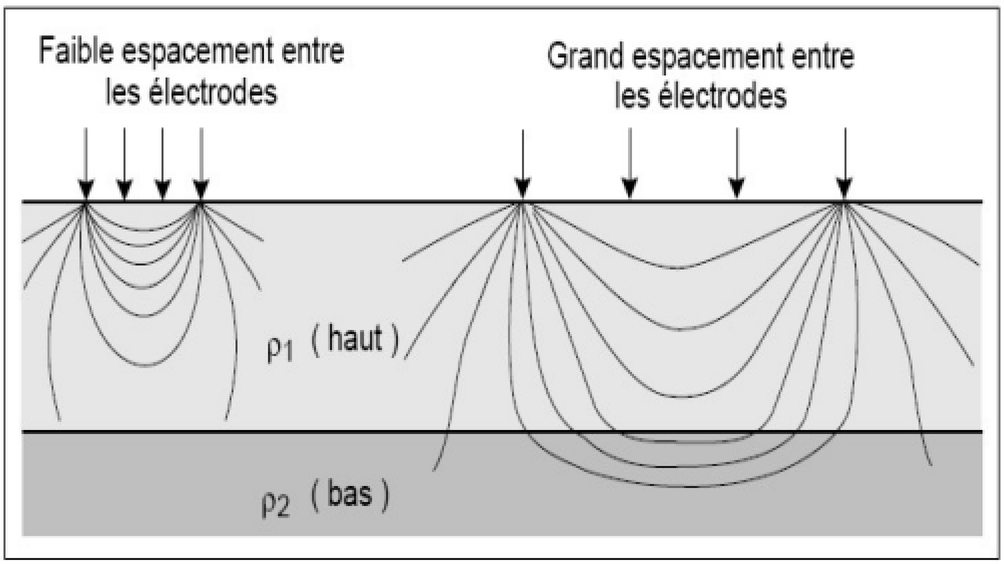



Figure: Current penetration in tabular soil

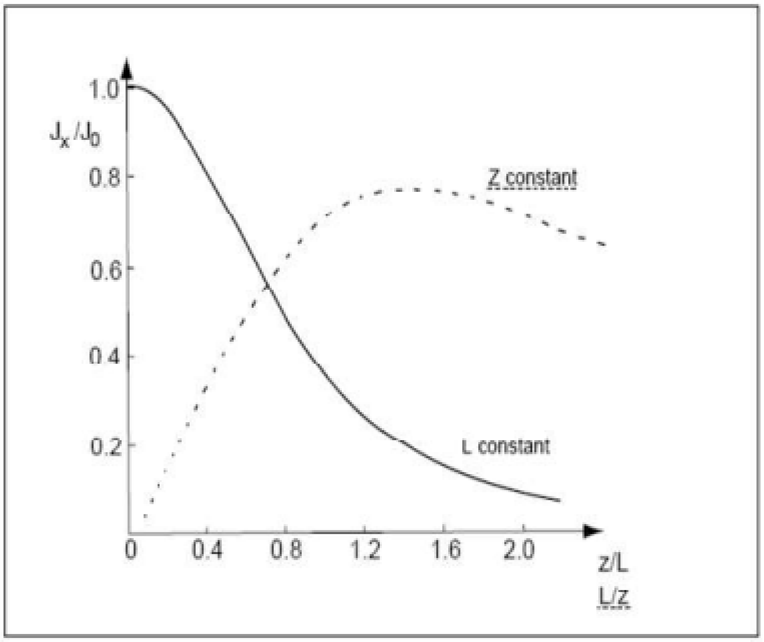
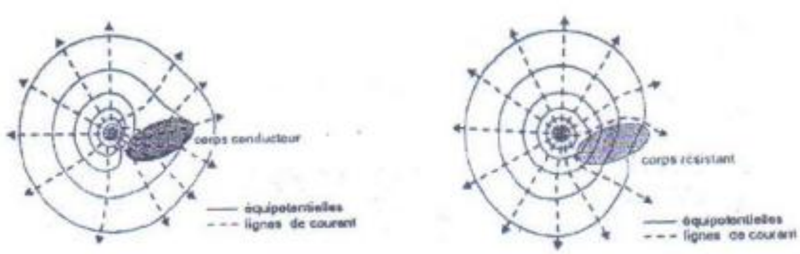



**Figure :** Densité du courant en fonction de la profondeur

**2.2 / Effect of heterogeneities**

In the presence of more or less local variations in resistivity, a conductive body will attract and concentrate current lines and push equipotentials away. Conversely, in the case of a resistive body, current flows will tend to bypass the resistive obstacles, and equipotentials will tighten in the vicinity and inside the body. Unfortunately, the effects of these heterogeneities diminish very quickly with distance, and become difficult to demonstrate as soon as the distance is of the order of magnitude of the disturbing body's dimensions.




**Corps conducteur** **Corps résistant**

**Figure :** Equipotentielles et filets de courant électrique en présence d'hétérogénéités

**3 / Prospecting methods:**

The immediate aim of electrical prospecting is to determine the distribution of resistivities in the subsoil. All the methods used are based on comparing the distribution of potential created by the emission of a current.

**3.1/ Principle of grounding: (application in mining exploration)**

Grounding involves replacing the emission electrode with a conductive deposit into which current is injected. The entire deposit then acts as an electrode, with its entire surface at roughly the same potential. This method is mainly used in mining research, and is particularly applicable to copper, nickel and lead sulfides. But for it to be applied effectively, the conductor's resistivity must be very low, lower than that of the environment, and the conductive deposit must be continuous and accessible by drilling. The principle involves placing current electrode A in the conductive ore through one borehole, with the other placed at infinity. The measurement point is a potential electrode, the other also being considered at infinity.

The current tends to flow uniformly from the conductive body into the surrounding rocks. There should be a uniformly distributed potential on the surface of the conductive body. In reality, this distribution is modified by the shape of the body, its dip and its resistivity contrast with the surrounding rock. The higher the contrast, the more uniformly the potential is distributed over the surface of the mineralized body. As the contrast decreases, the potential mapping of the body shape becomes less precise and, if there is no contrast, a hemispherical potential distribution is found.

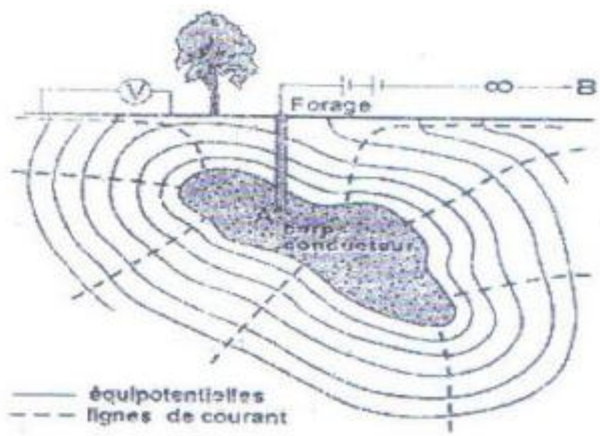



**Figure :** Principe de mise à la masse

**3.2 / Resistivity profiles and maps :**

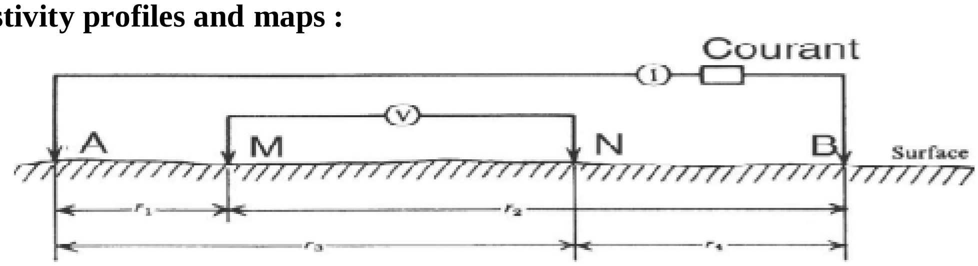



**Figure :** Dispositif d'électrodes en terrain homogène et isotrope.

The four AMNB electrodes are joined together to produce profiles and resistivity maps.

**3.3 / Device implementation**

**- The source:** 90 volt dry cells are generally used in series. More rarely, a gasoline generator coupled with a rectifier or a car battery. With newer devices, up to 10 batteries can be used in

series.
**- Emission electrodes:** Emission electrodes are generally made of steel rods. Let's assume a perfectly conducting metal electrode, and calculate its contact resistance:

$$dR = \rho \frac{dL}{s} = \rho \frac{dL}{2\pi L^2}$$

$$\text{en intégrant: } R = \frac{\rho}{2\pi}\int_r^L \frac{dL}{L^2} = \frac{\rho}{2\pi}\left(\frac{1}{r} - \frac{1}{L}\right)$$

Where :
**L** = Distance to electrode center [m] r = Electrode radius [m
**r** = Radius of electrode [m].
**R** = Resistance [ohm].
**ρ** = Resistivity of surrounding soil [ohm.m].

If the current flowing through electrodes A and B is too low, we can
- either change the electrode to one with a larger diameter
- or press it in more deeply - or reduce the resistivity of the soil around the electrode, by pouring in salt water for example.

**- Measuring electrodes**
Measuring potential difference is a tricky business. In soil, the M and N electrodes oxidize in different ways and become polarized. This is known as spontaneous polarization of the electrodes.
To limit the phenomenon of electrode polarization as effectively as possible, chemically stable metals (copper, lead) are chosen for the electrodes.

### 3.4 / Calculating resistivity
Having measured the potential difference between M and N and the current intensity, all that remains is to calculate the resistivity. In a homogeneous medium of resistivity ρ with two poles A and B, the conjugate action of A and B will give:

The potential in M : $$V_M = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM}\right)$$

The potential in M : $$V_N = \frac{\rho I}{2\pi}\left(\frac{1}{AN} - \frac{1}{BN}\right)$$

The potential difference between M and N : $$V_M - V_N = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)$$

Resistivity : $\rho = \frac{K\,dV}{I}$ avec $K = 2\pi\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)^{-1}$

K = geometric factors. For a device symmetrical about O, the midpoint of AB, the factor

Geometric K is: $K = \pi \frac{AM\,AN}{MN}$

If the subsoil is homogeneous and isotropic, a device of this type will give the true resistivity. If, on the other hand, the subsoil is heterogeneous, the apparent resistivity is measured, depending on the nature of the subsoil and the size of the device used.

The results obtained by keeping the distance between A, B, M and N constant, the whole moving along a profile, are used to draw up resistivity profiles and maps. An apparent resistivity map drawn from several profiles is a map of relative anomalies that relates to a substantially constant length and orientation of the entire measuring device. In fact, a given length of AMNB corresponds to a roughly constant depth of investigation, and therefore to the study of a slice of ground of given thickness and width. The dimensions of the device will therefore be chosen according to the problem to be addressed. It is often necessary to draw up maps with several line lengths in order to interpret the results correctly.

**4. Measuring device**

Every measuring device actually comprises four electrodes, two A and B, for sending current ("emission circuit") and two M and N, for measuring potential ΔV ("measurement circuit").

**- The dipoles**

Electrodes B and N are placed at infinity, and only A and M are concerned. This device is cumbersome because of the length of the cables needed to make the effect of the electrodes placed at infinity negligible.


**- Tripoles**

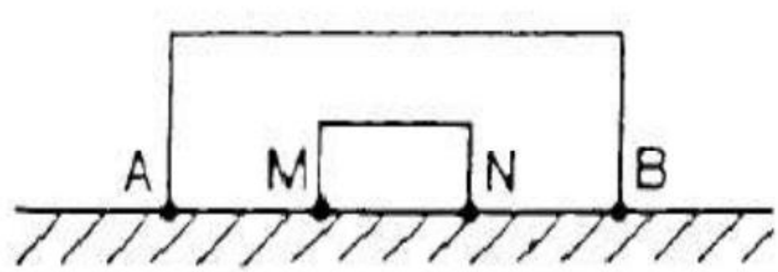
If only one of the four electrodes is rejected to infinity, the result is an AMN or ABM tripole. The most common tripole is one in which all three electrodes are arranged on the same straight line, with A outside MN. More generally, either these three electrodes are equidistant, or the distance MN is small compared with AN.


**- Quadripoles**

The four taps are arranged in the same alignment. The two measuring electrodes, M and N, are usually inside the AB gap, and generally symmetrical with respect to the middle O of this gap. The two most commonly used quadrupoles are:

**The Wenner**

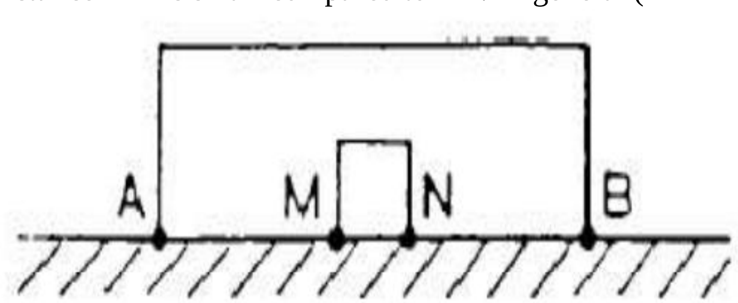
All electrodes are equidistant, AM = MN = NB = AB/3




Wenner

**The Schlumberger**

The distance MN is small compared to AB. In general (MN< AB/5)




Schlumberger

The geometrical arrangement of the electrodes plays a part in its definition by means of a coefficient k, written as :

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$$

Wenner's device has the advantage of having a larger MN line, which facilitates ΔV measurement; with modern voltmeters this advantage has lost its importance. What's more, a large MN line is always much more affected by parasites.

## 5. Different types of electrical probing

The shape of the curves obtained by electrical probing over stratified media is a function of resistivity, layer thickness and the configuration of the measuring device.

**Figure :** Appareil pour un sondage électrique

### 5.1 Homogeneous medium is isotropic

If the medium consists of a homogeneous, isotropic layer of infinite thickness and finite resistivity, the measured apparent resistivity will be a straight line whose ordinate is the resistivity ρ1 of this medium.

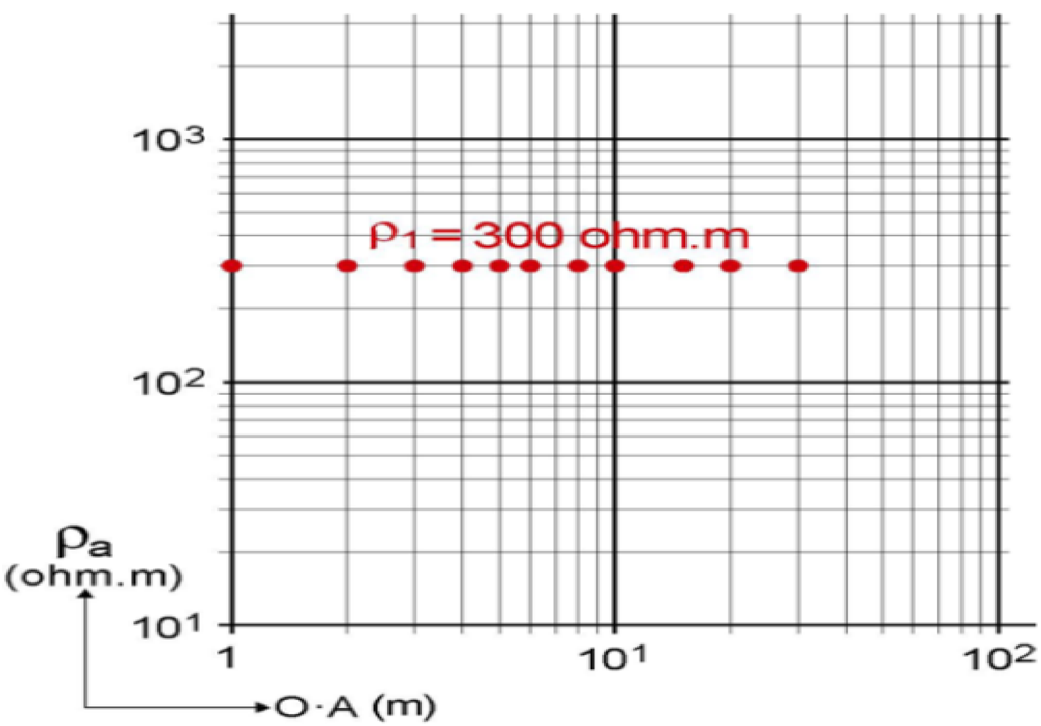



**Figure .27** Exemple de sondage à un terrain

### 5.2 Two-layer medium

If the subsoil is composed of two layers, a first layer of thickness h1 and resistivity ρ1 overlying a bedrock of infinite thickness and resistivity ρ2, then the electrical sounding begins, for small spacings, with a straight line portion where the apparent resistivity ρa is more or less equal to the resistivity ρ1 of the first ground. Then, as the spacing increases, the curve rises or falls depending on whether ρ2 is greater or smaller than ρ1 and finally reaches an asymptotic value which is that of ρ2. (Fig. 28 The spacing OA at which the value of ρ2 is reached depends on three factors:

- the thickness of h1
- the value of the resistivity ratio,
- the device used.
- The effect of h1 thickness is fairly obvious. The greater the thickness of the first field, the greater the spacing required to obtain the resistivity of the second field. This is true for any device and for any ratio of ρ2/ ρ1. However, whatever the device used, larger OAs are needed to reach ρ2 when ρ2 is resistive (ρ2/ρ1> 1) than when ρ2 is conductive (ρ2/ ρ1< 1), as the current is channelled into the first layer.
- If ρ2 > ρ1. To interpret (i.e. obtain the thicknesses and true resistivities of each layer from the measured apparent resistivities), a program must be used

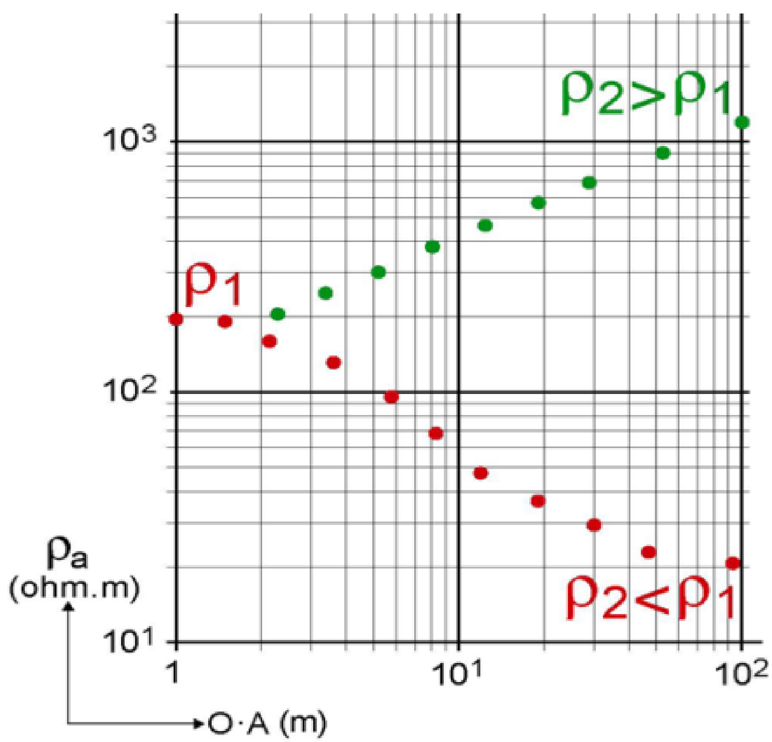



**Figure .28** Sondage éclectique pour un milieu de deux couches

**Example:** Interpretation of an electrical sounding with two horizontally superimposed layers of different resistivities (Fig.29,30)

Interpretation of two-layer electrical soundings is done by simply superimposing the electrical sounding curve on one of the curves in the CH1 abacus. Once the curve ρa has been constructed as a function of (AB/2) on a transparent bilogarithmic paper, this is moved onto an abacus so as to bring the field curve into line with a line on the abacus. We can then deduce ρ1 and h1. The K factor of the abacus line gives the ratio ρ2/ρ1.

**Note:** This gives an accuracy of 5-10%. The greater the inaccuracy of ρ1, the greater the error made when estimating the thickness of the first soil, so it's important to have enough measurements at the start of the survey.

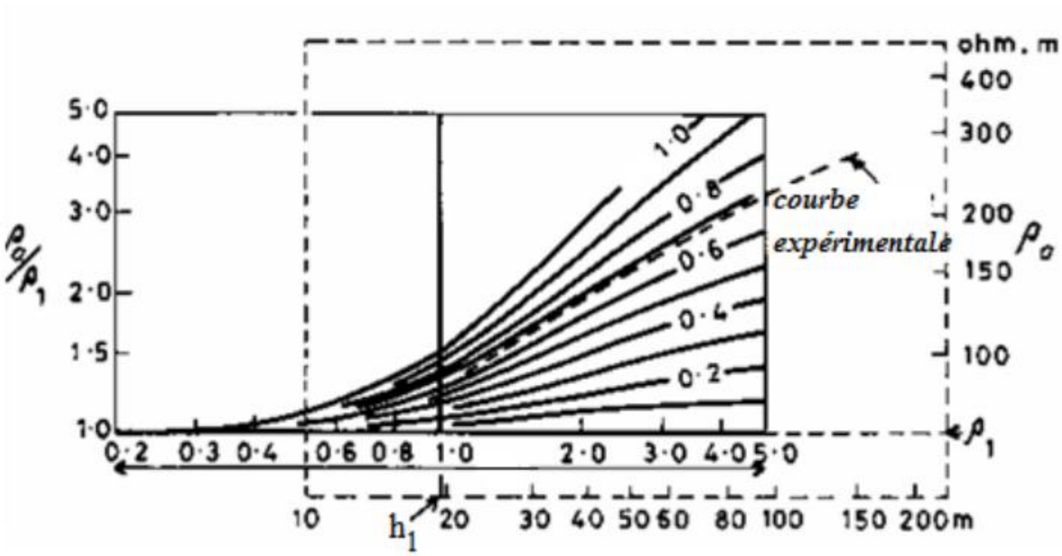



Figure.29 Method of superimposing the experimental curve on one of the theoretical curves

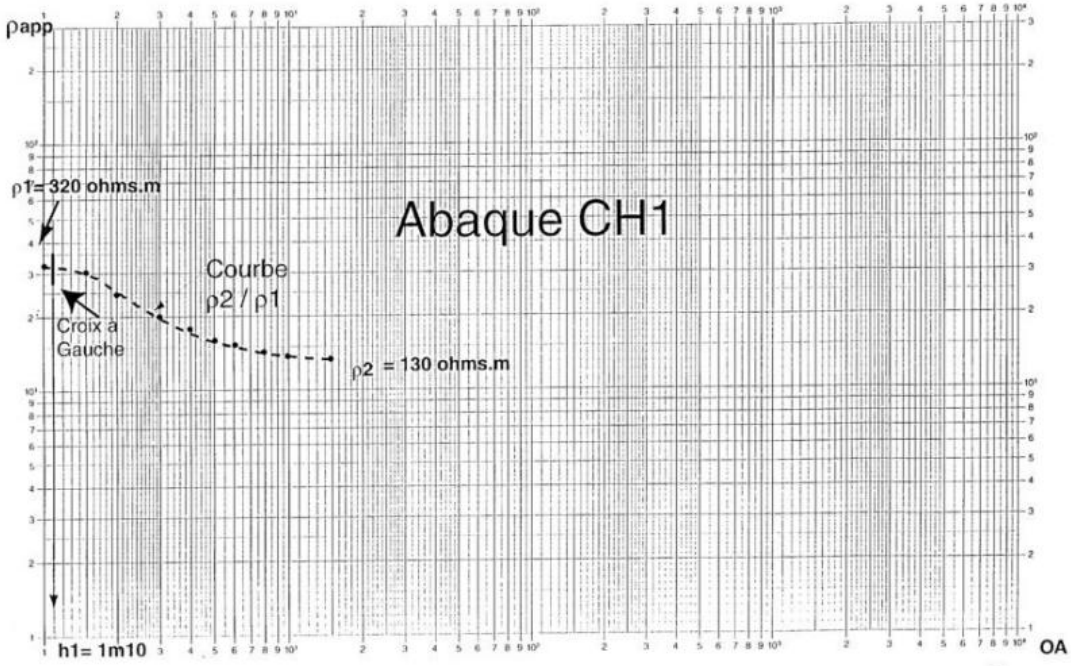



**Figure.30** Sondage électrique à deux couches superposées horizontalement

**5.3 Three-layer medium (and more...)**

If the subsoil is composed of three layers of resistivity ρ1, ρ2, ρ3 and thickness h1, h2. (Fig.31). There are then four possible combinations: (Fig.32)

1. Conductor between two resistors, H-type borehole
2. Resistor between two conductors, type K borehole
3. Stepwise increasing resistivity, type A borehole
4. Resistivity decreasing in steps, type Q borehole

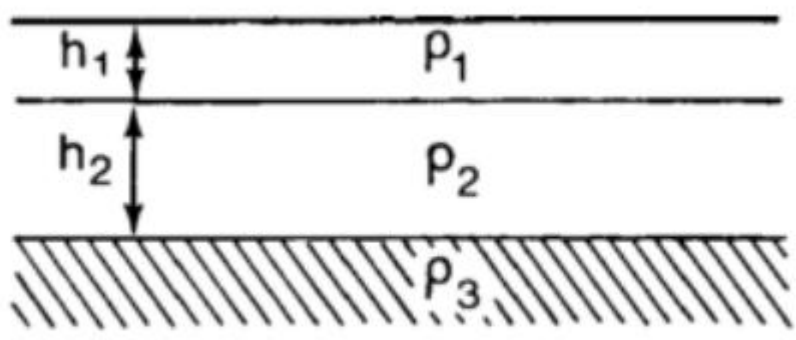



**Figure.31** Modèle du terrain à trois couches

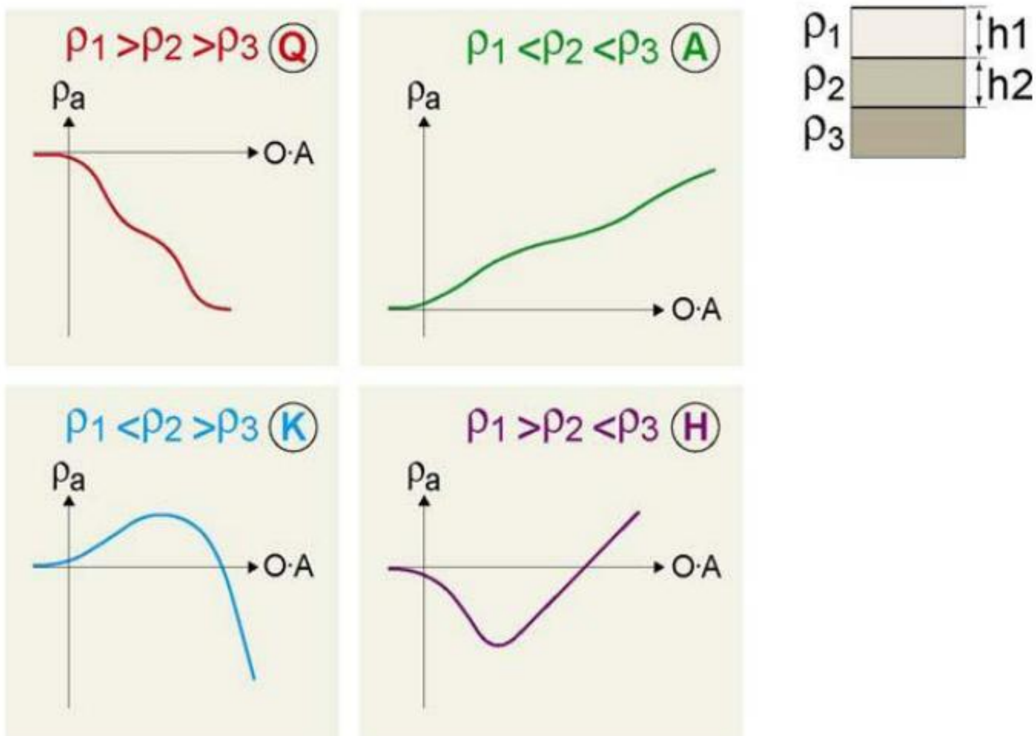



**Figure.32** Modèle de courbe de sondages électriques à trois couches

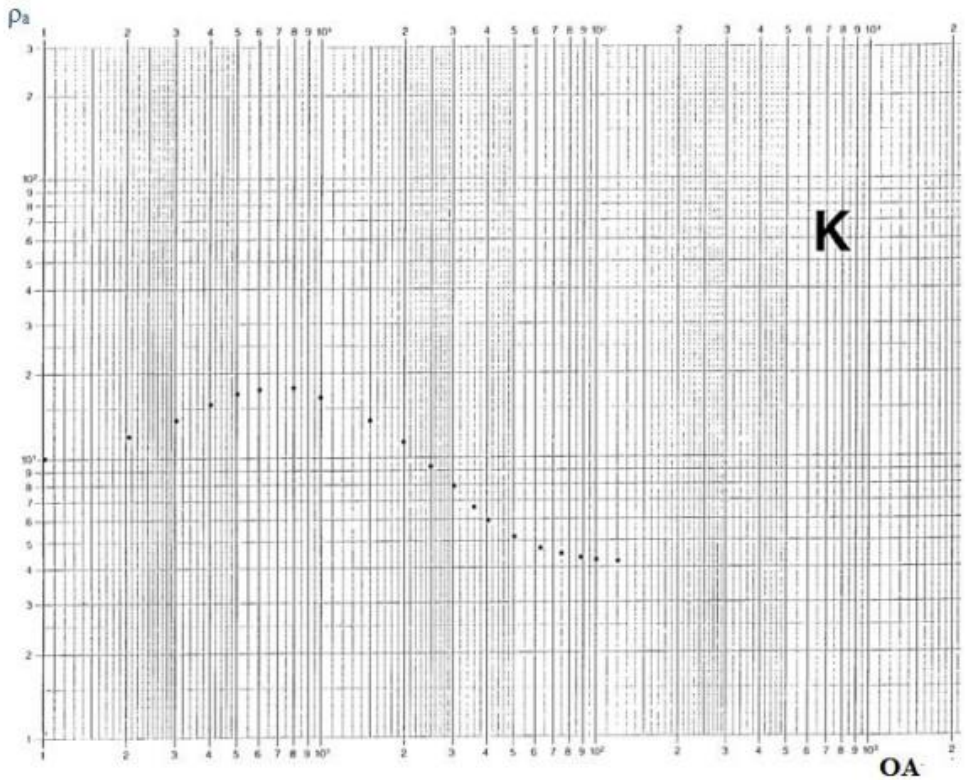



**Figure.33** Courbe de sondage électrique à trois couches (type K)

**Practical considerations**

- In the presence of noisy terrain and without any prior knowledge of the geometry of the body to be studied, use a Wenner-Schlumberger device. This device can be used for large-scale geological research, hydrogeology, civil engineering, archaeology and environmental problems.
- If you're looking for vertical structures in an area that isn't too noisy, with a resistivity meter that's sensitive enough and good contact with the ground, we recommend using a Dipôle-Dipôle device. This device can be used, for example, in archaeology, mining geophysics and civil engineering.