UNIVERSITY OF DIYALA
COLLEGE OF SCIENCE
DEPARTMENT OF PETROLEUM AND MINRALS GEOLOGY

Geophysics and geophysical prospecting

ELECTRICAL RESISTIVITY METHOD Lectures

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The electrical methods

is one of the geophysical techniques, and it is basing on passing natural electrical currents or artificial in the earth.

These methods have been used for many decades in **hydrogeoloical, mining** and **geotechnical** investigation, and in recent years, for **environmental**, **archeological** and **engineering** surveys. However, there are many electrical methods some of which **passive** and other active method , such as:-

1- Resistivity Method (active method).

2- Self-Potential Method(passive method)

3- Electromagnetic Method(active method).

4- Induced Polarization Method (active method)

- This course involve concentration on Resistivity Method

- **What is the physical property on which resistivity method depends?**

The fundamental physical properties that controls resistivity method is electrical conductivity or resistivity

Electrical conductivity (or resistivity) :is a bulk property of material describing how well that material allows electric currents to flow through it.

•Resistivity Method

In the resistivity method, artificially –generated electric currents are introduced into the ground by two current electrodes(A,B), and the resulting potential differences between a second pair of electrodes (Potential electrodes, M,N) are measured at the surface .

In homogeneous ground the current lines will be taking semicircles shapes, while the equipotential lines are perpendicular on it, as shown in figure , so that any changes in conductivities of subsurface material lead to changes the current flow lines, as a result that equipotential lines will be disturbed . Therefore, the measurements values will change on the ground surface.

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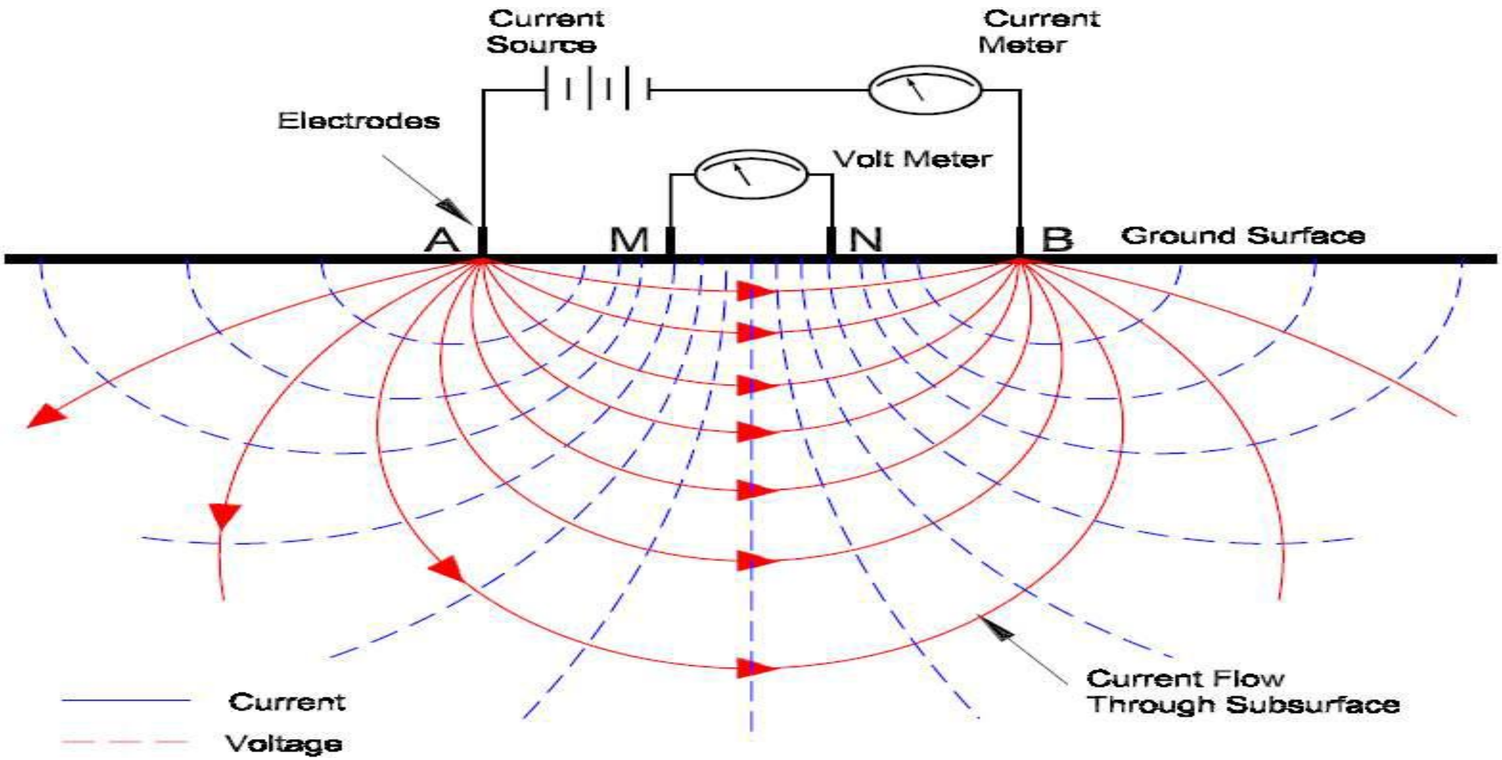


Basic Theory of resistivity method

The Basic of electrical resistivity theory is the Ohm's law which states that the " ratio of potential difference (V) between two ends of a conductor in an electrical circuit to the current (I) flowing through it is a constant.

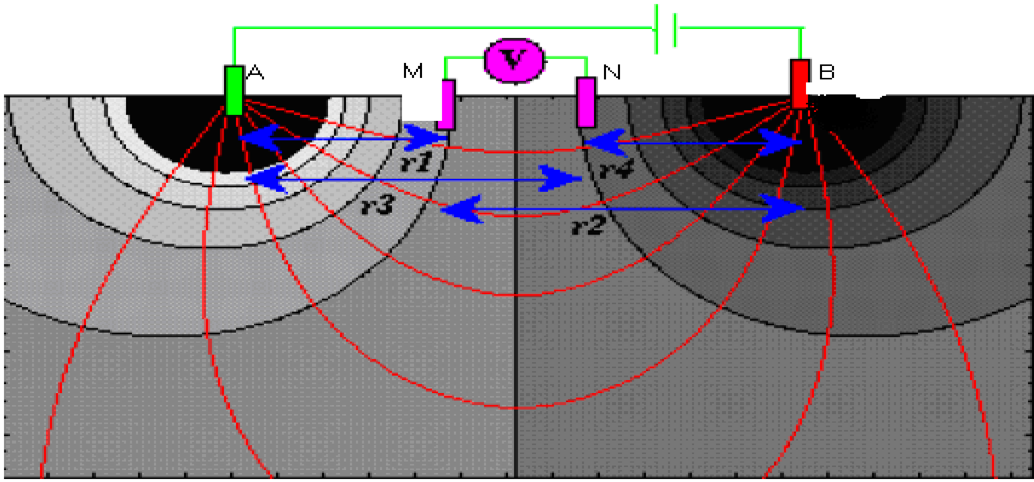
$$R = \frac{V}{I}$$

- where **R** is a constant known as resistance measured in ohms (Ω)

What is the equation used to calculate resistivity?

The equation below is used to calculate the resistivity

$$\rho = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{r1}-\frac{1}{r2}\right)-\left(\frac{1}{r3}-\frac{1}{r4}\right)\right\}} = K\,{\Delta V}/{I} = KR$$



Where r_1, r_2, r_3, r_4 as showing in figure

ρ = resistivity of the medium

K : Geometric Factor depend on type of array and electrodes spacing

<u>What is the difference between True and Apparent resistivity?</u>

If the ground is homogenous and uniform , the resistivity calculated should be constant and independent of both electrode spacing and surface location and called true resitivity (*ρ*) . When subsurface inhomogeneities exist however ,the resistivity will vary with the relative position of the electrodes. Any computed value is then known as the apparent resistivity *(ρa)* and will be a function of the form of the inhomogeneities.

➔ In general, all field data are apparent resistivity. They are <u>interpreted</u> to obtain the true resistivities of the layers in the ground.

Electrical properties of earth materials

What are the main types of conduction in earth materials ?define these types?

There are two main types of conduction these are **<u>metallic conduction</u>** and **electrolytic conduction .**

Metallic conduction : is the conduction Occurs as a result of movement of ions through the metal , this conduction occurs metalliferous minerals which are usually good conductors.

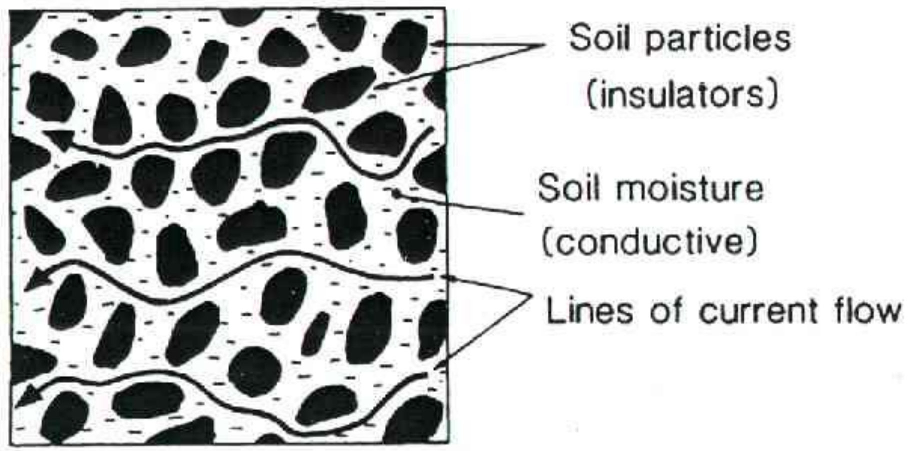
electrolytic conduction:- is the conduction Occurs by the movement of ions in electrolytes that fill pores **, this conduction occurs in most common rocks.**

-Why the Most rocks conduct electricity by **electrolytic** conduction rather than **metallic conduction?**

-Because

1- Most rock forming minerals are insulators (Soils and rocks are composed mostly of silicate minerals, which are essentially insulators, meaning that they have low electrical conductivity).

2- Rocks are usually porous and pores are filled with fluids, mainly water. As the result, Electrical current is carried through a rock mainly by the passage of ions in pore waters.



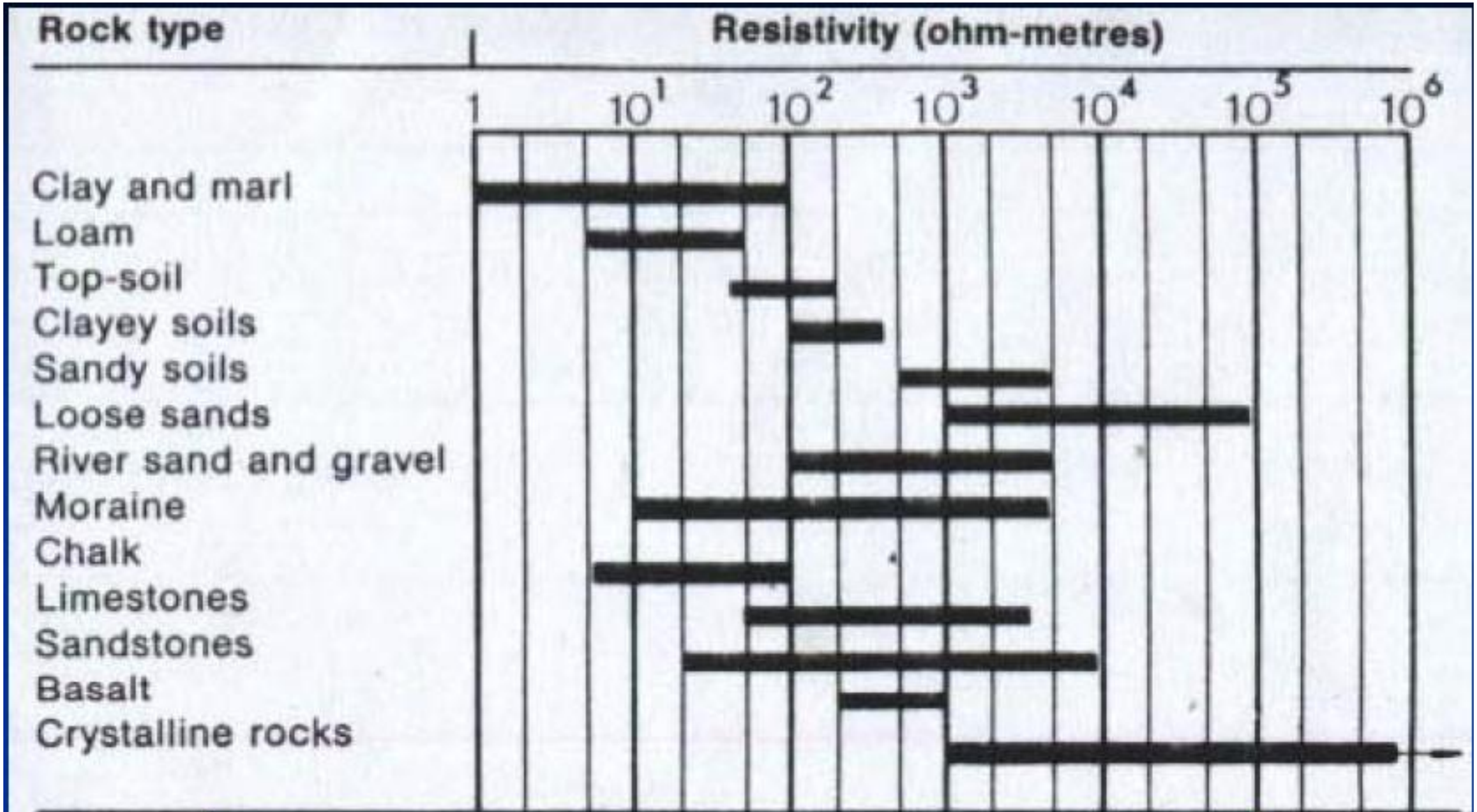
➔ An increase in the number of ions in soil water (groundwater contamination) linearly decreases the soil resistivity.

What are the factors influence resistivity values?

The factors influencing resistivity are:-

- Porosity, shape of pores, size of pores, and connection of pores.
- water content and degree of water saturation.
- Clay content.
- Salinity and Dissolved electrolytes.
- Temperature of pore water (resistivity decreases with increasing temperature).
- Conductivity of minerals.

Therefore, the rocks and soils have a large range of resistivity. For sedimentary rocks, which are usually more porous and have higher water content, normally have lower resistivity values compared to igneous and metamorphic rocks. Clay –bearing rocks and soil will tend to have lower resistivities than non clay-bearing rocks and soils. Therefore the resistivity of rocks change not only from the sediments of formation to another but through the sediments of the same formation, this mean there is no obvious relationships between lithology and resistivity These generalization are reflected in the typical resistivity values for different soil and rock type given in figure below .



Approximate ranges for the electric resistivity of rocks and soils.

Electrodes Configuration(Electrodes Arrangements).

- There are many configurations used in the electrical surveys.
- The choice of best array for a field survey depends on different **factors**, such as:-

1- The aim of the electrical survey 2- The maximum depth of investigation required

3- sensitivity of resistivity meter and background noise level

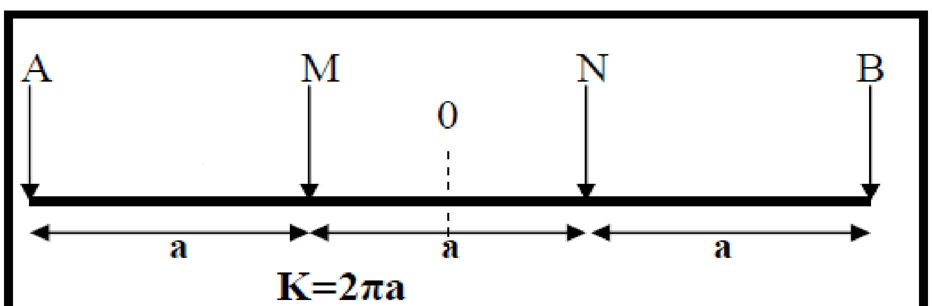
4- rapidity of field work achievement 5- easiness of interpretation for acquired data

- The most commonly arrays that used in resistivity survey are:-
  - Wenner array
  - Schlumberger array
  - dipole – dipole array

1- Wenner array

This array consists of four electrodes (A, B, M, N) placed at the surface of the ground along a straight line. Where (A, B) are current electrodes, and (M, N) are potential electrodes.

- In this array the spacing (a) between each two adjacent electrodes is equal, (figure below)



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•The values of apparent resistivity (*ρa*) for this array can be calculated by following equation:-

$$\rho a = 2\pi a R$$

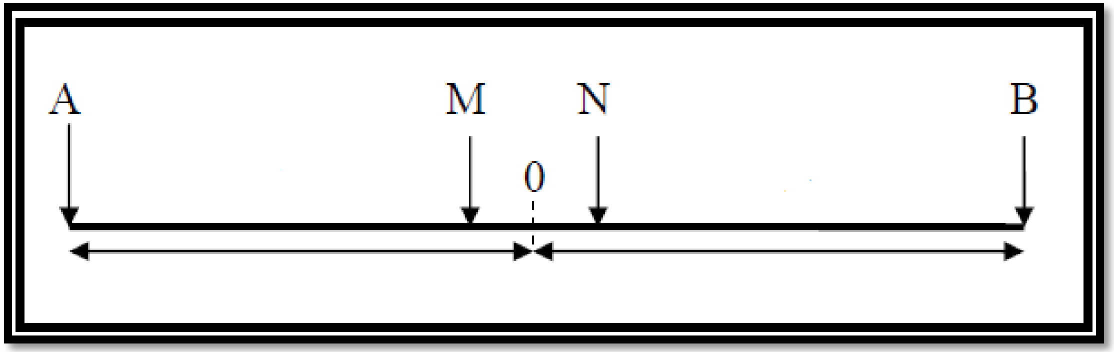
•Wenner array is **characterized** by many features, some of which which are:-

-It is relatively less sensitive to vertical changes in the subsurface resistivity below the center of the array
-it is good in resolving horizontal changes in earth layers, especially near surface earth
- The Wenner array has the strongest signal strength, so this can be an important factor if the survey is carried in areas with high background noise.

Schlumberger Array

•The Schlumberger array consists of four collinear electrodes. The outer two electrodes are current (AB) electrodes and the inner two electrodes are the potential (MN) electrodes.

• In this array, the spacing between potential electrodes (MN) is less than one fifth(1/5) of the spacing between the current electrodes (AB) , as showing in figure below.



•**The values of apparent resistivity (*ρa*) for this array can be calculated by following equation:-**

$$\rho_a = K.R$$

The geometric factor (K) can be calculated by two equations,

- **The first** is called **practical equation**, and it is represent practical case of the array.

$$K_{pr} = \pi\left[(AB\backslash 2)^2/MN - MN/4\right] \ldots\ldots..(10\text{-}1)$$

- **The second** is called **theoretical equation**, and it is represent theoretical case of the Schlumberger array.

$$K_{th} = \pi(AB\backslash 2)^2/MN$$

- The difference between these equations are the first equation (K *pr*)involve derivation (K) when the (MN) distance not equal zero, but it is small in comparison with the (AB) distance, and it is represent practical case in the field . While the second equation (K th) involves derivation (K) when the (MN) distance equal zero approximately, that is the array in this case is represent theoretical case, which does not application in the field.

- However, the array is characterized by many features, some of which are:-

1- High sensitivity to vertical changes in the subsurface resistivity below the center of the array.

2- It is easy in application, due to the electrode spacing (MN) is fixed for many (AB) spacing , especially in the VES surveys. Also easy in removing inhomogenity effect on apparent resistivity field curves.

3- Schlumberger array generally have better resolution, greater penetration depth, and less time-consuming field deployment than the Wenner array.

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4- in this array short potential electrodes cables are required .

3- dipole-dipole array

- The dipole-dipole electrode array consists of two sets of electrodes, the current (AB) and potential (MN). The potential electrodes (MN) are located outside the current electrodes (AB).
- The electrode spacing (AB) is equal or not equal the electrode spacing (MN), and it has a factor marked as (n) as shown in figure below , which controls the depth of investigation

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

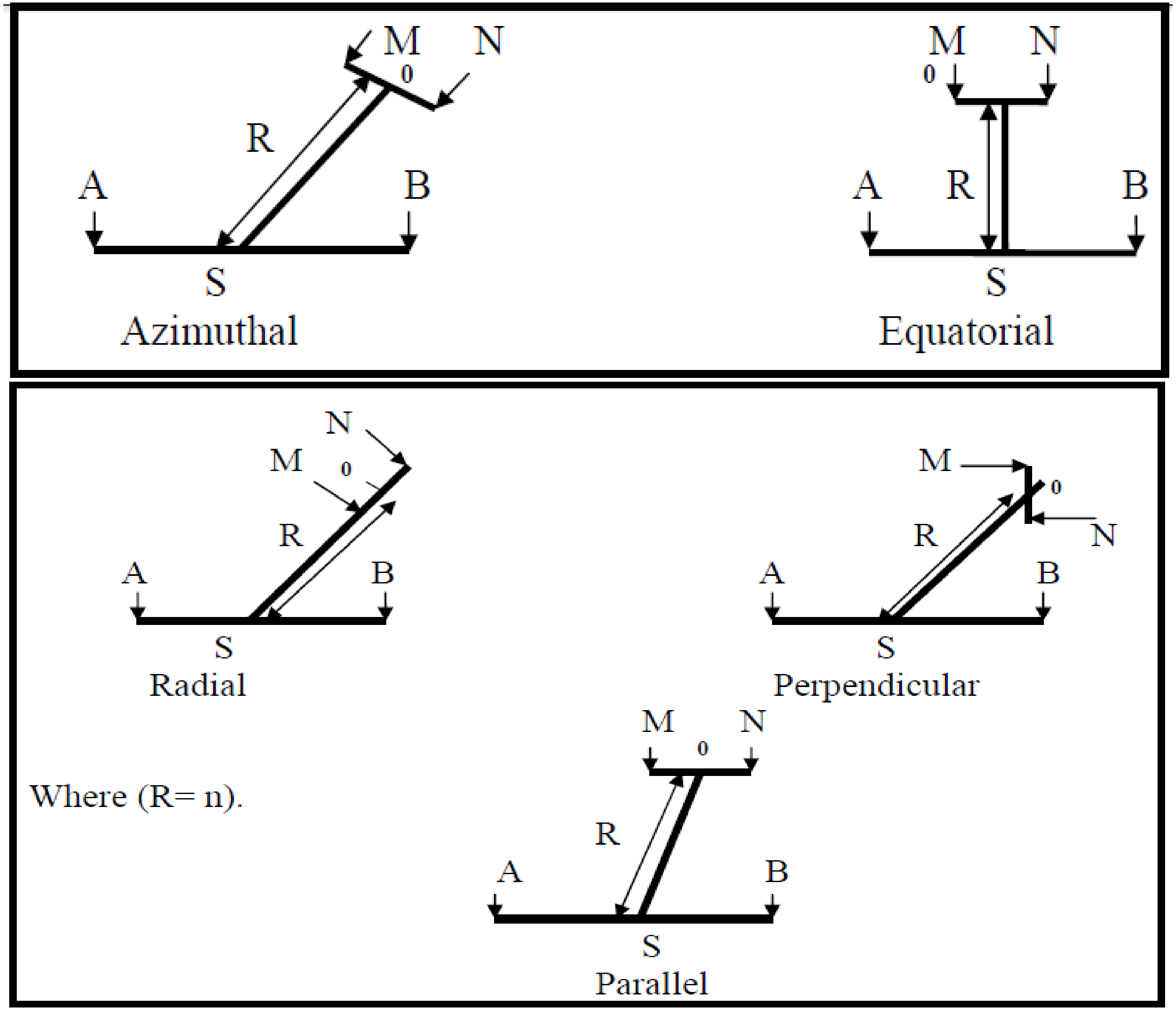
- This array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes, which means it is good in mapping vertical structures, such as faults, but relatively poor in mapping horizontal structures such as sedimentary layers.
-This array have greater penetration depth compared with wenner and schlumberger array.
- this array is More sensitive to the lateral heterogeneity

The disadvantage of this array involves to:-

- high electrical current source is required if this array is applied , therefore a large generator may be needed to transmit a greater current magnitude for the measurement, especially for deep sounding

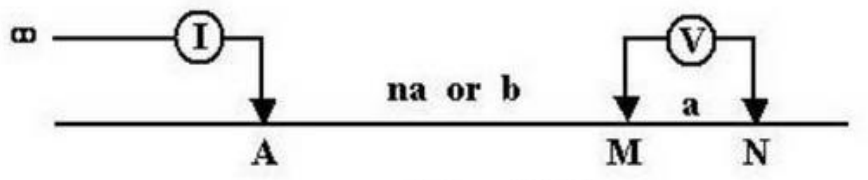
- The crew of field work in this array are more than other array type

- There are different types of dipole – dipole array such as Equatorial, Azimuthal,parallel ,Radial, Parallel, Perpendicular, and Polar or Axial array , as shown in figures below:-



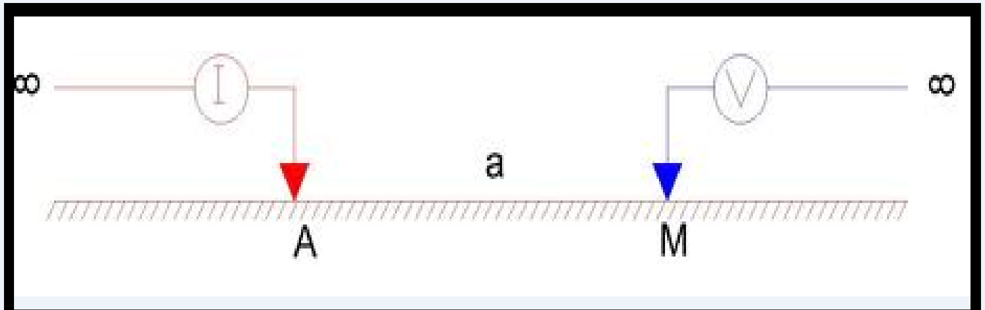
Other configurations (Array)

There are many other arrays can be used in resistivity survey such as , pole-pole array Dipole –pole array , square array , lee array and offset wenner array , figures below show Some of these arrays.

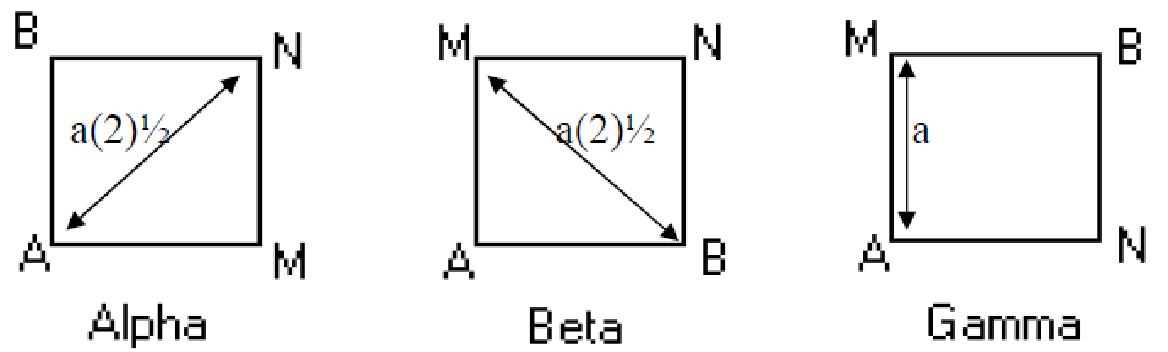


$$\rho_A = 2\pi \frac{b\,(a+b)}{a}\frac{V}{I}$$

pole -Dipole array



pole - pole array



Types of Square array

- Field Techniques of Measurements.

There are many procedures or field techniques for electrical resistivity surveys , some of which are:-

A- Constant Separation Traverse (CST) or what is known as horizontal profiling or mapping

B - Vertical Electrical Sounding (VES):

C- Pseudosection

D- Azimuthal Resistivity Survey.

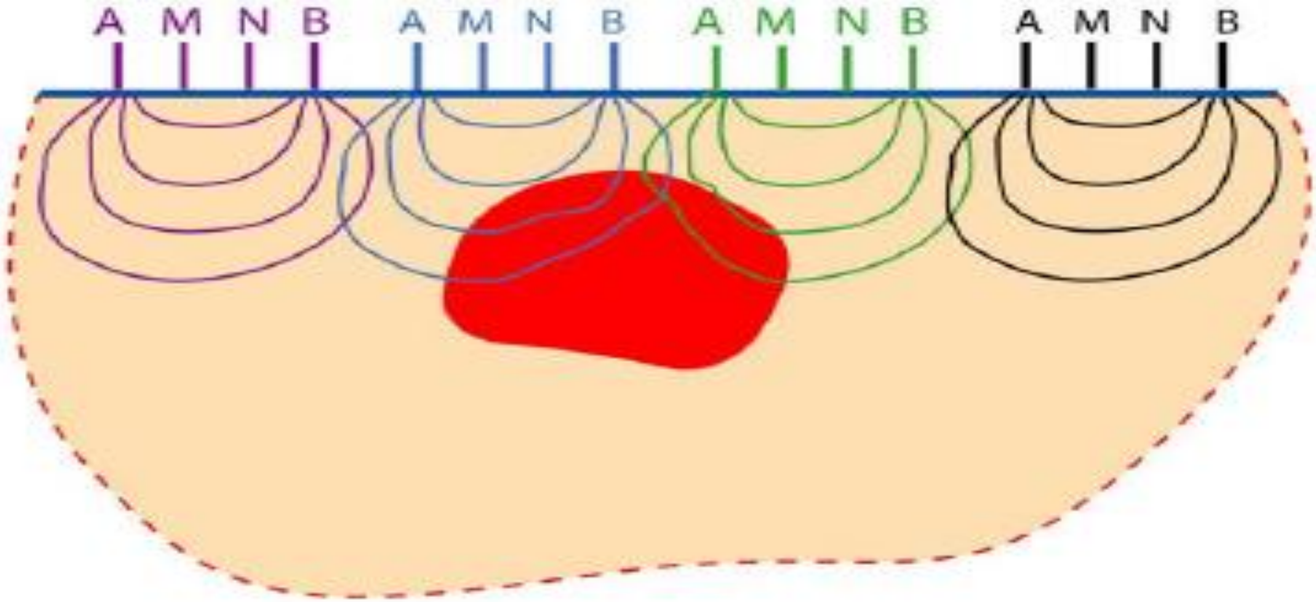
E- 2 D (2Dimentional survey)

F- 3D (3 Dimensional survey)

A- Constant Separation Traverse (CST) or what is known as horizontal profiling or mapping

This techniques is used to determine the horizontal (or lateral) variation in apparent resistivity . In this technique, a fixed electrode spacing is chosen while the whole electrode array is moved along a profile after each measurement, figure below.

- The electrode spacing must be carefully chosen because it the factor which determines the depth of penetration. In order to find the best spacing between the electrodes it is advisable to carry out an electrical resistivity sounding(VES) in the area before applying this technique .



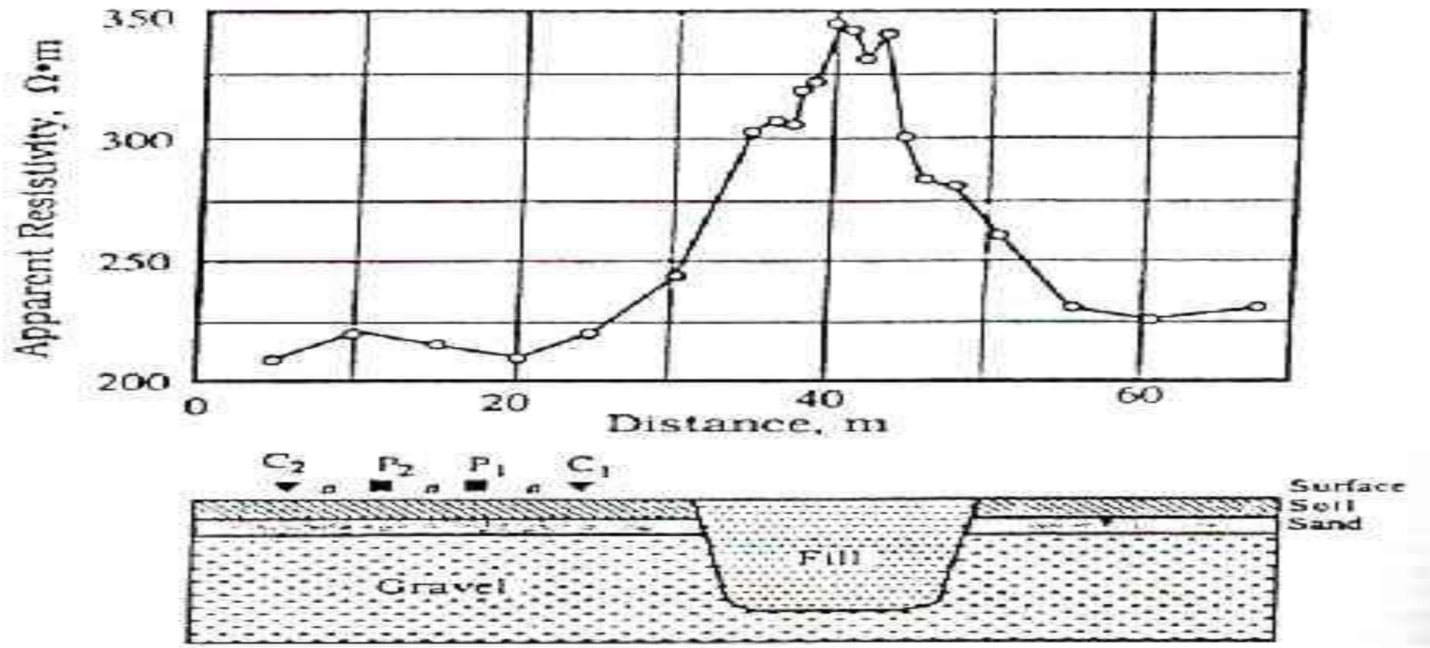
- **This technique gives some information about lateral changes in the subsurface apparent resistivity, but it cannot detect vertical changes in the resistivity**

- In general, all types of electrode arrays have been used in this technique, but the most commonly used are dipole – dipole and Wenner array.

- This method is employed in mineral prospecting to locate faults or shear zones or to determine localized bodies of anomalous conductivity.
- It is used in geotechnical surveys to determine variations in bedrock depth and the presence of steep discontinuities.

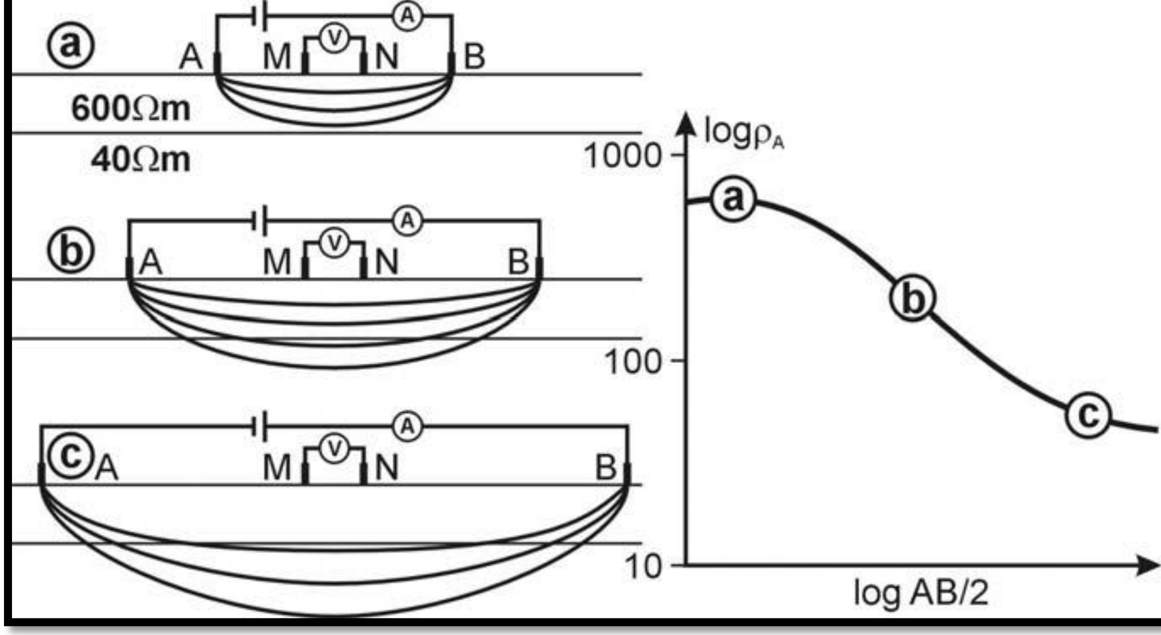
- The results of profiling technique is represented as a profile of resistivity variation along the traverse or as iso resistivity contour maps .

- The interpretation of horizontal profiling is mainly qualitative.

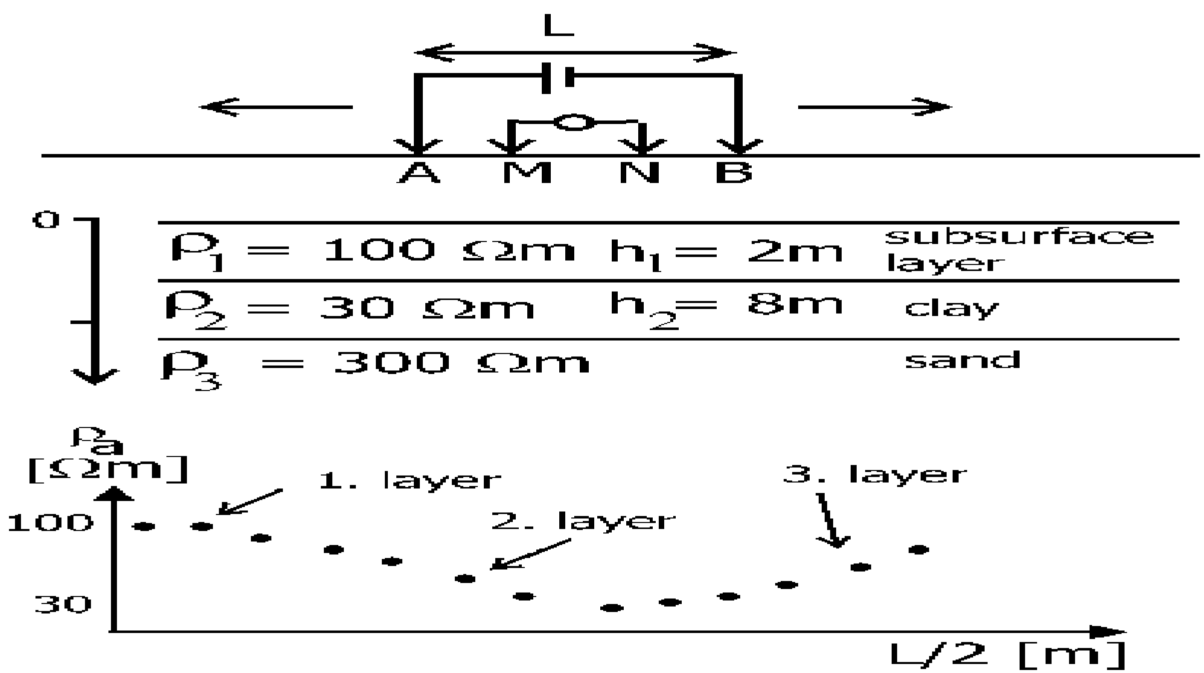


- Vertical Electrical Sounding (VES).

- This techniques is used to determine the vertical variation in apparent resistivity below the ground surface. In this technique, the center point of the electrode array remains fixed, but the spacing between the electrodes is increased to obtain more information about the deeper section of the subsurface, figure below.



a
A
M
V
N
B
A
600Ωm
40Ωm
b
c
logρA
1000
100
10
log AB/2



L
A
M
N
B
0
ρ1 = 100 Ωm h1 = 2m
subsurface layer
ρ2 = 30 Ωm h2 = 8m
clay
ρ3 = 300 Ωm
sand
ρa [Ωm]
1. layer
2. layer
3. layer
100
30
L/2 [m]

- This techniques is based on fact that the depth of penetration of the current is increased by increasing the distance between current electrodes .

- This technique can be use by any types of electrodes array , but the Schlumberger array is more widespread in VES, because, it offers better control over lateral resistivity variation close to the potential electrodes.

- Using the Wenner array of electrodes the separation "a" is increased by moving each of the electrodes out such that the center point of the system remains constant.

- Using Schlumberger array of electrodes the potential electrodes are kept fixed at the center of the line "C_1 C_2" while the current electrodes are moved symmetrically outwards. At any stage , the potential difference becomes to small, then the potential electrodes separation should be increased and measurements continued.

- Since only two electrodes are moved, the field procedure with the Schlumberger array is quicker than that with

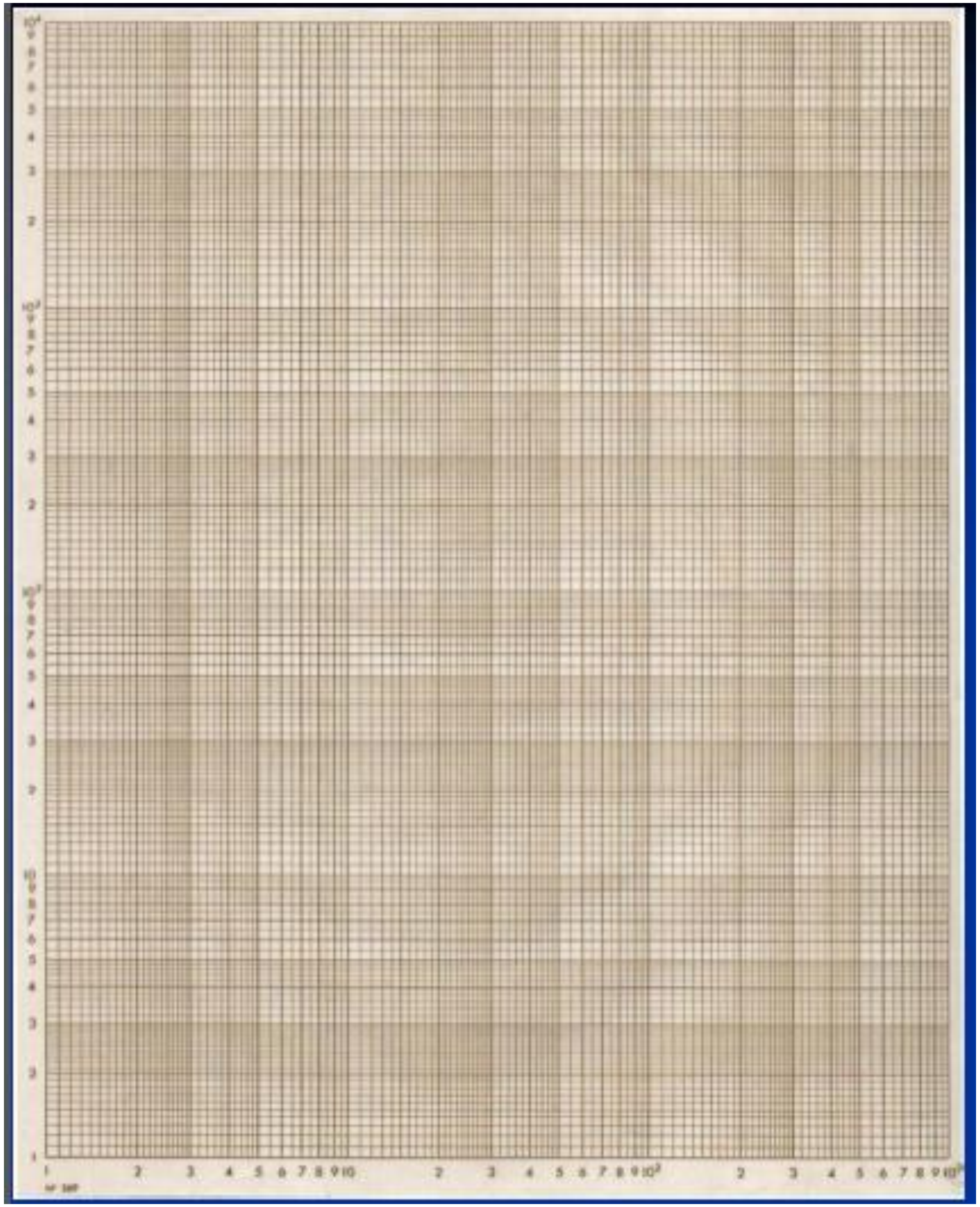
Wenner array

- This technique is used for groundwater and shallow engineering studies,
- The interpretation of VES data is mainly Quantitative and Qualitative

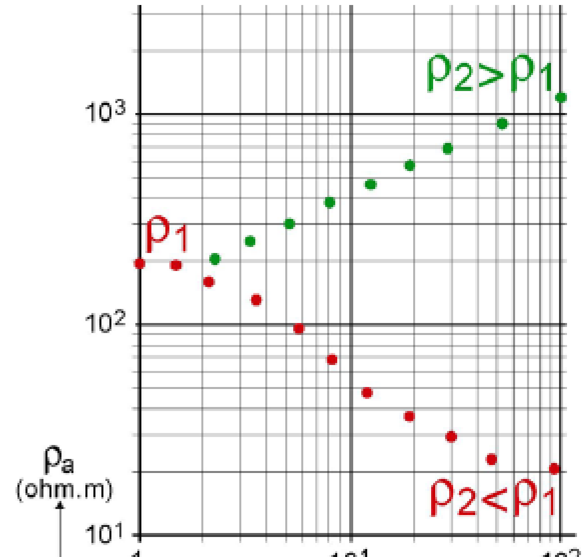
Presentation of resistivity surveys data

- In the case of electrical resistivity sounding surveys the measured apparent resistivities are usually plotted on the ordinate against the electrode separation or some function of this on the abscissa.

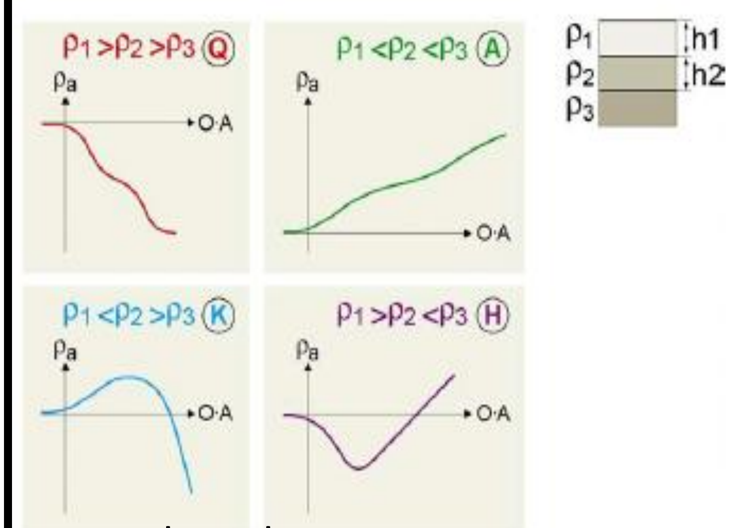
- Bilogarithmic papers with cycle base 6.25 cm usually used. See Fig. below



Bi-logarithmic paper used for the plotting of VES data (base 6.25 cm).



Two layers curves.

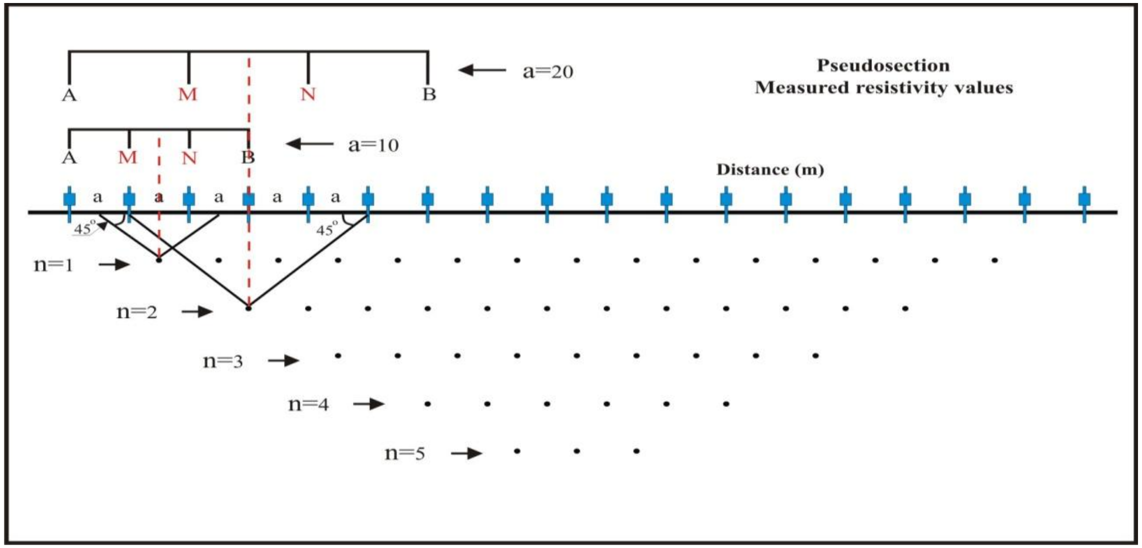


Three layers curves.

C:- Pseudo section:-

- In this technique the Vertical Electrical Sounding (VES) and Constant Separation Traverse (CST) techniques are used together to determine the lateral and vertical changes of subsurface apparent resistivity at the same time.

- The obtained data of (*Pa*) values are plotted to form a pseudosection. One common method to plotting pseudosection is to place the plotting point of *(Pa*) measurements at the intersection of two lines starting from the mid-point of the (A-B) and (M-N) dipole pairs, with an angle equal (45º) to the horizontal, as shown in figure below.

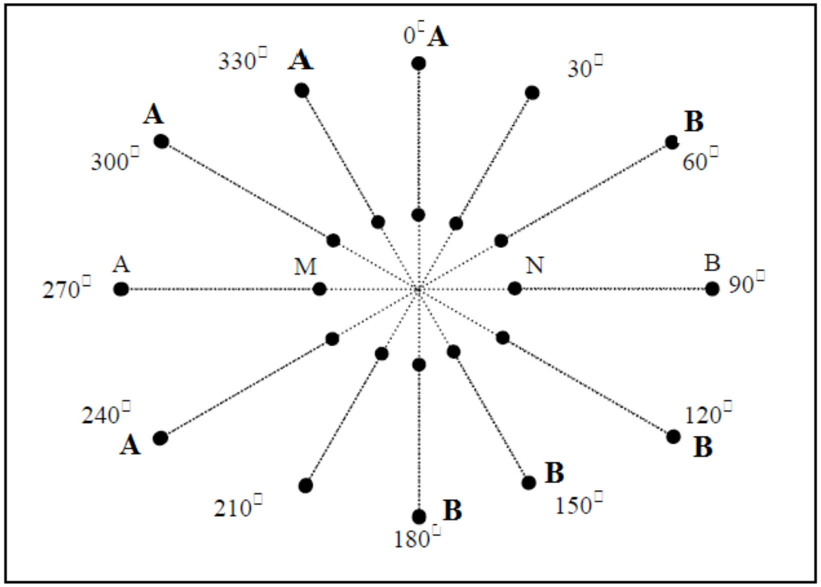


- **The interpretation of pseudosection data is mainly qualitative and it gives very approximate and not actual image of the true subsurface resistivity distribution**

- However, the pseudo section is mainly using for mineral investigation and the detailed surveys about the under ground structures. In the last years, this technique is used in the 2D imaging surveys , which represents the modern technique in the electrical resistivity surveys.

D:- Azimuthal sounding

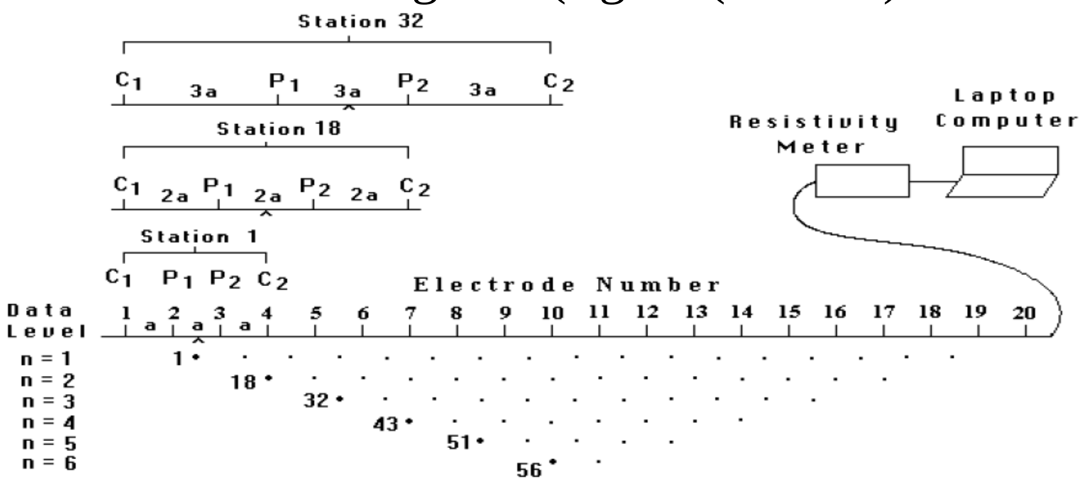
Azimuthal resistivity or as called circular or crossed sounding is a modified resistivity method where the magnitude and direction of the electrical anisotropy are determined. In this technique , an electrode array is rotated about its center so that the apparent resistivity is observed for several directions .This technique can be sensitive to variations in a subsurface that has preferentially aligned fractures. Line azimuths that are perpendicular to water- filled fractures should exhibit higher resistivity, allowing us to map the direction of subsurface fracturing .



Layout of symmetrical azimuthal resistivity survey. A Wenner array is rotated 30 degrees clockwise.

E: - 2D Imaging :-

A more accurate model of the subsurface is a two– dimensional (2-D) Model where the resistivity changes in the vertical direction ,as well as in the horizontal direction along the survey line. Such surveys are usually carried out using a large number of electrodes (20 or more) connected to a multi –core cable , A laptop together with an electronic switching unit (figure (below)



To take the sequence of measurements, the type of array used and other survey parameters (such the current to use) is normally entered in to a text which can be read by a computer program.

After reading the control file, the computer program then automatically selects the appropriate electrodes for each measurement ,and the measurements are taken automatically and sorted in the computer

Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements . resistivity data are then recorded to build pseudo- section of apparent resistivity beneath the survey line .after that the pseudo –section converted to yield section whith bulk resistivity and true depth, see figure below.

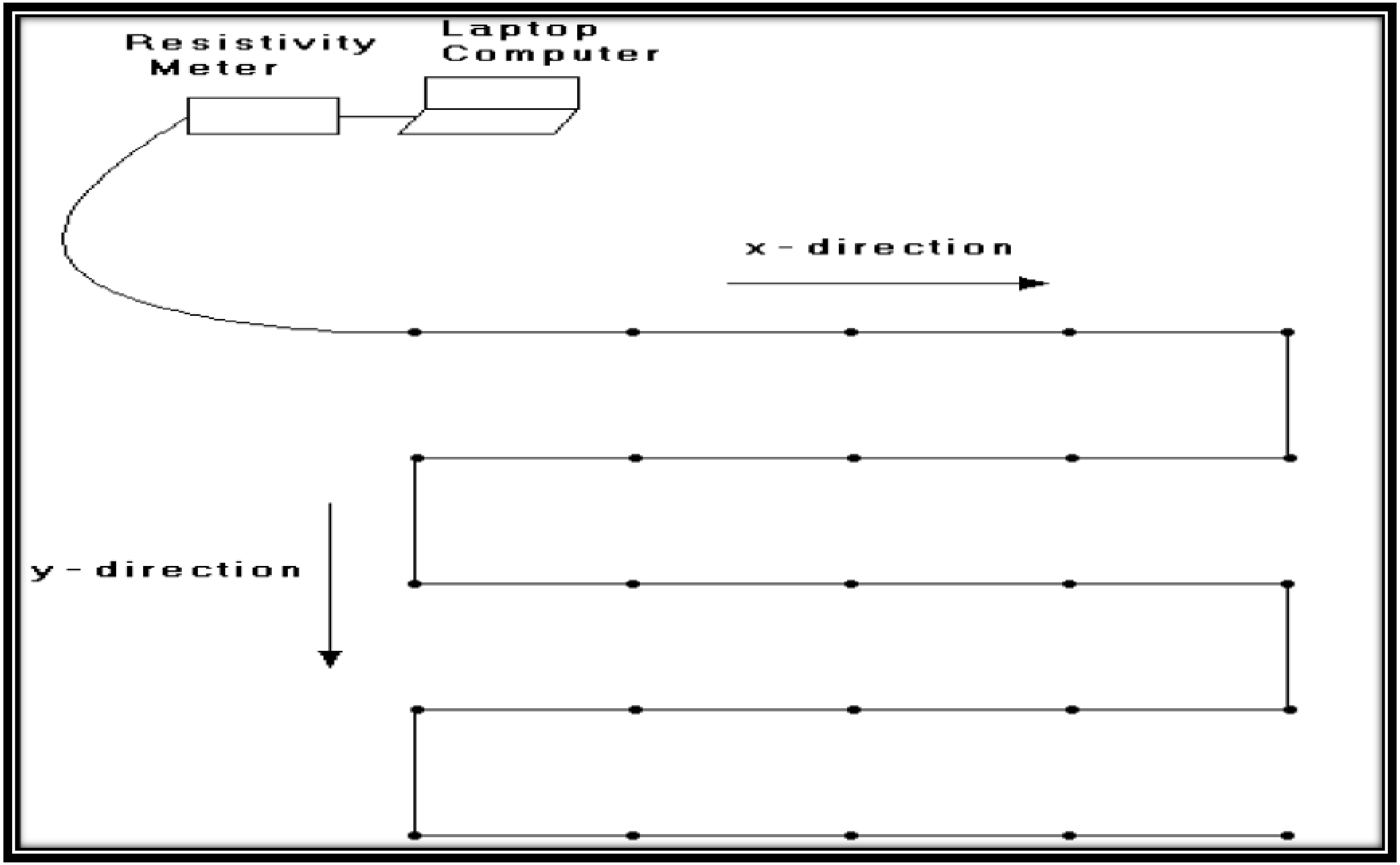
In the 1D resistivity sounding surveys usually involve about (10) to (20) readings, while 2D imagi surveys involve about (100) to (1000) measurements. The cost of a typical 2D survey could be several times the cost of a 1D sounding survey. In many geological situations, 2D electrical imaging surveys can give useful results that are complementary to the information obtained by other geophysical method.

3D Electrical Imaging Survey.

Since all geological structures are 3D in nature, a fully 3D resistivity survey using a 3D interpretation model should in theory give the most accurate results. At the present time 3D surveys is a subject of active research. However, it has not reached the level where , like 2D surveys, it is routinely used. The main reason is that the survey cost is comparatively higher for a 3D survey of an area, which is sufficiently large.

There are two current developments that should make 3D surveys a more cost-effective option in the near future:-
1- the development of multi-channel resistivity meters which enables more than one reading to be taken at a single time. This is important to reduce the survey time.

2- development faster microcomputers to enable the inversion of very large data sets (with more than 8,000) data points and survey grids of greater than (30 by 30) to be completed within a reasonable time.



Field Work of Vertical Electrical Sounding (VES).

In this technique, that is the Schlumberger array is the most widely used for deep sounding, especially in investigation of groundwater aquifers. Four electrodes (AMNB) are placed along a straight line on the earth surface in the same direction when taking measurements the potential electrodes remain fixed, while the current electrodes expanding to various distances, until the potential difference between (M, N) drops to such degree, that it can not be measured. In this case it is necessary to increase the distance between potential electrodes.

There are many notes must be taken into account during carrying out the (VES) survey, because it is caused errors in measurements , for example:-

- **Bad connection between the electrode and the cable**

• **One (or more) of the electrodes was stick inclinely which may cause bad Contact between this electrode and the ground.**

• **Touching the cable during the measuring operation.**

• **Touching the electrode or the clips cord during the measuring operation.**

• **Putting the clips cord nearly the ground surface while it is connected to the electrode.**

Interpretation of (VES) Data.

The measurements of vertical electrical sounding are plotted and Processing, then using two methods of interpretations; the first method is called qualitative interpretation, which is included primary evaluation of the apparent resistivity values using many techniques such as:-

A – Study the Curve Types of VES.

B – Apparent resistivity pseudo cross – section.

C – Apparent resistivity Profiles.

D – Apparent resistivity maps.

The second method is called quantitative interpretation which includes determination of the resistivities and thicknesses of electrical horizons for VES field curves using two techniques

1. the first is manually by using curve matching, and the
2- second is computerized programs.

Usually both techniques are used together.

However, the results of interpretation must be consolidated by geological and hydrogeological information available from maps and drilled wells, to obtain a more reliable geologic picture of the subsurface.

As for the Constant Separation Traverse (CST) and Pseudo section technique are being interpreted by quantitative method only.

Ambiguity in electrical resistivity method

As can be seen in other geophysical methods, ambiguity in electrical resistivity interpretation procedures may also appeared due to the presence of the following important principles:-

1- Principles of Equivalence

Equivalent means the matching of a field curve with more than a standard curve, or several layer sections vary in resistivity and thickness give approximately the same field curve .

for any sounding curve , there is a range in which the values of resistivity and thickness of the intermediate layer changes without any changes in the shape of the curve sounding if the ratio ($S2=E2/\rho 2$) remains constant for (H),(A) curves type and the values of ($T2=E2.\rho 2$) remain constant for (K) ,(Q) curves type , where the (S2) represent the longitudinal conductivity and (T2) represent the transverse resistance for intermediate layer .

In both these cases the determination of the resistivity and thickness of the intermediate layer is difficult , and determine exactly from information of drilling.

2- Principles of Suppression

The suppression principle is another type of ambiguity which also accompanies interpretation o field curves, is related to the presence of layers have little thickness and medium resistivity between the layers that lie under and above it. Where the impact of these layers appear when the thickness increases but remain vague in case of small relative thickness because it doesn't changing the shape of field curve.

The impact of the principle of suppression appears through the studying of groundwater and in case of presence the thin layer of wet alluvial deposit between dry alluvial deposits and underlying layer containing groundwater which have high conductivity or a layer of high resistivity , where the impact of wet layer will merge with next layer and both appear as one layer. Therefore , the estimation of the groundwater depth will be inaccurate