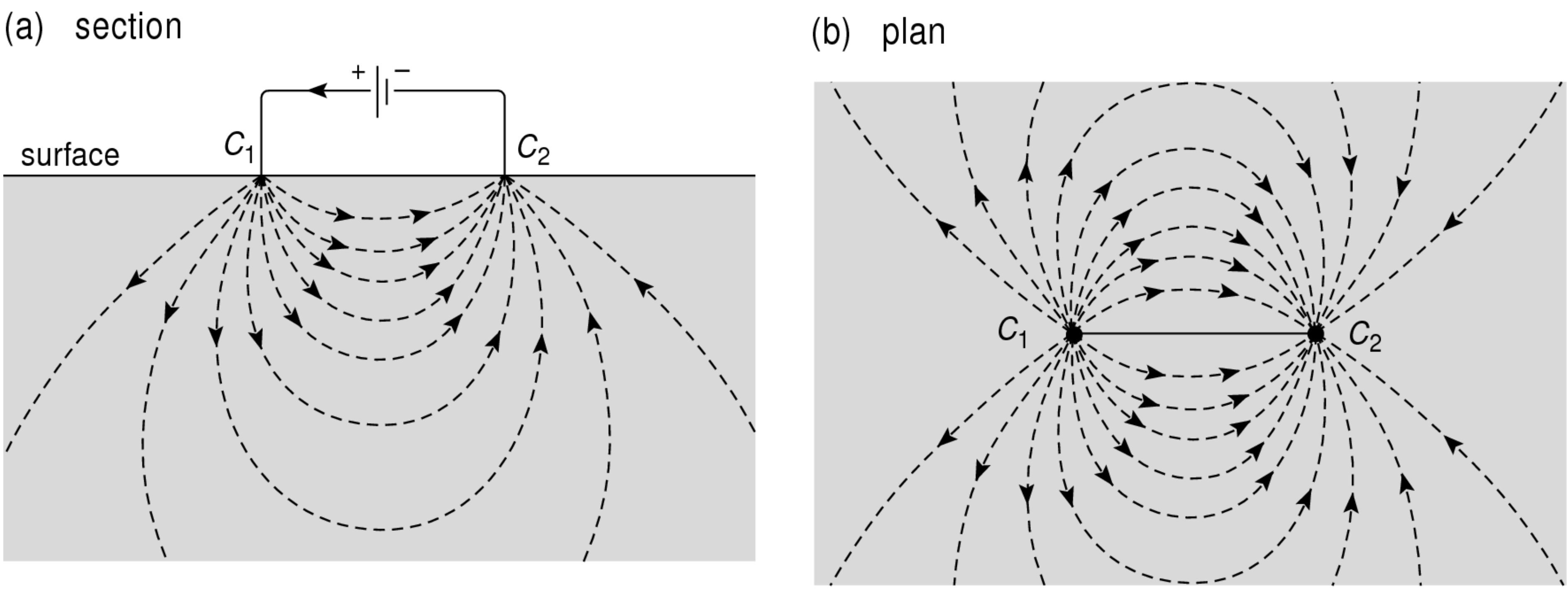
Lesson Plan 4:

Various Resistivity configuration and geometrical factor

Electrode Configuration,
Geometrical constant,
definition of apparent resistivity.

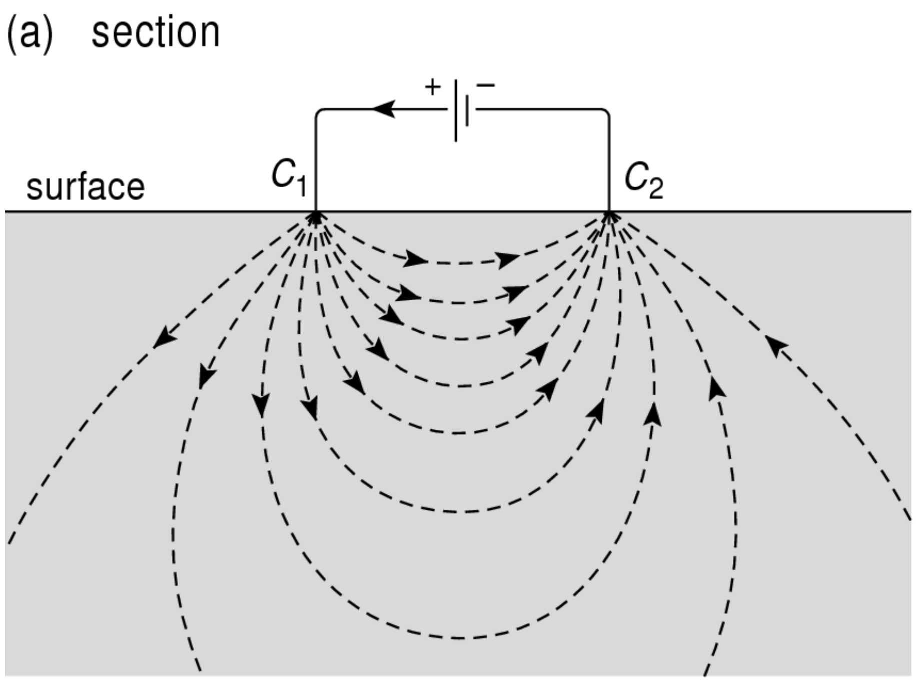
Subsurface Current Paths

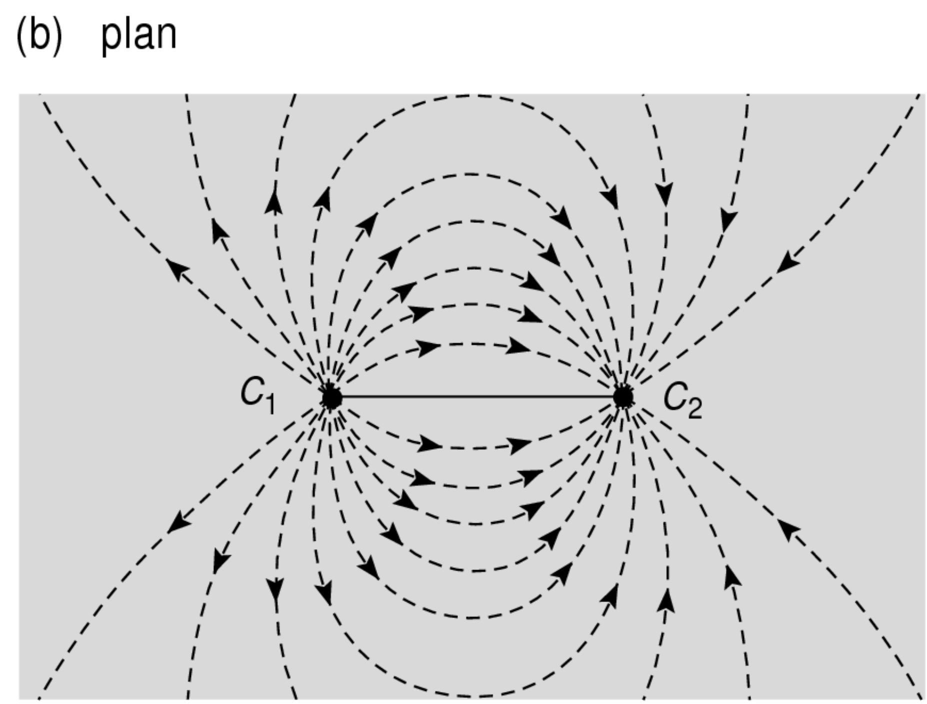
- About 70% of the current applied by two electrodes at the surface stays within a depth equal to the separation of the electrodes
- Typically your electrode spacing is 2x your target depth
  - But this depends on array type (we'll cover this later)



Subsurface Current Paths

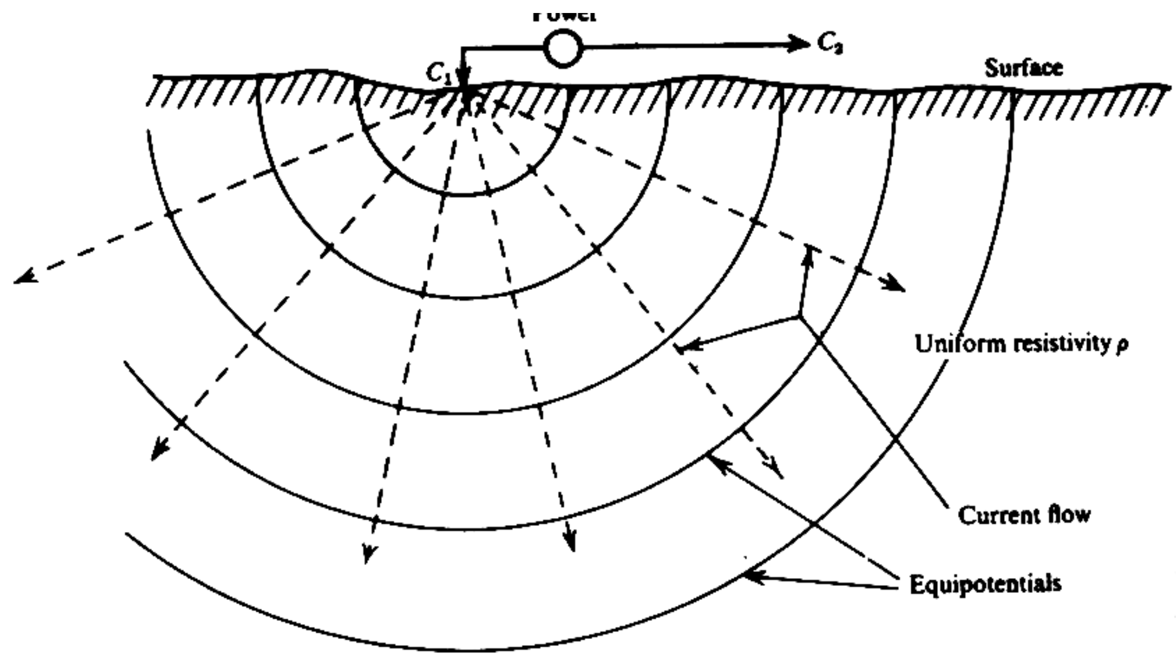
- Why does electricity spread out and follow a curved path in the subsurface?
  - A thin layer has a large resistance $R = \rho \frac{l}{a}$
  - Electricity follows the path or area of least resistance





Current Source on Surface

Electric potential at distance away from current source on surface given as $V(r)=\rho I/2\pi r$. How?

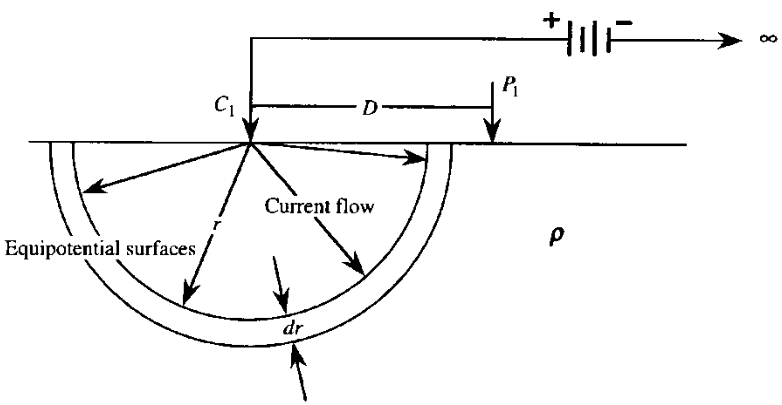


<u>Boundary conditions</u>:

1) As $r \Rightarrow \infty$, $V \Rightarrow 0$.
2) V is continuous across any boundary
3) Tangential **E** continuous across any boundary
4) Normal **i** continuous across any boundary.
5) Surface leads to no vertical current crossing earth-air interface.

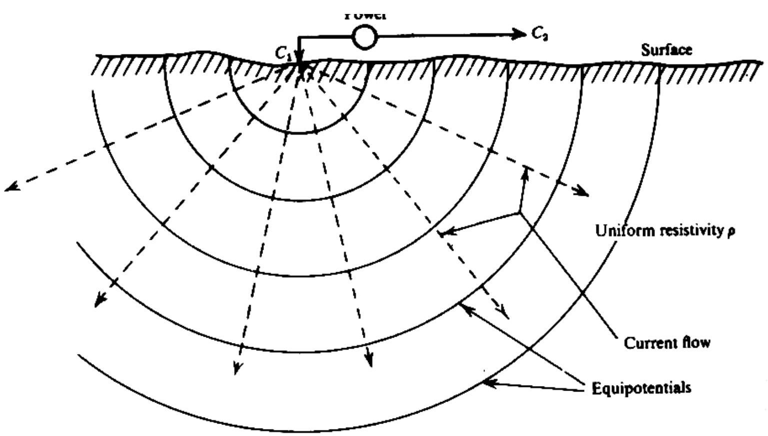
Current Flow in a Homogeneous and Isotropic Medium

Point Current Source:



$$dV = iR_{shell} = i\rho\frac{dr}{A} = i\rho\frac{dr}{2\pi r^2}$$

Voltage decreases as the inverse of the distance from the current source.



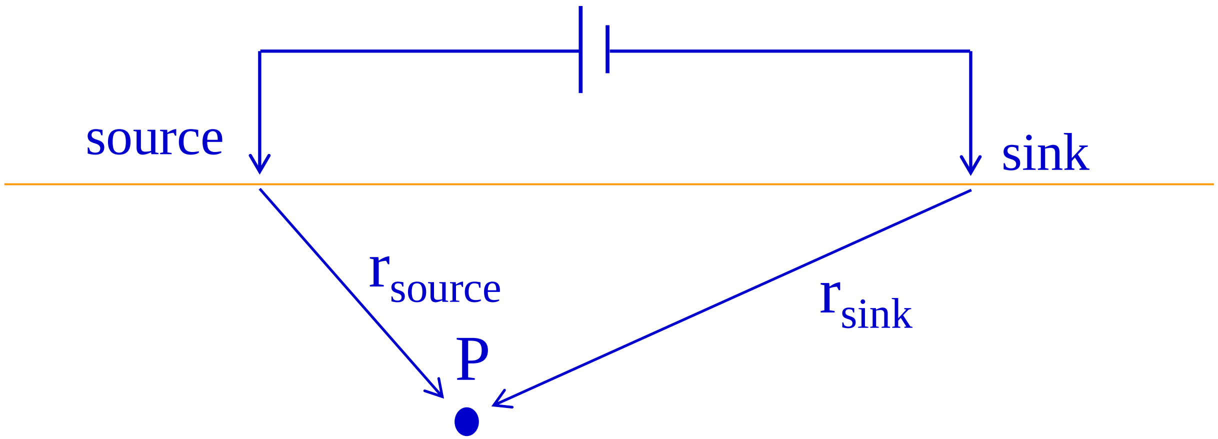
Shape of constant voltages are hemispheres for a single point source

$$V_D = \int_D^\infty dV = \frac{i\rho}{2\pi}\int_D^\infty \frac{dr}{r^2} = \frac{i\rho}{2\pi}(-1)\frac{1}{r}\Big|_D^\infty$$

$$= \frac{i\rho}{2\pi}(-1)\left(\frac{1}{\infty} - \frac{1}{D}\right) = \frac{i\rho}{2\pi D}$$

Two Current Electrodes: Source and Sink

- Why run an electrode to infinity when we can use it?



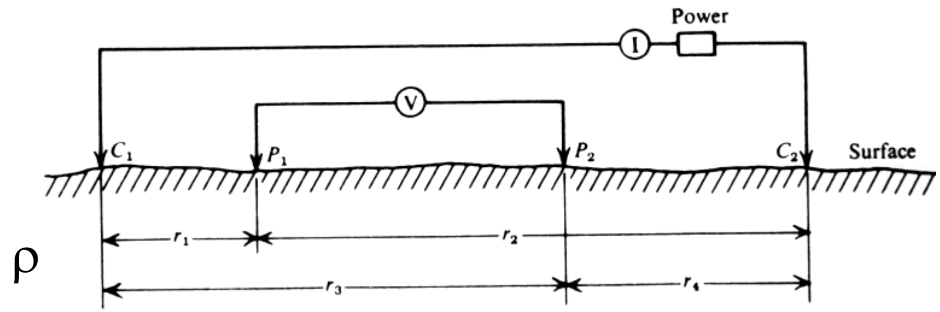
$$V_{source} = \frac{i\rho}{2\pi r_{source}} \qquad V_{sink} = \frac{i\rho}{2\pi r_{sink}}$$

Total Voltage at P:
(superposition)

$$\boxed{V_p = V_{source} - V_{sink} = \frac{i\rho}{2\pi}\left(\frac{1}{r_{source}} - \frac{1}{r_{sink}}\right)}$$

Measurements

You cannot measure potential at single point unless the other end of our volt meter is at infinity. It is easier to measure the *potential difference* (ΔV). This lead to use of four electrode array for each measurement.



Resulting measurement given as
$$\Delta V = V_{P1} - V_{P2} = \frac{i\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)$$

Can be rewritten
$$\Delta V = \frac{i\rho}{2\pi G}$$

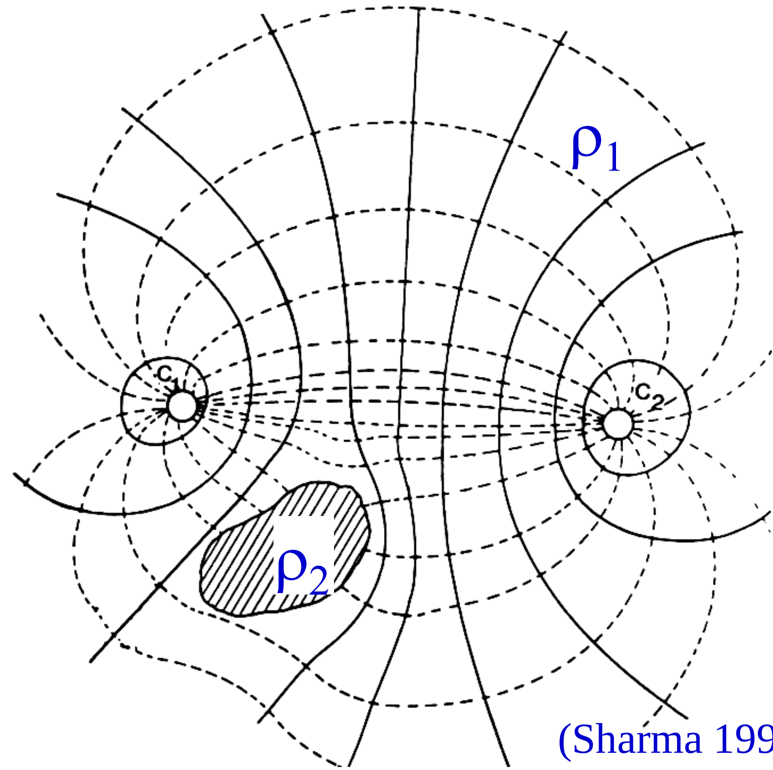
where $2\pi G$ is the ***Geometrical Factor*** of the array.

Apparent Resistivity

Previous expression can be rearranged in terms of resistivity:

$$\boxed{\rho = 2\pi G \frac{\Delta V}{i}}$$

This can be done even when medium is inhomogeneous. The result is then referred to as *Apparent Resistivity* ρ_a.

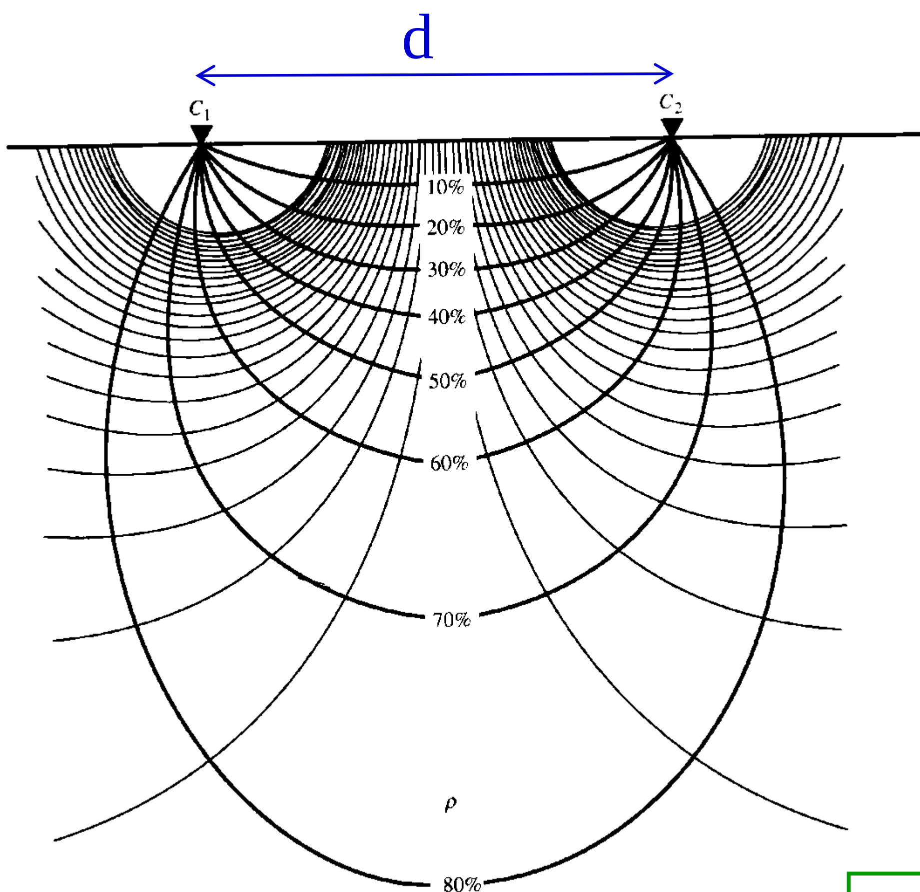


(Sharma 1997)

Definition: Resistivity of a fictitious homogenous subsurface that would yield the same voltages as the earth over which measurements were actually made.

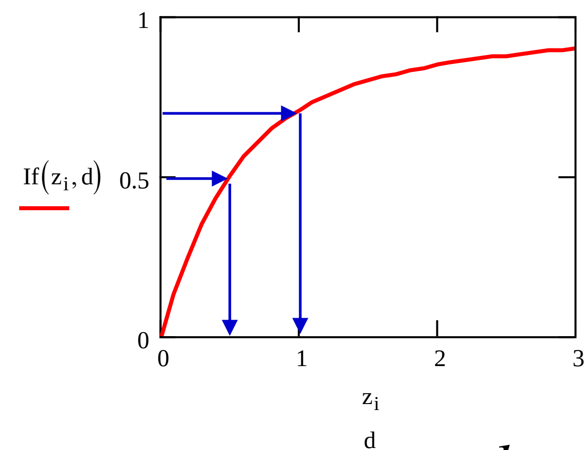
Current Distribution

Homogeneous medium



fraction total current

$$I_f = \frac{2}{\pi} \arctan\left(\frac{2z}{d}\right)$$



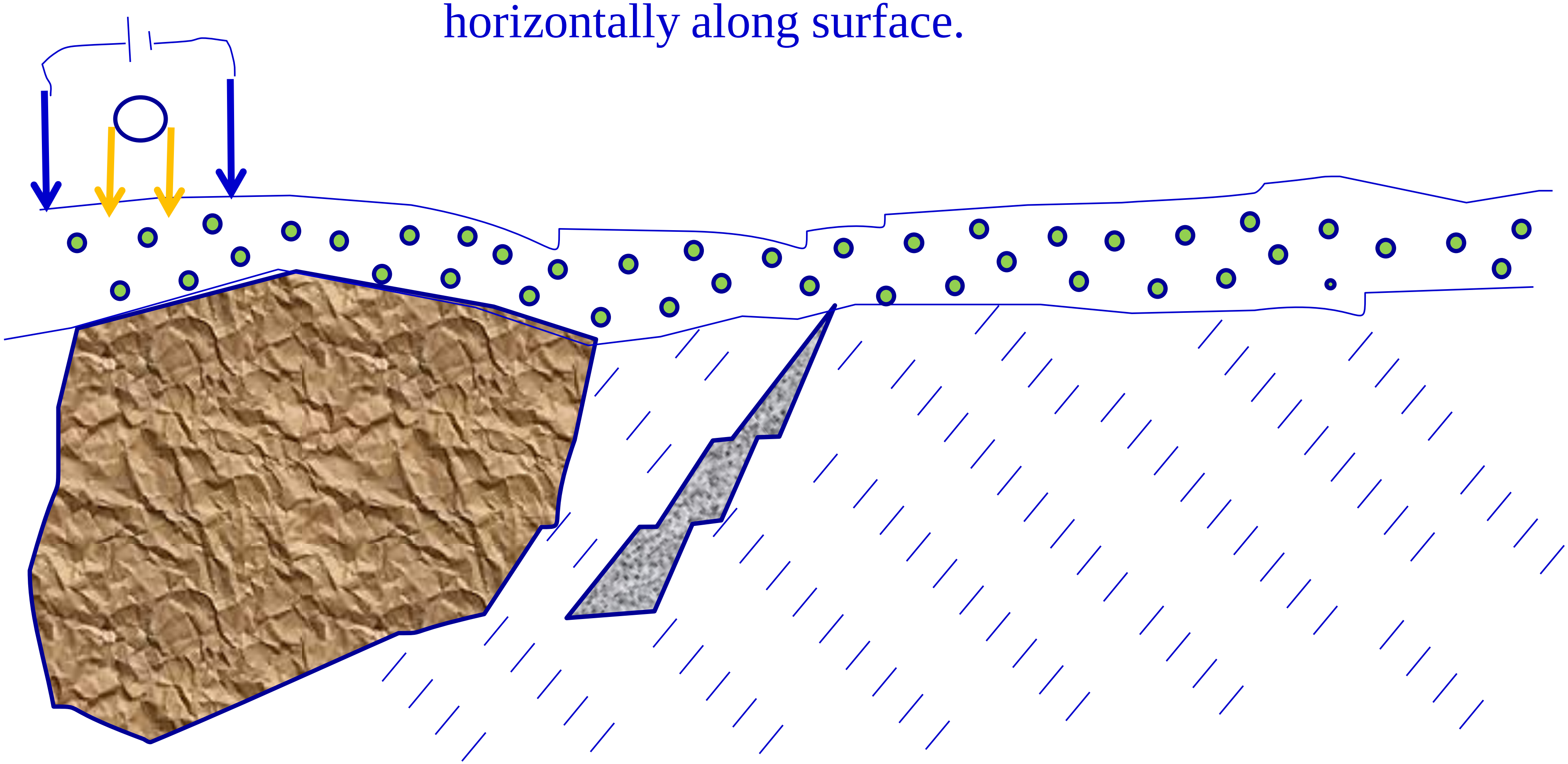
i_f=0.5 at $z = \dfrac{d}{2}$

i_f=0.7 at $z = d$

Wider spacing → Deeper currents

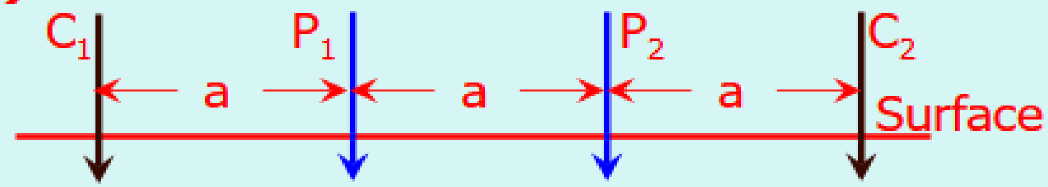
Horizontal Profiling

- Used for rapid location/delineation of lateral variations in resistivity.
- Usually involves moving an electrode array of constant separation horizontally along surface.

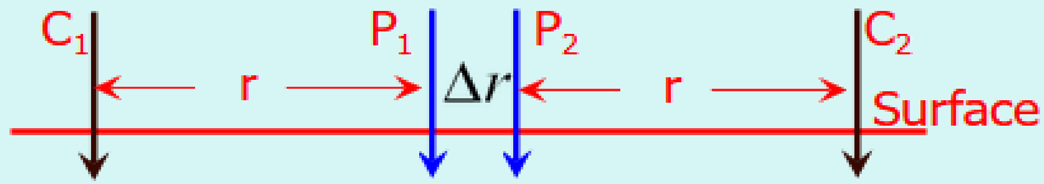


Electrode Spread (Array type)

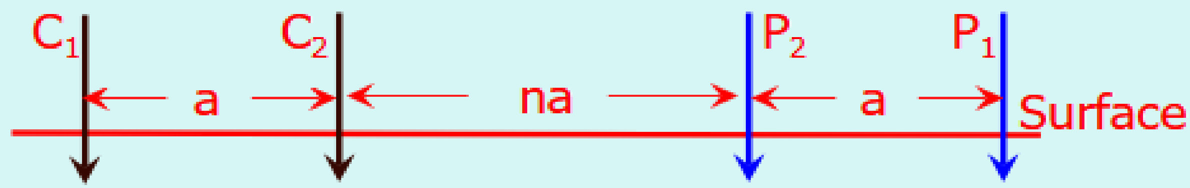
1- Wenner Array



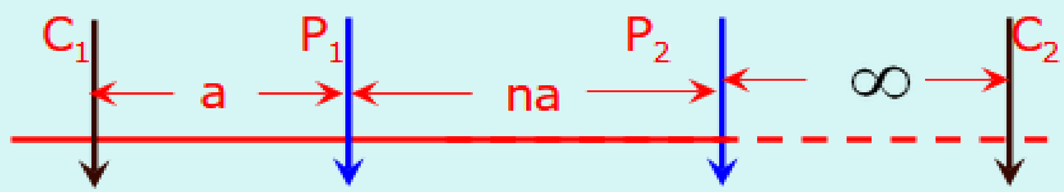
2- Schlumberger Array



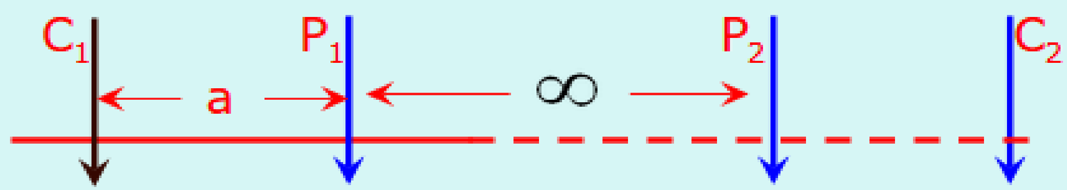
3- Dipole-Dipole Array



4- Pole-Dipole Array

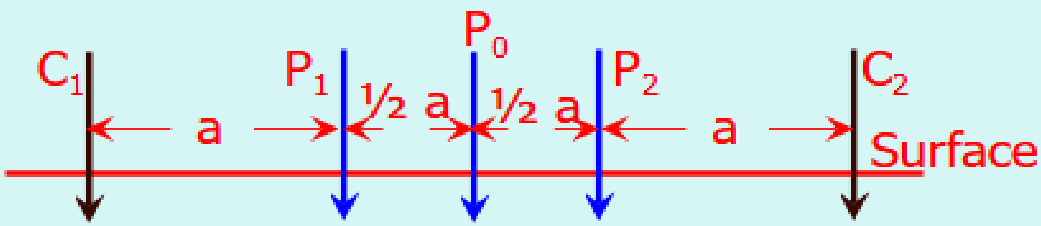


5- Pole-Pole Array

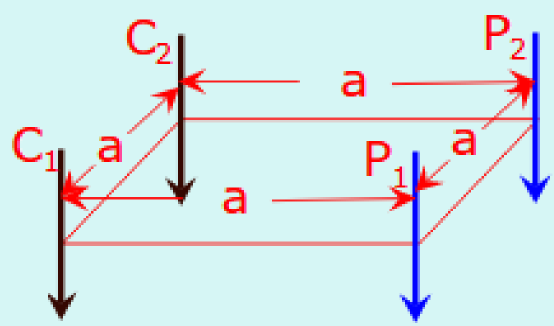


6- Gradient Array

7- Lee-partition Array



8- Square Array



In vertical sounding. the potential electrodes remain fixed while the current-electrode spacing is expanded symmetrically about the center of the spread. This procedure is more convenient than the Wenner expanding spread because only two electrodes need move.

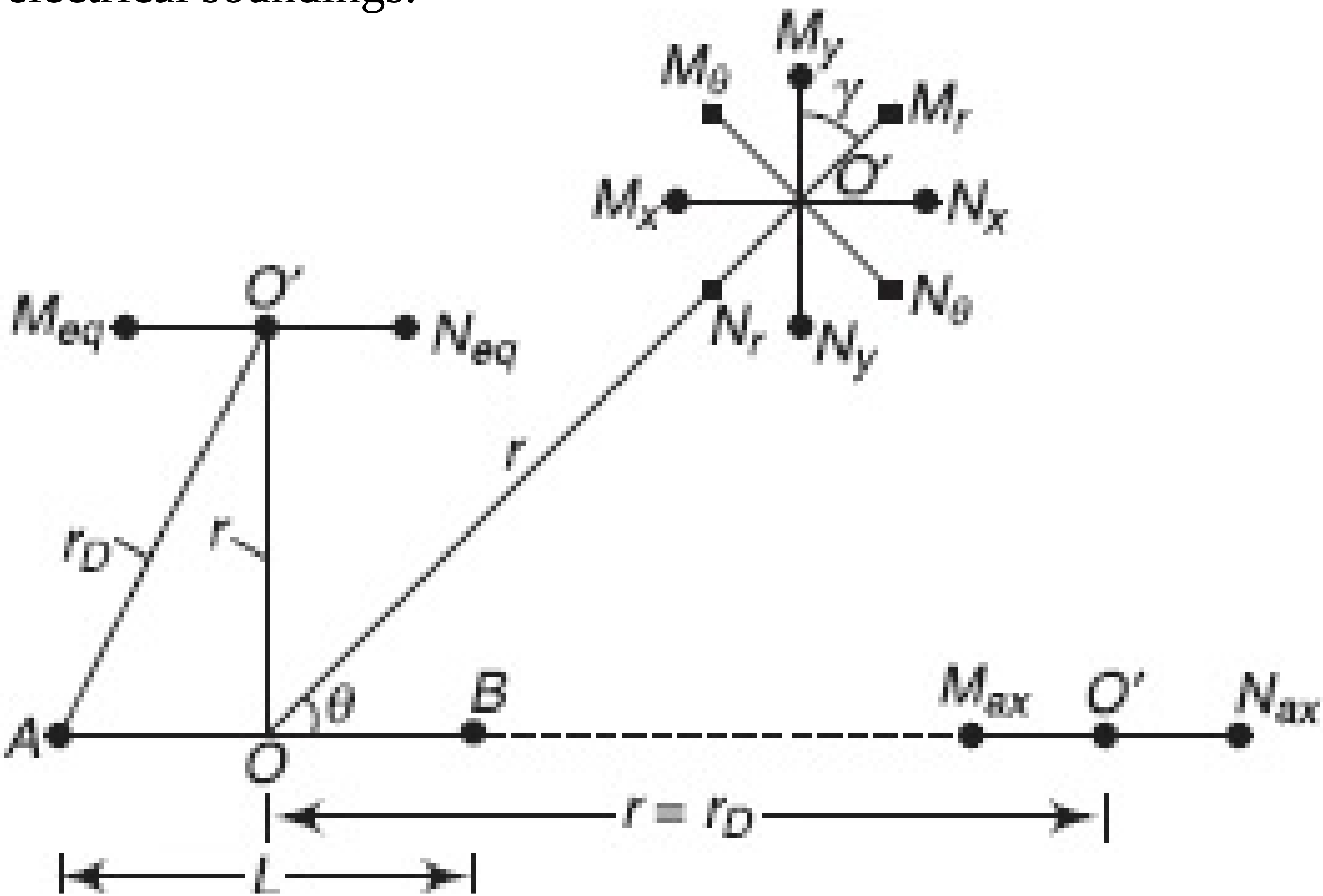
In addition, the effect of shallow resistivity variations is constant with fixed potential electrodes.

Lateral profiling (§8.5.4c) may be done in two ways. With a very large fixed separation of the current electrodes (300 m or more), the potential pair is moved between them, also with fixed spacing, subject to the limitation $(L - x) >> 3l$.
Apparent resistivity is plotted against the midpoint of the potential electrodes.

Half-Wenner array. rx = a, r2 = r3 = r4 = Infinity For the preceding configurations, the results are:

Half-Schlumberger array. r1 = L - l, r3=L +l, r2 = r4 = infinity, L>>l

The equatorial and axial dipole set-ups are most commonly used in dipole sounding (DS). The dipole sounding is is extensively used in deep electrical soundings.



Classifications of dipole arrays:

(i) $ABM_\theta N_\theta$ - azimuthal, $\gamma = 90°$ (DAS);

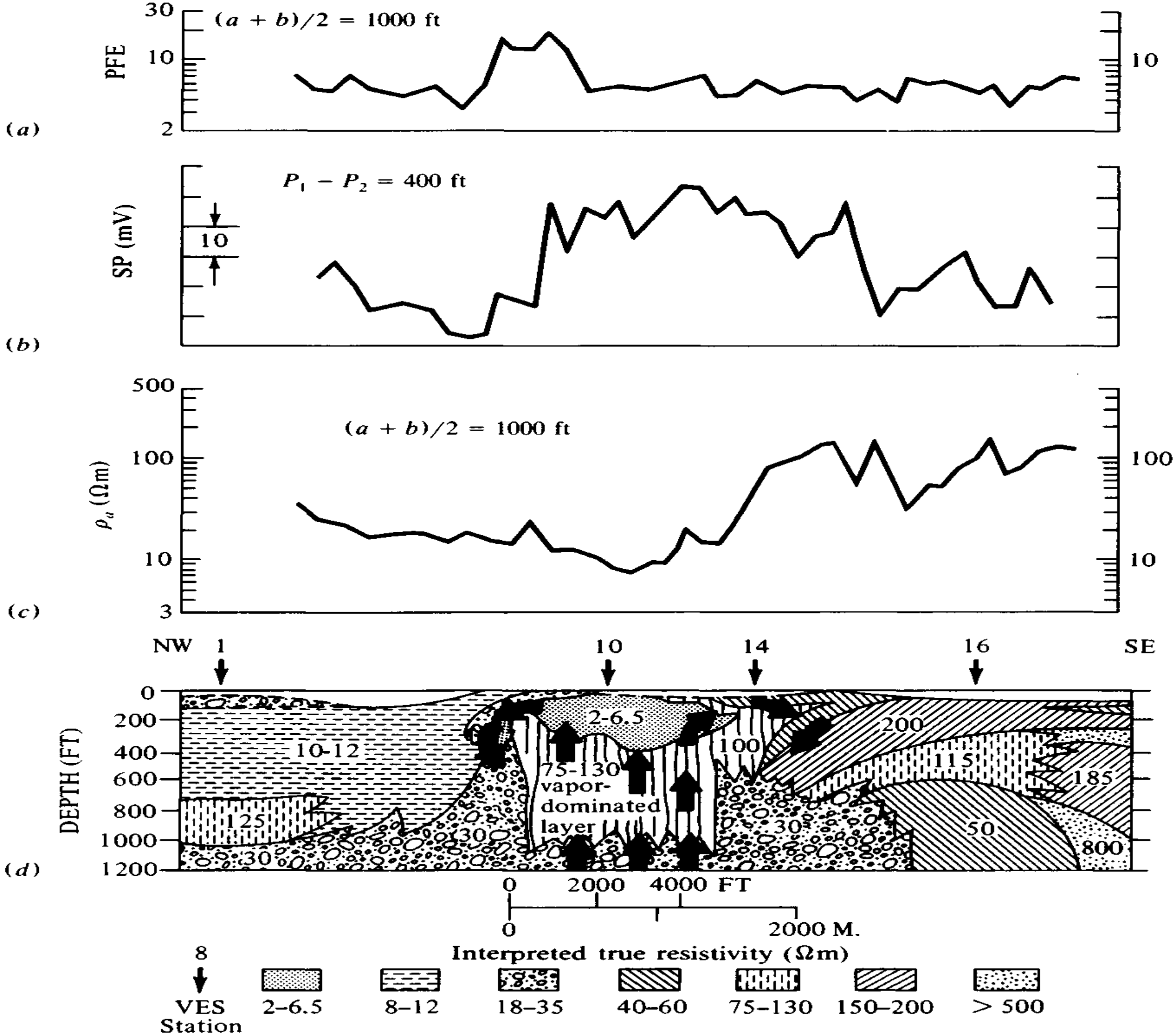
(ii) ABMyNy - perpendicular, $\gamma = 90° – \theta$;

(iii) ABMrNr - radial (DRS), γ = 0o;

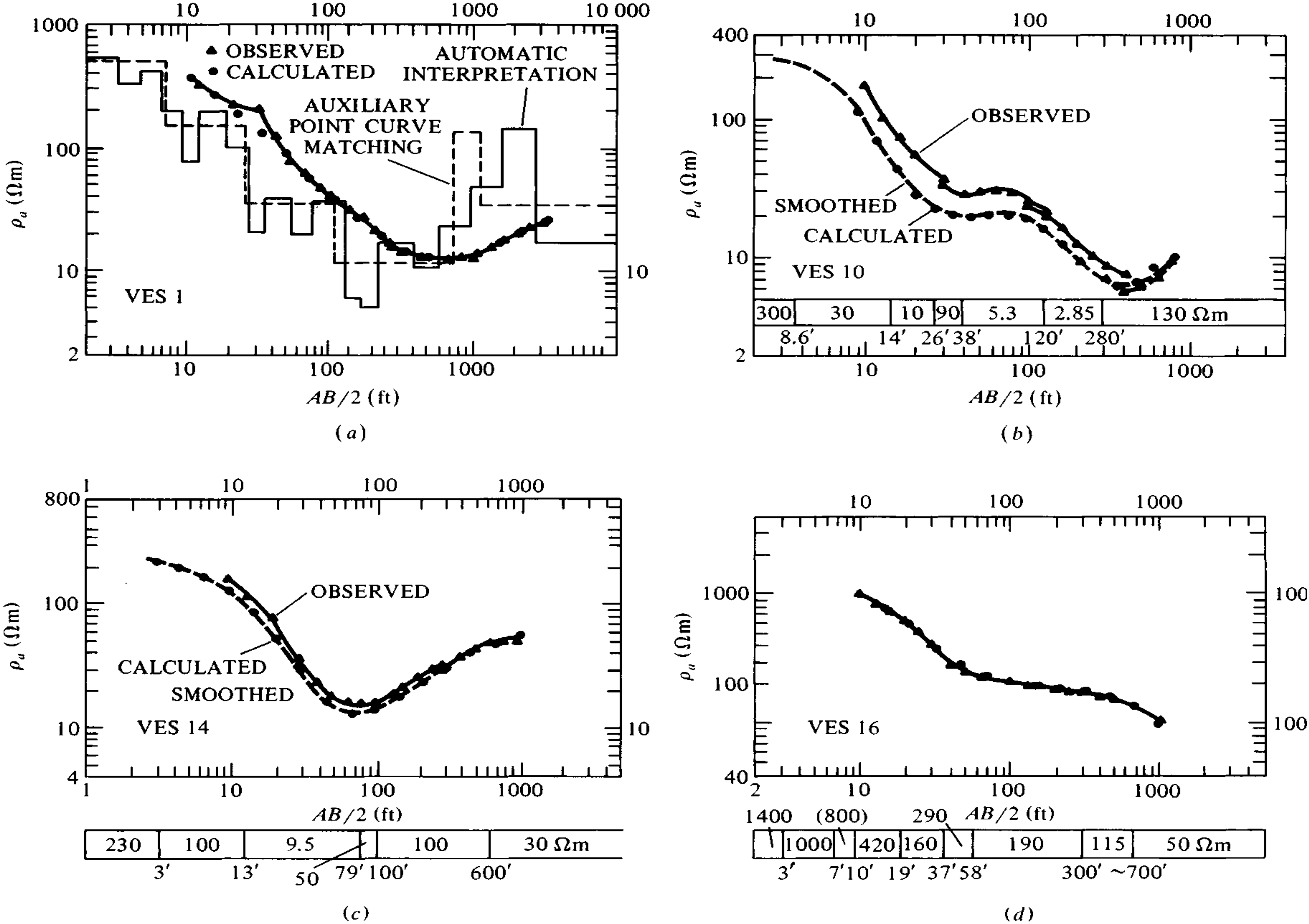
(iv) ABMxNx - parallel, $\gamma = –\theta$;

(v) ABMeqNeq - equatorial, $\theta = 90°$ (DES);

(vi) ABMaxNax - axial, $\theta = 0°$(DAxS)

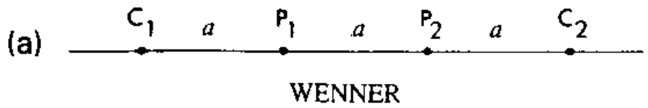


(a + b)/2 = 1000 ft
PFE
30
10
2
(a)
$P_1 - P_2$ = 400 ft
SP (mV)
10
(b)
(a + b)/2 = 1000 ft
ρ_a (Ωm)
500
100
10
3
(c)
NW
SE
1
10
14
16
DEPTH (FT)
0
200
400
600
800
1000
1200
2-6.5
10-12
75-130
vapor-
dominated
layer
100
200
115
185
125
30
50
800
(d)
0 2000 4000 FT
0 2000 M.
Interpreted true resistivity (Ωm)
8
VES
Station
2–6.5
8–12
18–35
40–60
75–130
150–200
> 500

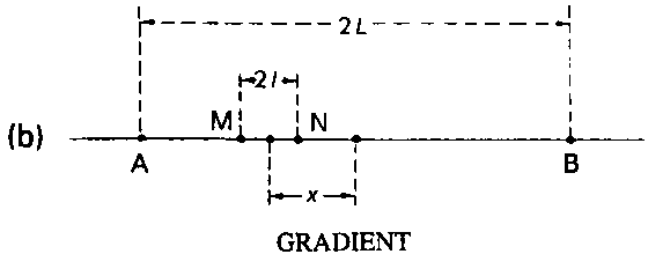


OBSERVED
CALCULATED
AUTOMATIC INTERPRETATION
AUXILIARY POINT CURVE MATCHING
VES 1
ρ_a (Ωm)
AB/2 (ft)
(a)
OBSERVED
SMOOTHED
CALCULATED
VES 10
300 | 30 | 10 | 90 | 5.3 | 2.85 | 130 Ωm
8.6′ 14′ 26′ 38′ 120′ 280′
ρ_a (Ωm)
AB/2 (ft)
(b)
OBSERVED
CALCULATED
SMOOTHED
VES 14
ρ_a (Ωm)
AB/2 (ft)
230 | 100 | 9.5 | 100 | 30 Ωm
3′ 13′ 50 79′ 100′ 600′
(c)
VES 16
ρ_a (Ωm)
AB/2 (ft)
1400 (800) 290
1000 | 420 | 160 | 190 | 115 | 50 Ωm
3′ 7′ 10′ 19′ 37′ 58′ 300′ ~700′
(d)

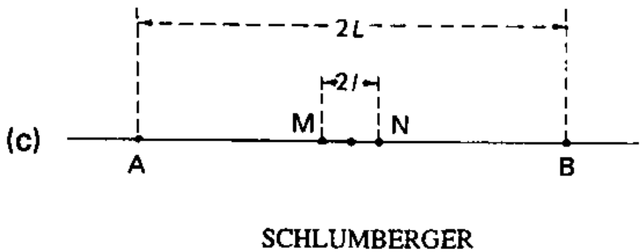
Geometric Factors



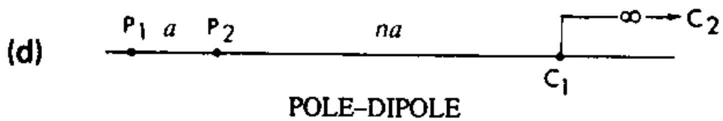
$$\rho_a = 2\pi a \frac{\Delta V}{i}$$



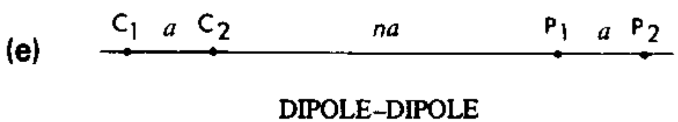
$$\rho_a = \frac{\pi}{2l} \cdot \frac{\left(L^2 - x^2\right)^2}{L^2 + x^2} \frac{\Delta V}{i}$$



$$\rho_a = \pi \frac{L^2}{2l} \frac{\Delta V}{i}$$



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



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

(Sharma 1997)

		Electrodes array	K
2D	Wenner	$A \xleftrightarrow[a]{} M \xleftrightarrow[a]{} N \xleftrightarrow[a]{} B$	$2\pi a$
	Wenner-Schlumberger	$A \xleftrightarrow[na]{} M \xleftrightarrow[a]{} N \xleftrightarrow[na]{} B$	$\pi n(n+1)a$
	Dipole-Dipole	$A \xleftrightarrow[a]{} B \xleftrightarrow[na]{} M \xleftrightarrow[a]{} N$	$\pi n(n+1)(n+2)a$
	Pole-Pole	$B \xleftrightarrow[x]{} A \xleftrightarrow[a]{} M \xleftrightarrow[x]{} N$	$2\pi a$
	Pole-Dipole *Forward*	$A \xleftrightarrow[na]{} M \xleftrightarrow[a]{} N$	$2\pi n(n+1)a$
	Reversed	$M \xleftrightarrow[na]{} N \xleftrightarrow[a]{} A$	
3D	Square	$\begin{array}{ccc} A & \leftrightarrow & B \\ \updownarrow & & \updownarrow\ a \\ M & \leftrightarrow & N \end{array}$	$\frac{2\pi a}{2-\sqrt{2}}$

Advantages and Disadvantages of Wenner and Schlumberger Arrays

The following table lists some of the strengths and weaknesses of Schlumberger and Wenner sounding methods.

Schlumberger		Wenner	
Advantage	**Disadvantage**	**Advantage**	**Disadvantage**
Need to move the two potential electrodes only for most readings. This can significantly decrease the time required to acquire a sounding.			All four electrodes, two current and two potential must be moved to acquire each reading.
	Because the potential electrode spacing is small compared to the current electrode spacing, for large current electrode spacings very sensitive voltmeters are required.	Potential electrode spacing increases as current electrode spacing increases. Less sensitive voltmeters are required.	
Because the potential electrodes remain in fixed location, the effects of near-surface lateral variations in resistivity are reduced.			Because all electrodes are moved for each reading, this method can be more susceptible to near-surface, lateral, variations in resistivity. These near-surface lateral variations could potentially be misinterpreted in terms of depth variations in resistivity.
	In general, interpretations based on DC soundings will be limited to simple, horizontally layered structures.		In general, interpretations based on DC soundings will be limited to simple, horizontally layered structures.

Array advantages and disadvantages

Array	Advantages	Disadvantages
Wenner	1. Easy to calculate ρ_a in the field 2. Less demand on instrument sensitivity	1. All electrodes moved each sounding 2. Sensitive to local shallow variations 3. Long cables for large depths
Schlumberger	1. Fewer electrodes to move each sounding 2. Needs shorter potential cables	1. Can be confusing in the field 2. Requires more sensitive equipment 3. Long Current cables
Dipole-Dipole	1. Cables can be shorter for deep soundings	1. Requires large current 2. Requires sensitive instruments

Survey Design and Procedure

Survey design depends on the specific characteristics of the site and the objective of the survey. The three most common modes of electrical resistivity surveying are profiling, sounding, and profiling-sounding, each having its own specific purpose. If the purpose of the survey is to map the depths and thickness of stratigraphic units, then the electrical resistivity data should be collected in the sounding mode. Lateral electrical resistivity contrasts, such as lithologic contacts, can best be mapped in the profiling mode. In cases where the electrical resistivity is expected to vary both vertically and horizontally, such as in contaminant plume mapping, the preferred mode is profile sounding.

1- Sounding Mode

As we've already shown, the resistivity method can detect variations in resistivity that occur solely in depth. In fact, this method is most commonly applied to look for variations in resistivity with depth. Surveys that are designed to determine resistivity variations with depth above some fixed surface location are referred to as *resistivity soundings*. In these experiments, electrode spacing is varied for each measurement. The center of the electrode array, where the electrical potential is measured, however, remains fixed. An example of a problem for which one might employ resistivity soundings is the determination of the depth to water table

The two most common arrays for electrical resistivity surveying in the sounding mode are the Schlumberger and Wenner arrays. Electrode geometry for both arrays is shown in Figure below.

Increasing the separation of the outer current electrodes, thereby driving the currents deeper into the subsurface increases the depth of exploration.

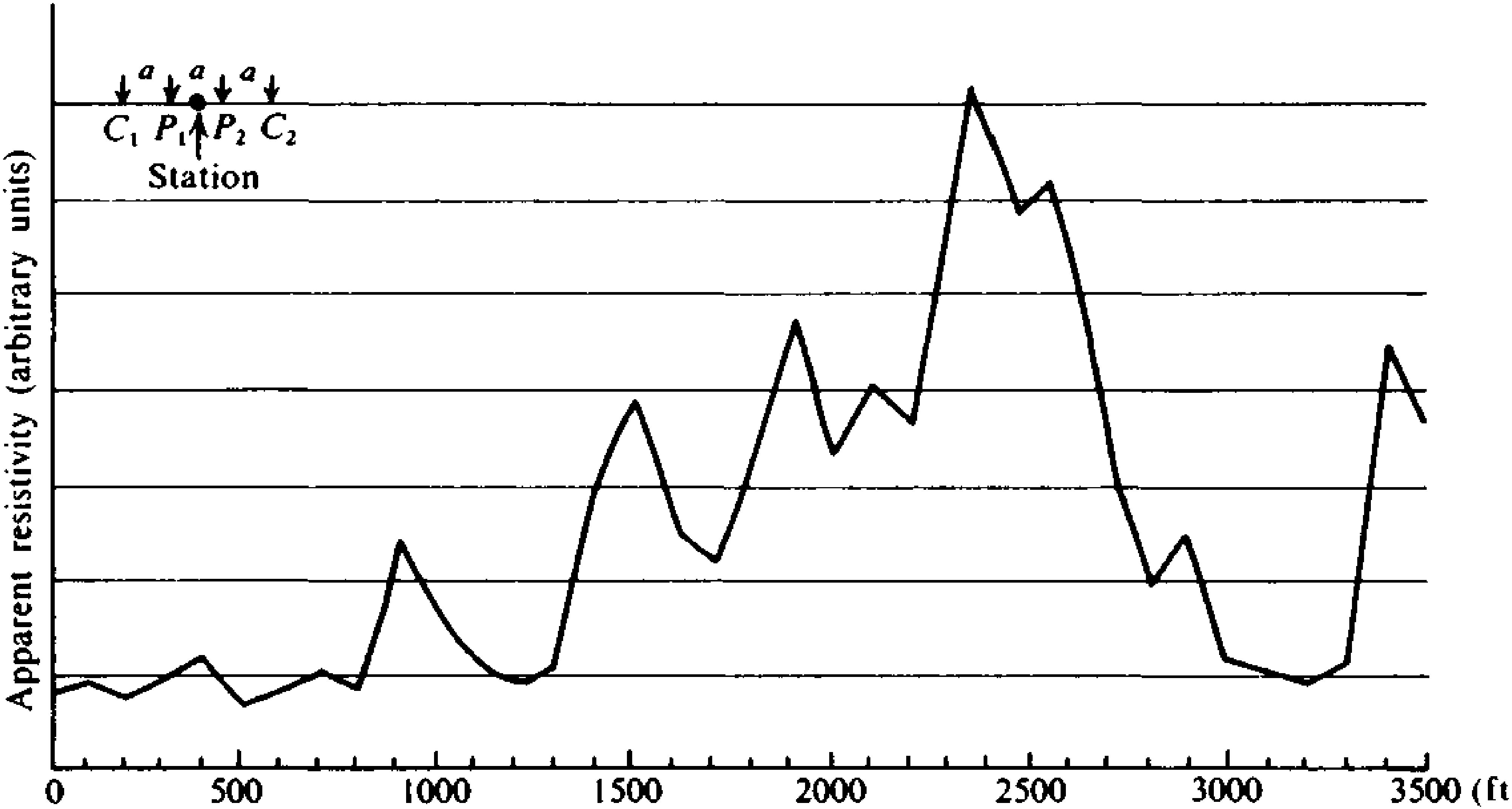
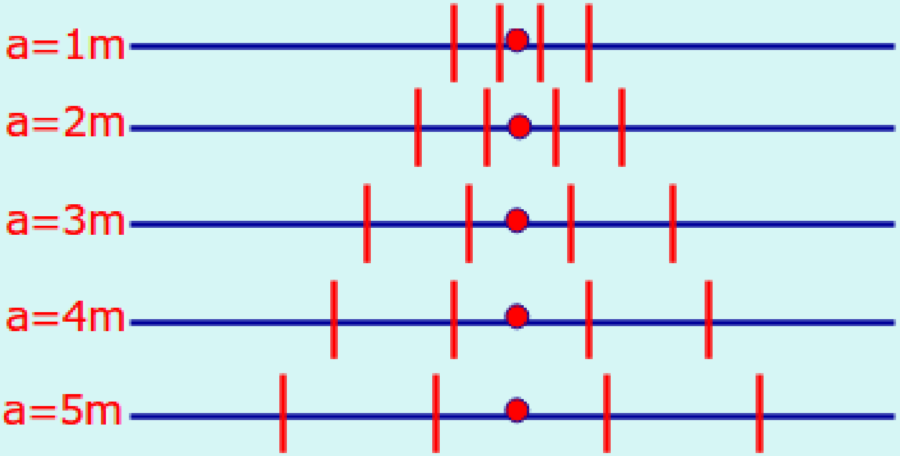


Figure 8.46. Resistivity mapping with Wenner spread over karst topography, Hardin County, Illinois. Station interval = 100 ft, a = 100 ft. (After Van Nostrand and Cook, 1966.)

Wenner Sounding

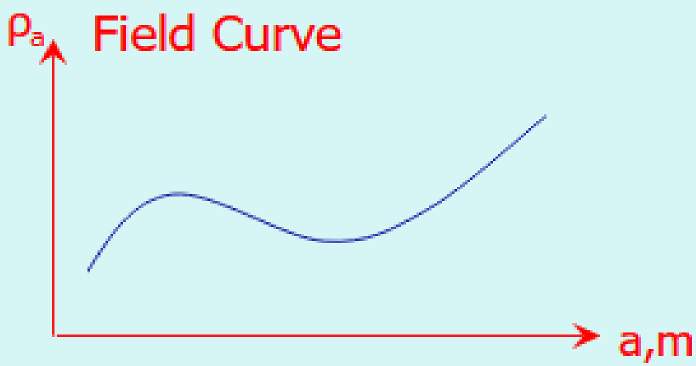
VES-1



Data Table

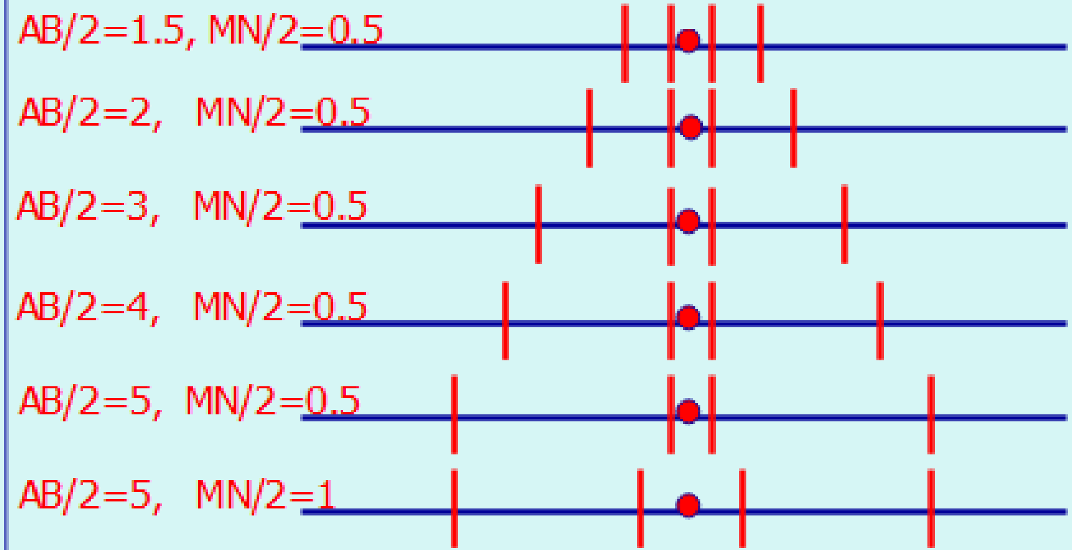
a,m	R	ρ_a
1		
2		
3		
4		

Field Curve



Schlumberger Sounding

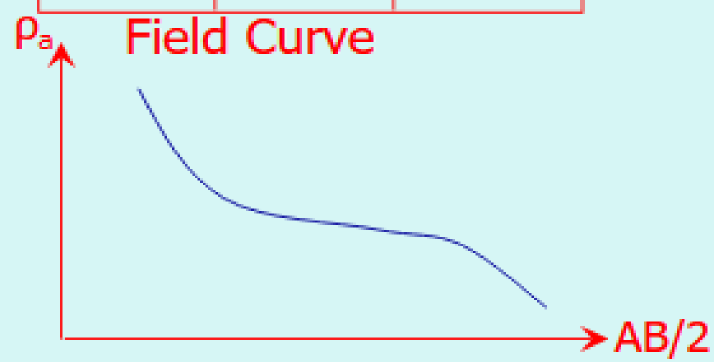
VES-1



Data Table

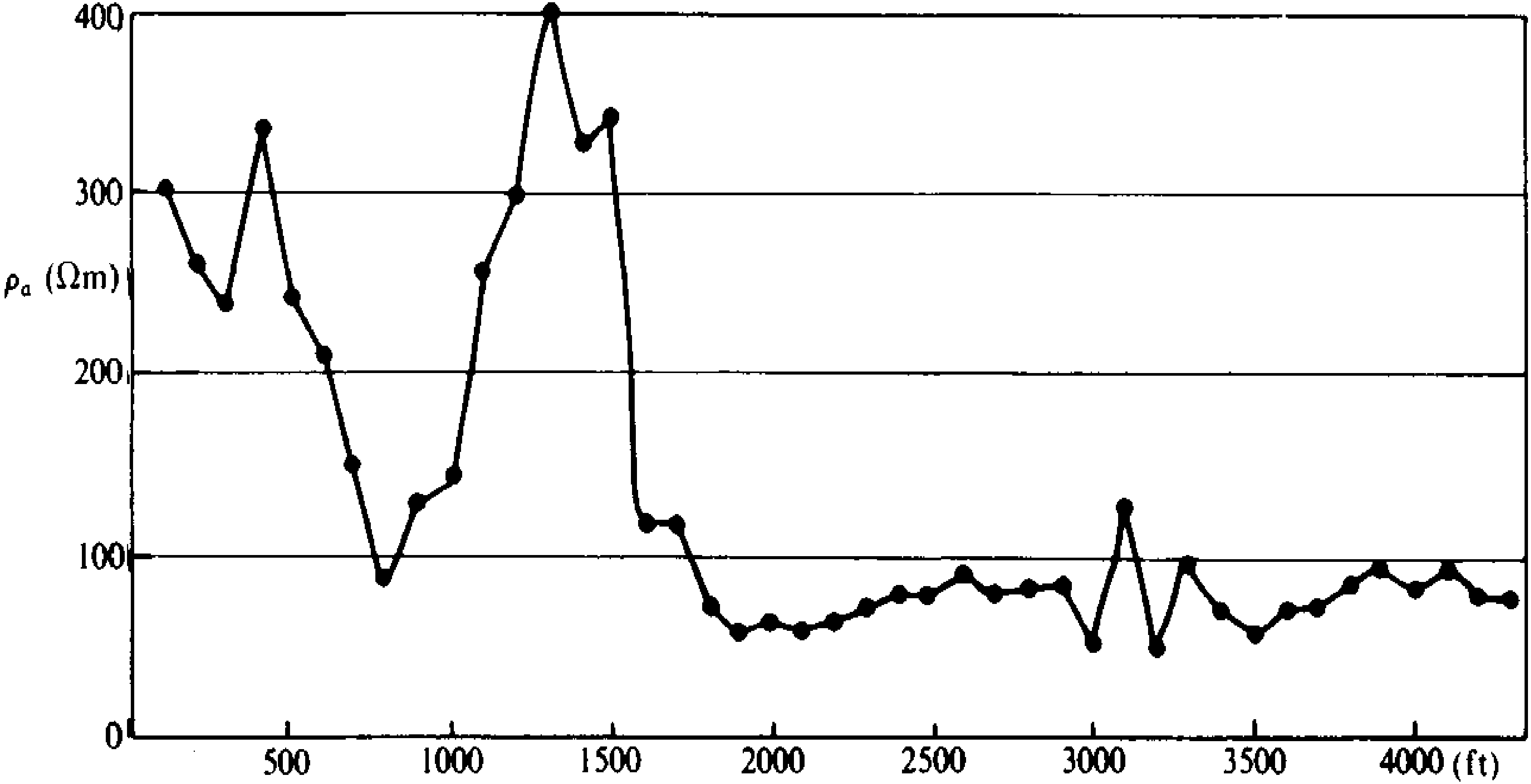
AB/2	R	ρ_a
1.5		
2		
3		
4		

Field Curve



In an investigation to determine the depth of a conducting layer of brine at Malagash, Nova Scotia, the readings in Table 8.2 were taken with a Megger using an expanding Wenner spread. The surface layer was found to have a resistivity of 29 12 m. Determine the depth and resistivity of the brine layer.

Separation (ft)	ρ_a (Ωm)
40	28.5
60	27.1
80	25.3
100	23.5
120	21.7
140	19.8
160	18.0
180	16.3
200	14.5
220	12.9
240	11.3
260	9.9
280	8.7
300	7.8
320	7.1
340	6.7
360	6.5
380	6.4



Resistivity mapping with Wenner spread over limestone and sandstone section separated by vertical contacts. Station interval 100 ft, a = 100 ft. (After Van Nostrand and Cook, 1966.)

2- Profiling Mode

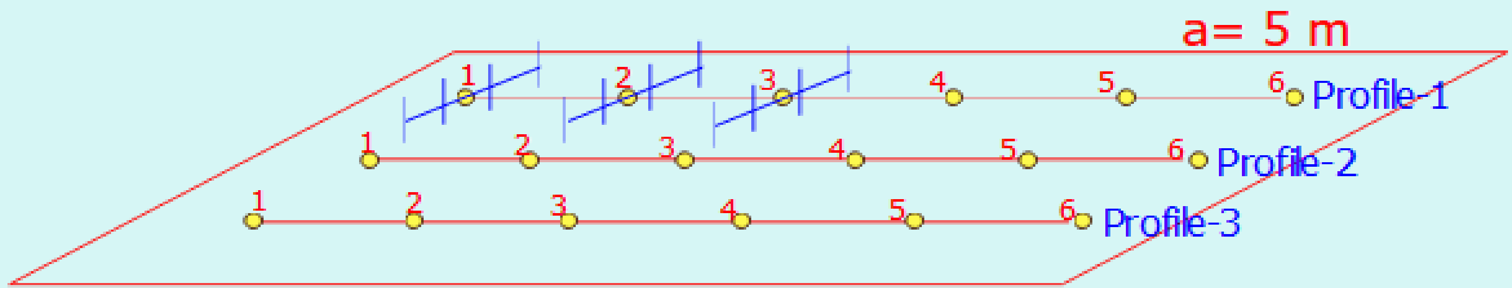
The two most common arrays for electrical resistivity surveying in the profiling mode are the Wenner and dipole-dipole arrays. The electrode geometry for the Wenner array is the same as the sounding mode — the difference is that in profiling mode the entire array is moved laterally along the profile while maintaining the potential and current electrode separation distances.

The electrode geometry for the dipole-dipole array is shown in Figure below. In the profiling mode, the distance between the potential and current dipoles (a dipole consists of a pair of like electrodes) is maintained while the array is moved along the profile.

As was mentioned on the previous page, the data collected from resistivity soundings is usually interpretable only for horizontally stratified structures. If you are employing resistivity methods to find vertical structures, one would typically use resistivity profiles instead of resistivity soundings.

As described previously, resistivity profiles are resistivity surveys in which the electrode spacing is fixed for all readings. Apparent resistivity is computed for different electrode center points as the electrode spread is moved. Usually the center point is moved along the line of the electrodes, although this does not have to be the case. Shown below is a geological structure involving a vertical boundary between a higher resistivity material to the left and a lower resistivity material to the right. Below the geological model is the apparent resistivity you would observe using a Wenner array as the array is moved from left to right. Note that the distance shown along the bottom of this plot is the distance between the vertical fault and the current electrode farthest to the left of the array.

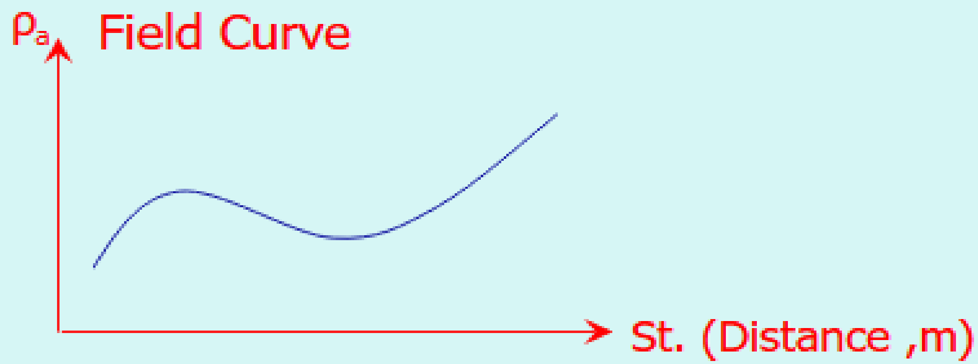
Profiling by Wenner array



Data Table

St.	R	ρ_a
1		
2		
3		
4		

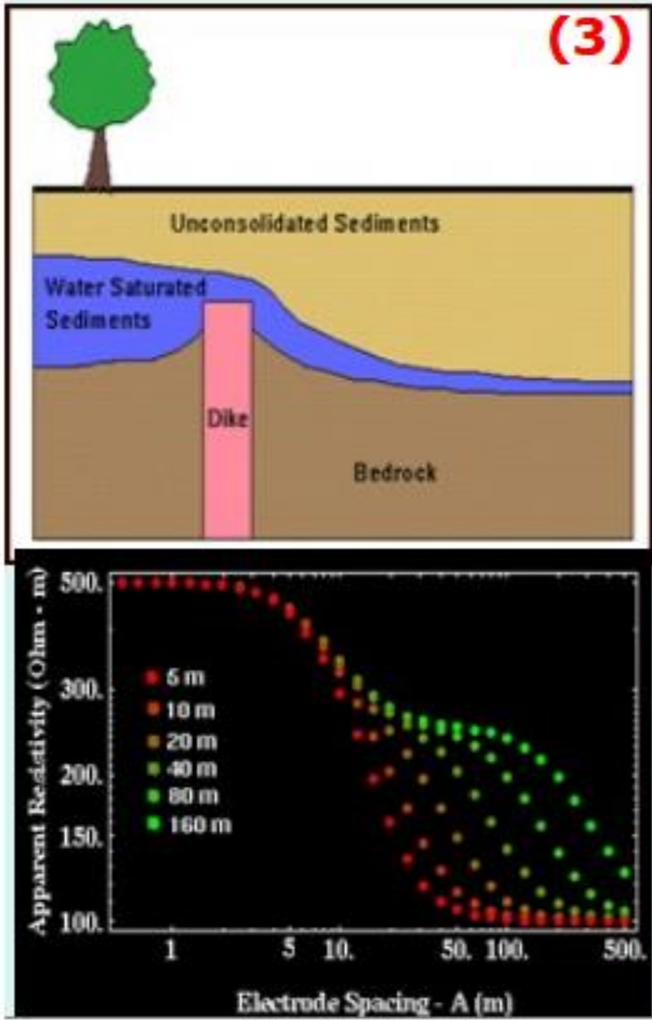
Field Curve

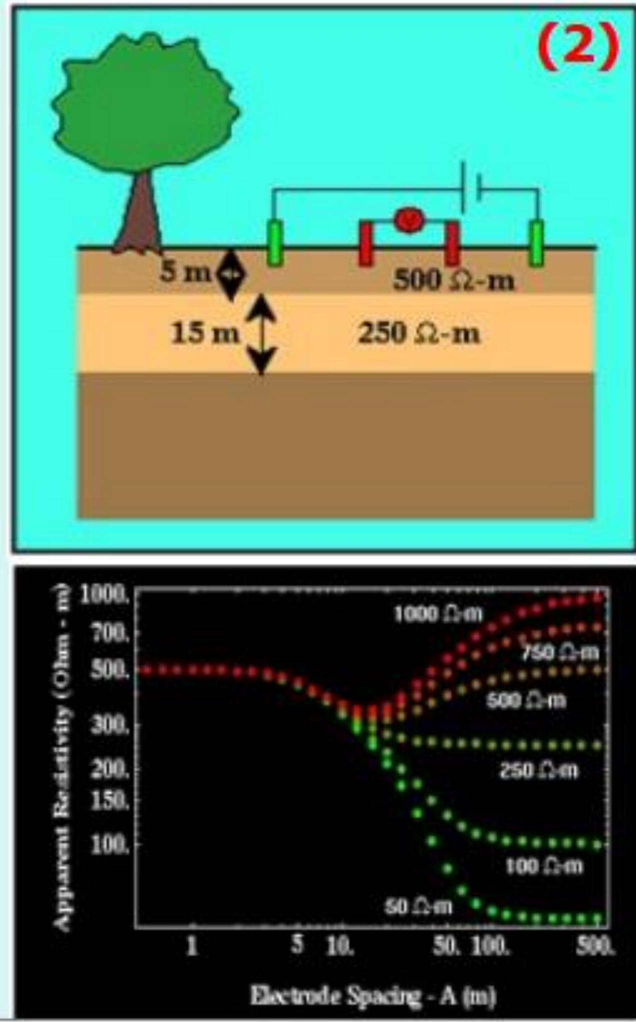


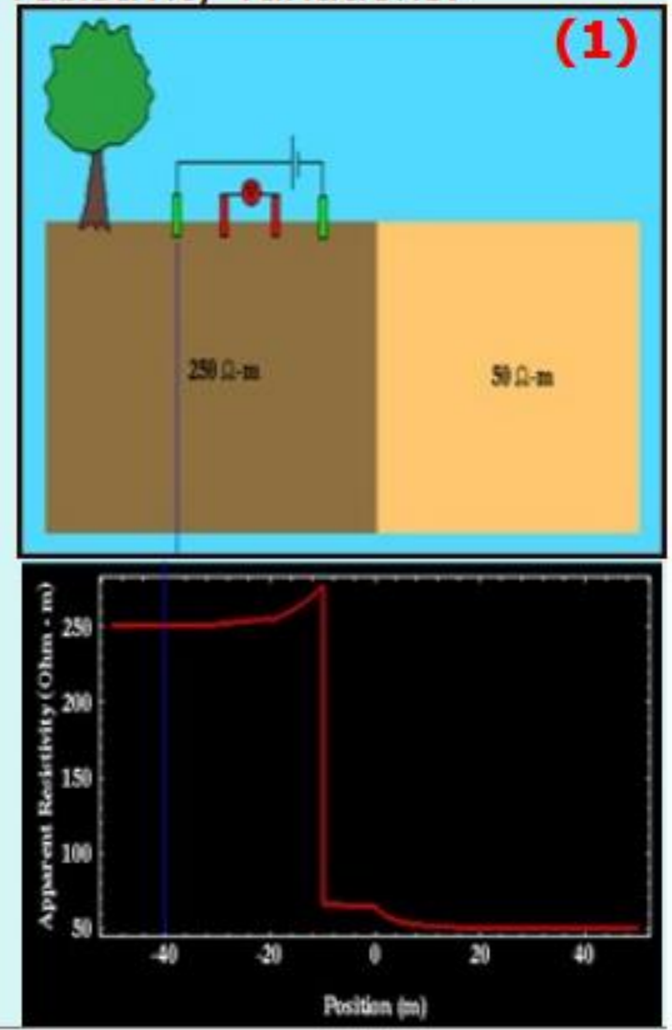
3- Profiling-Sounding Mode

As in the profiling mode, the Wenner and dipole-dipole arrays are the most common arrays used in the profiling sounding mode. As the name implies, this mode is a combination of the profiling and sounding modes.

In the Wenner array the typical field procedure is to collect the data in a succession of profiles, each having a different electrode separation. The resulting data therefore contains information about the lateral and vertical electrical resistivity variations.







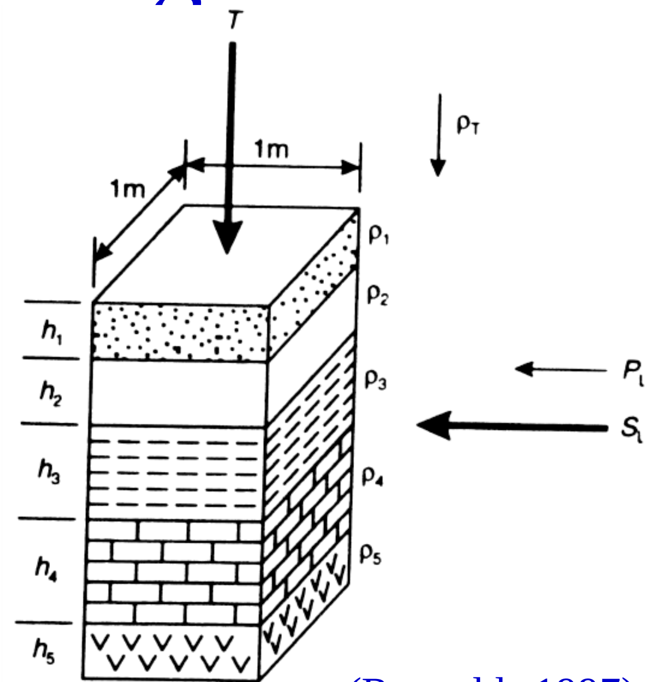
Electrical Resistivity

- Resistivity surveying investigates variations of electrical resistance, by causing an electrical current to flow through the subsurface using wires (electrodes) connected to the ground.
  – Resistivity = 1 / Conductivity

Geo-electric Layering

- Goal of the resistivity survey is to determine thickness and resistivity of near surface layers.

- Often the earth can be simplified within the region of our measurement as consisting of a series of horizontal beds that are infinite in extent.



(Reynolds 1997)

Longitudinal conductance (one layer): $S_L = h/\rho = h\,\sigma$ [S]

Transverse resistance (one layer): $T = h\,\rho$ [Ω]

Longitudinal resistivity (one layer): $\rho_L = h/S_L$ [Ωm]

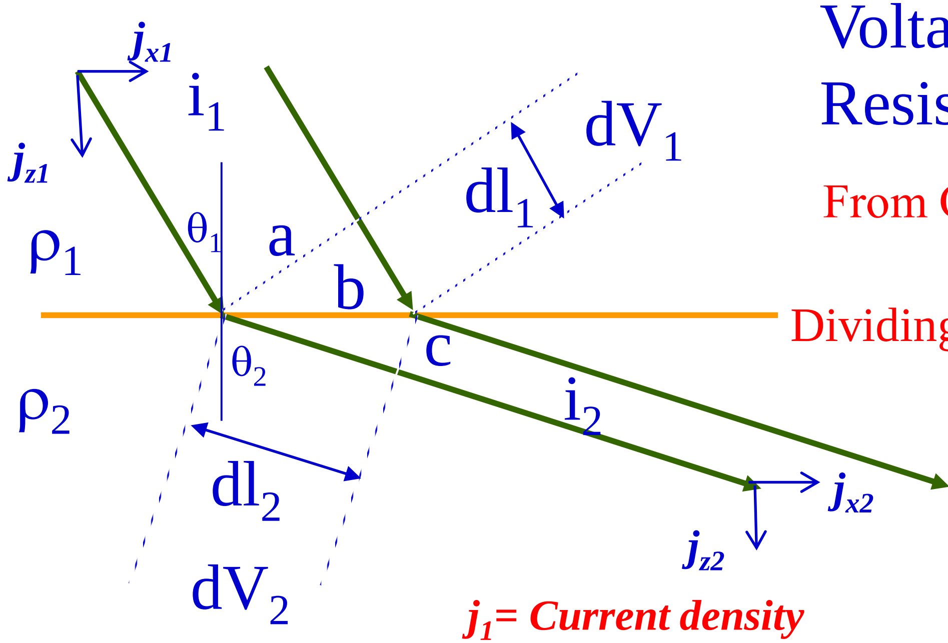
Transverse resistivity (one layer): $\rho_T = T/h$ [Ωm]

Longitudinal conductance (for n-layers): $S_L = \Sigma(h_i/\rho_i)$ [S]

Transverse resistance (for n-layers): $T = \Sigma(h_i\,\rho_i)$ [Ω]

Voltage and Flow in Layers

Tangent Law: The electrical current lines are bent at a boundary



j_1= *Current density*

Relations:

Current: $i_1 = i_2$

Voltage: $dV_1 = dV_2$

Resistivity: $\rho_1 > \rho_2$

From Ohm's law: $j_{x1}\rho_1 = j_{x2}\rho_2$ and $j_{z1} = j_{z2}$

Dividing we get: $\rho_1 (j_{x1}/j_{z1})$ and $\rho_2 (j_{x2}/j_{z2})$

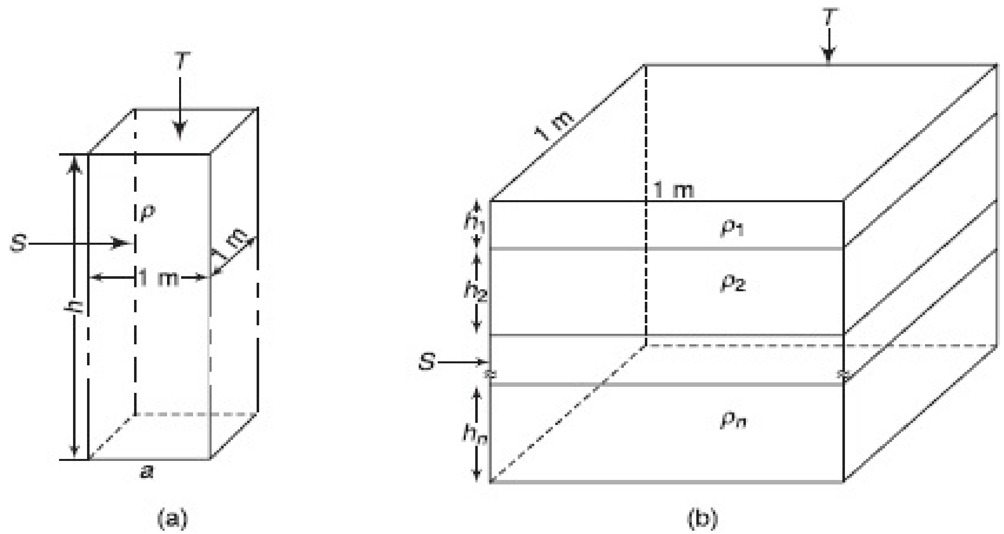
So that $\rho_1 \tan\theta_1$ and $\rho_2 \tan\theta_2$

$$\boxed{\frac{\rho_2}{\rho_1} = \frac{\tan\theta_1}{\tan\theta_2}}$$

If $\rho_2 < \rho_1$ then the current lines will be refracted away from the normal

If $\rho_2 > \rho_1$ then the current lines will be refracted closer to the normal

Let us consider a prism of unit cross section, with thickness *h* and resistivity *ρ* (Fig a). The *n*–layer distribution of the prism of unit cross section is shown in Fig. (b). The resistance *T* and conductance *S* normal and parallel to the face of the prism respectively, are expressed as

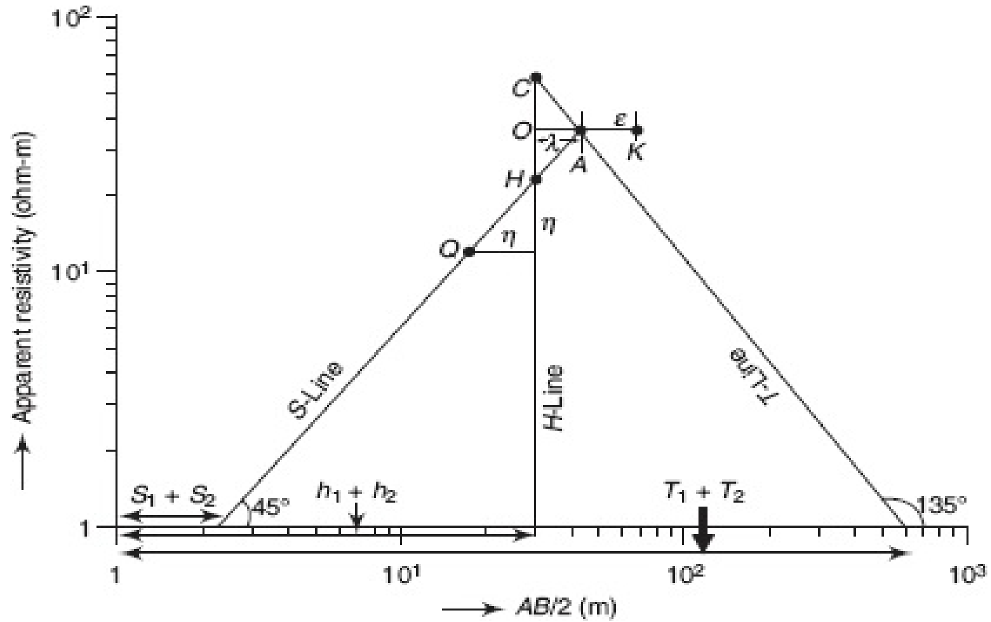


(a) (b)

Longitudinal conductance (S) and transverse resistance (T) determined from a rectangular prism of unit cross section: (a) For a homogeneous layer (b) Multilayer section

$$T = h\rho$$

$$S = \frac{h}{\rho}$$



Characteristic intersection of T and S lines and triangle of anisotropy

Let us now consider a prism of unit cross section consisting of n parallel homogeneous and isotropic layers, each of resistivities ρ_1, ρ_2, ρ_3 … ρ_{n-1}, ρ_n and the corresponding thicknesses h_1, h_2, h_3, … h_{n-1}, respectively. In n–layered earth, the last layer is infinitely thick.

$$T = T_1 + T_2 + T_3 + \cdots + T_{n-1} = \sum_{i=1}^{n-1} T_i \tag{3.181}$$

$$T = \rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3 + \cdots + \rho_{n-1} h_{n-1} = \sum_{i=1}^{n-1} \rho_i h_i \tag{3.182}$$

And, the total conductance S of the prism when the flow of the current is normal to the bottom of the n–1th layer is

$$S = S_1 + S_2 + S_3 + \cdots + S_{n-1} = \sum_{i=1}^{n-1} S_i \tag{3.183}$$

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots \frac{h_{n-1}}{\rho_{n-1}} = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i} \tag{3.184}$$

The parameters S and T are longitudinal conductance and transverse resistance, respectively and also referred as Dar Zarrouk parameters (Maillet, 1947).

For a two-layer prism, Eqs (3.182) and (3.184) will reduce to

$$T = T_1 + T_2 = \rho_1 h_1 + \rho_2 h_2 \tag{3.185}$$

and

$$S = S_1 + S_2 = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} \tag{3.186}$$

Equations (3.185) and (3.186) in terms of transverse resistivity ρ_v and longitudinal resistivity ρ_h of the two-layer prism are

$$T = \rho_v (h_1 + h_2) = \rho_1 h_1 + \rho_2 h_2 \tag{3.187}$$

and

$$S = \frac{(h_1 + h_2)}{\rho_h} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} \tag{3.188}$$

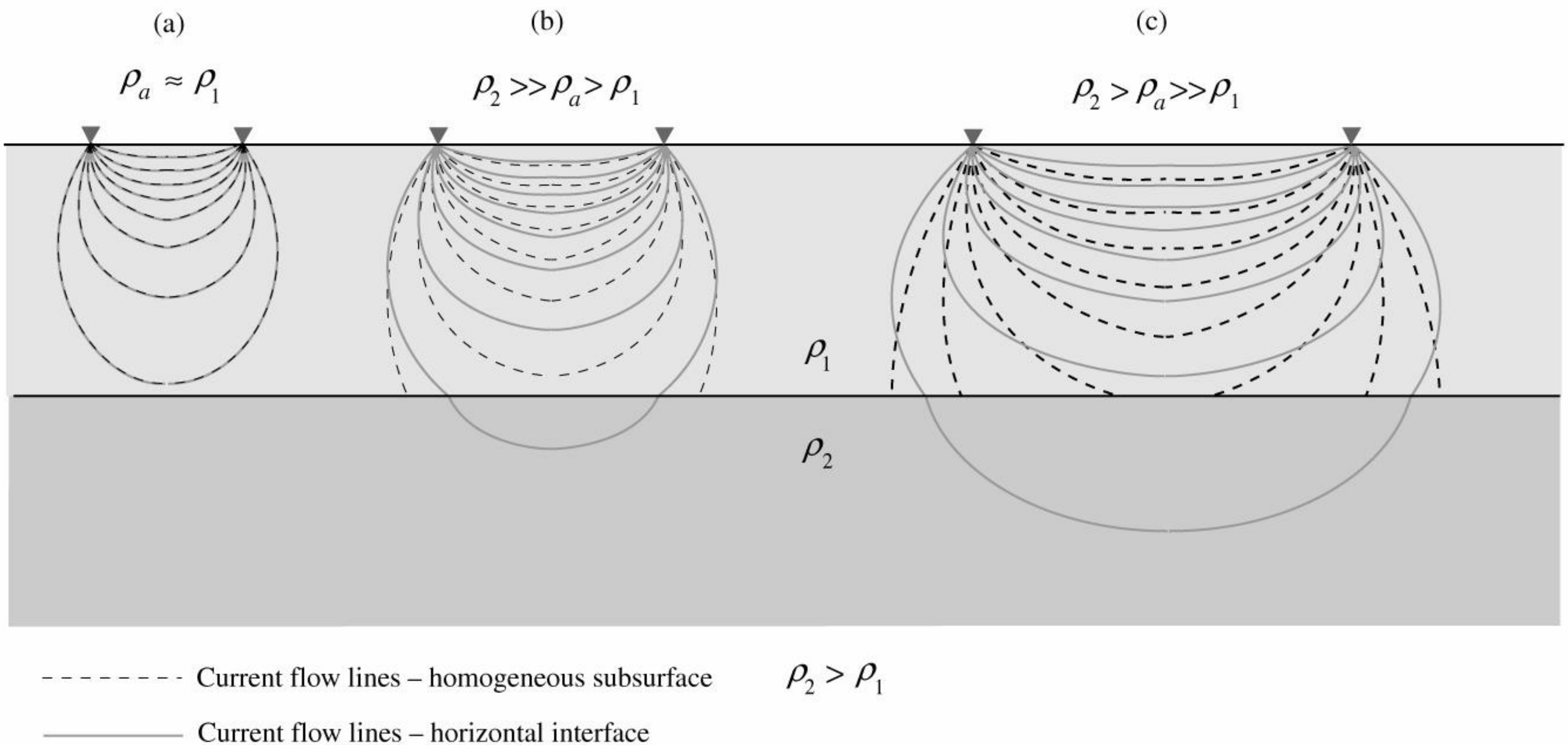
The coefficient of anisotropy (λ) and mean resistivity (ρ_m) thus, can be expressed as

$$\lambda = \sqrt{\frac{\rho_v}{\rho_h}} = \frac{1}{h_1 + h_2} \left\{ (\rho_1 h_1 + \rho_2 h_2) \left(\frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} \right) \right\}^{1/2} \tag{3.189}$$

$$\rho_m = \sqrt{\rho_v \rho_h} = \left\{ \frac{(\rho_1 h_1 + \rho_2 h_2)}{\left(\frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} \right)} \right\}^{1/2} \tag{3.190}$$

If a medium consists of two different isotropic layers [Fig. 3.52(a)] as a suite of formations with cyclic intercalations of two thin isotropic layers of resistivity of ρ_1 and ρ_2 and having thicknesses as Δh_{1i}

Resistivity Pattern in a One-Layer System



(Burger et al. 2005)

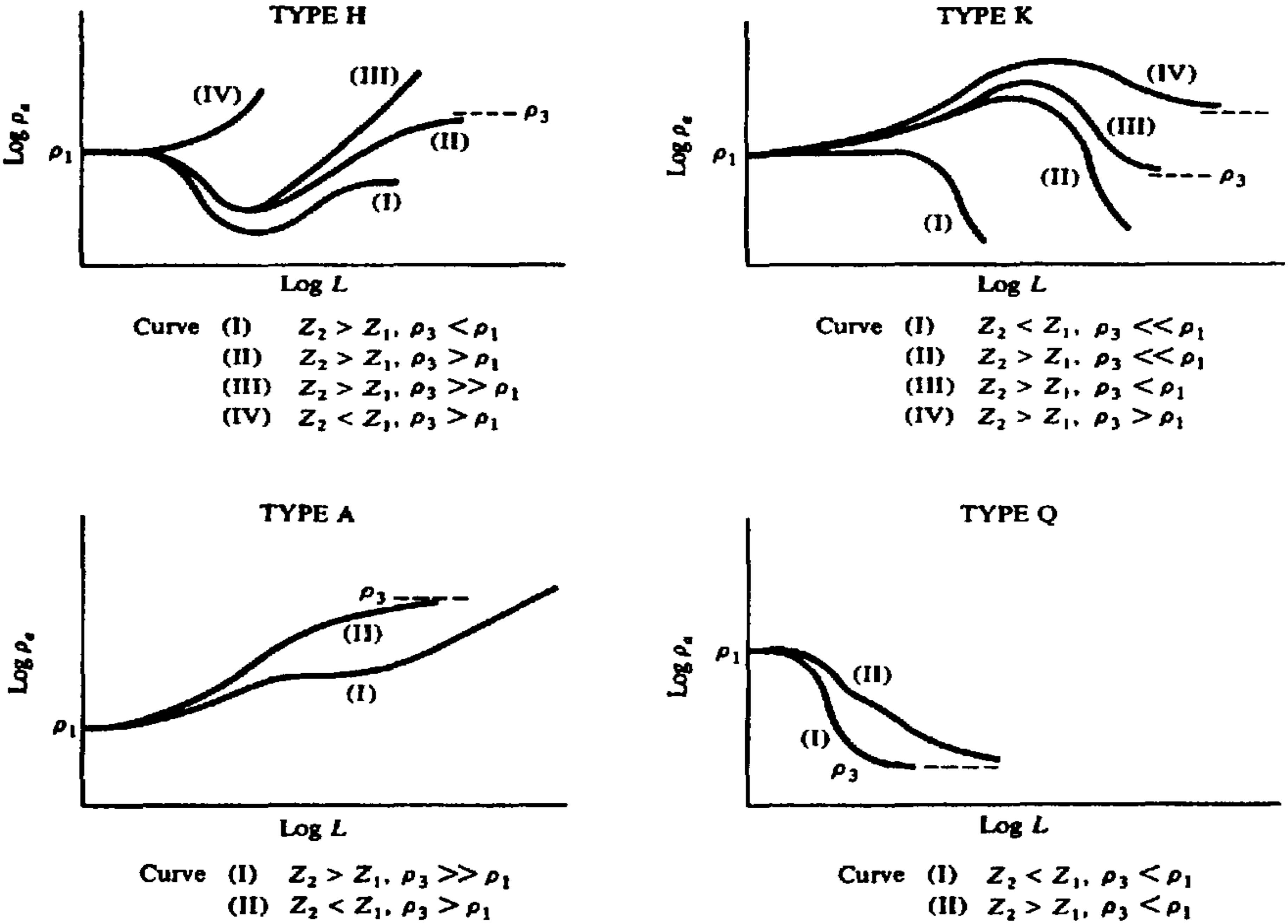
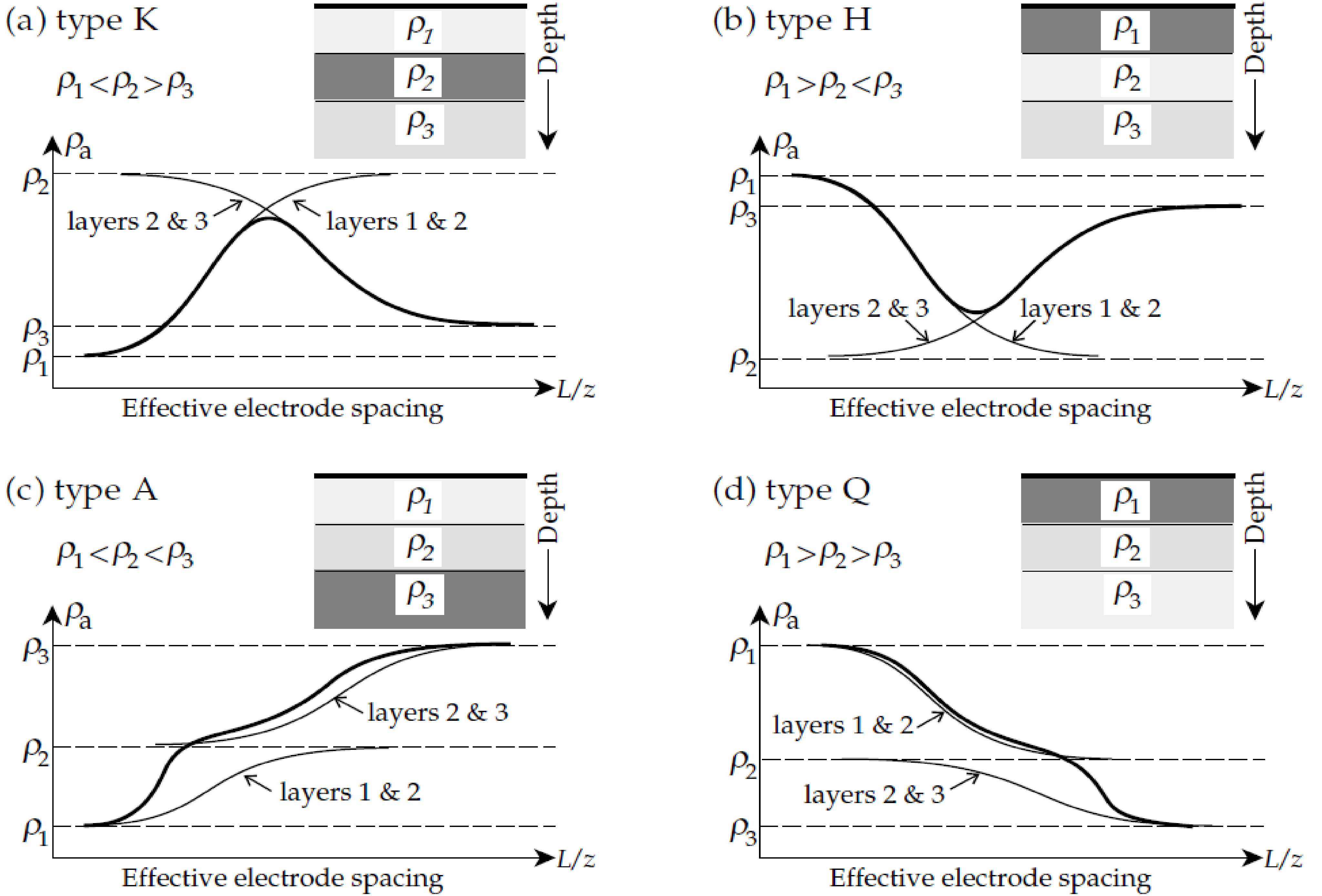
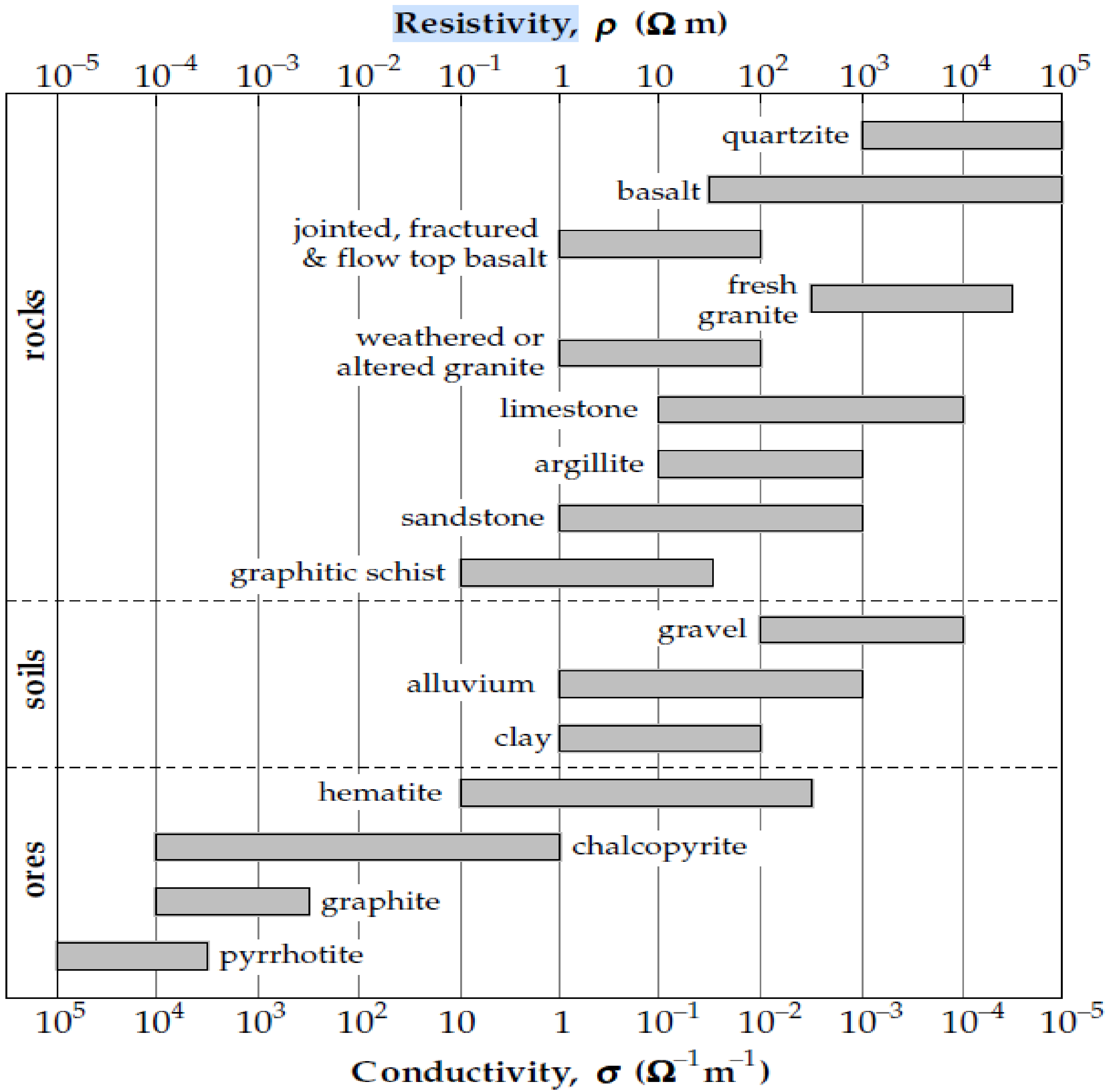


Figure 8.24. Various types of sounding curves over multilayer structures of three or more beds.

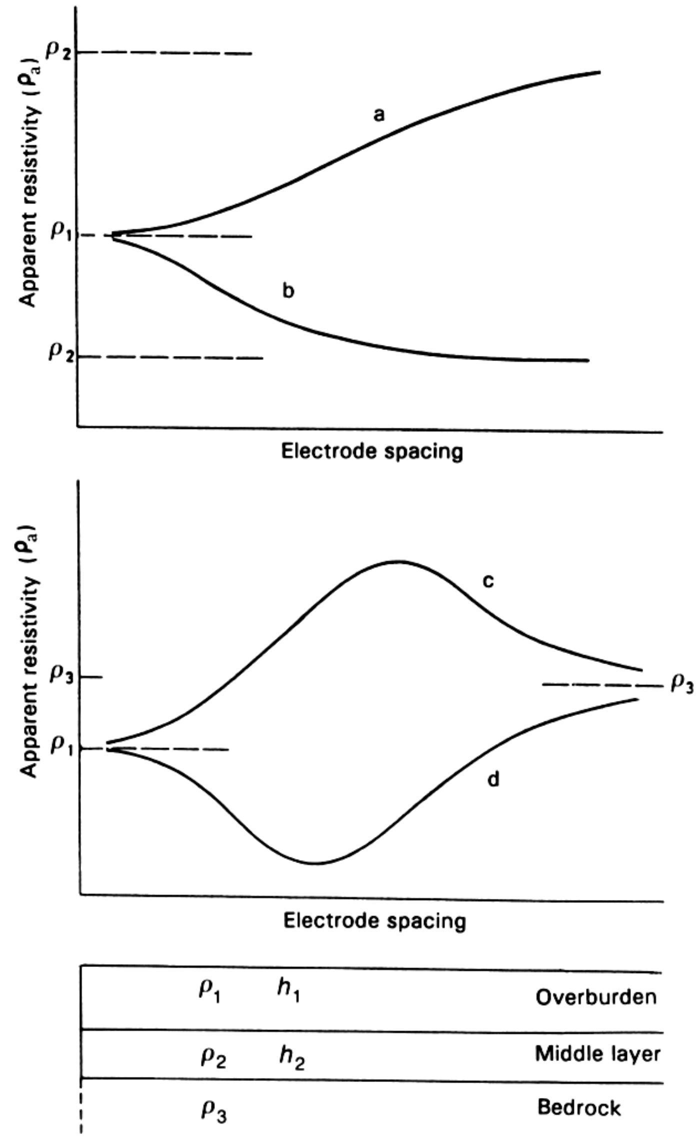


(a) type K
$\rho_1 < \rho_2 > \rho_3$
layers 2 & 3
layers 1 & 2
Effective electrode spacing
(b) type H
$\rho_1 > \rho_2 < \rho_3$
layers 2 & 3
layers 1 & 2
Effective electrode spacing
(c) type A
$\rho_1 < \rho_2 < \rho_3$
layers 2 & 3
layers 1 & 2
Effective electrode spacing
(d) type Q
$\rho_1 > \rho_2 > \rho_3$
layers 1 & 2
layers 2 & 3
Effective electrode spacing
Depth
ρ_a
L/z


Resistivity, ρ (Ω m)
10^−5 10^−4 10^−3 10^−2 10^−1 1 10 10^2 10^3 10^4 10^5
rocks
quartzite
basalt
jointed, fractured & flow top basalt
fresh granite
weathered or altered granite
limestone
argillite
sandstone
graphitic schist
soils
gravel
alluvium
clay
ores
hematite
chalcopyrite
graphite
pyrrhotite
10^5 10^4 10^3 10^2 10 1 10^−1 10^−2 10^−3 10^−4 10^−5
Conductivity, σ (Ω^−1 m^−1)

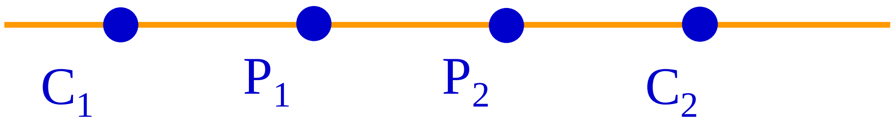
VES Data Plotting Convention

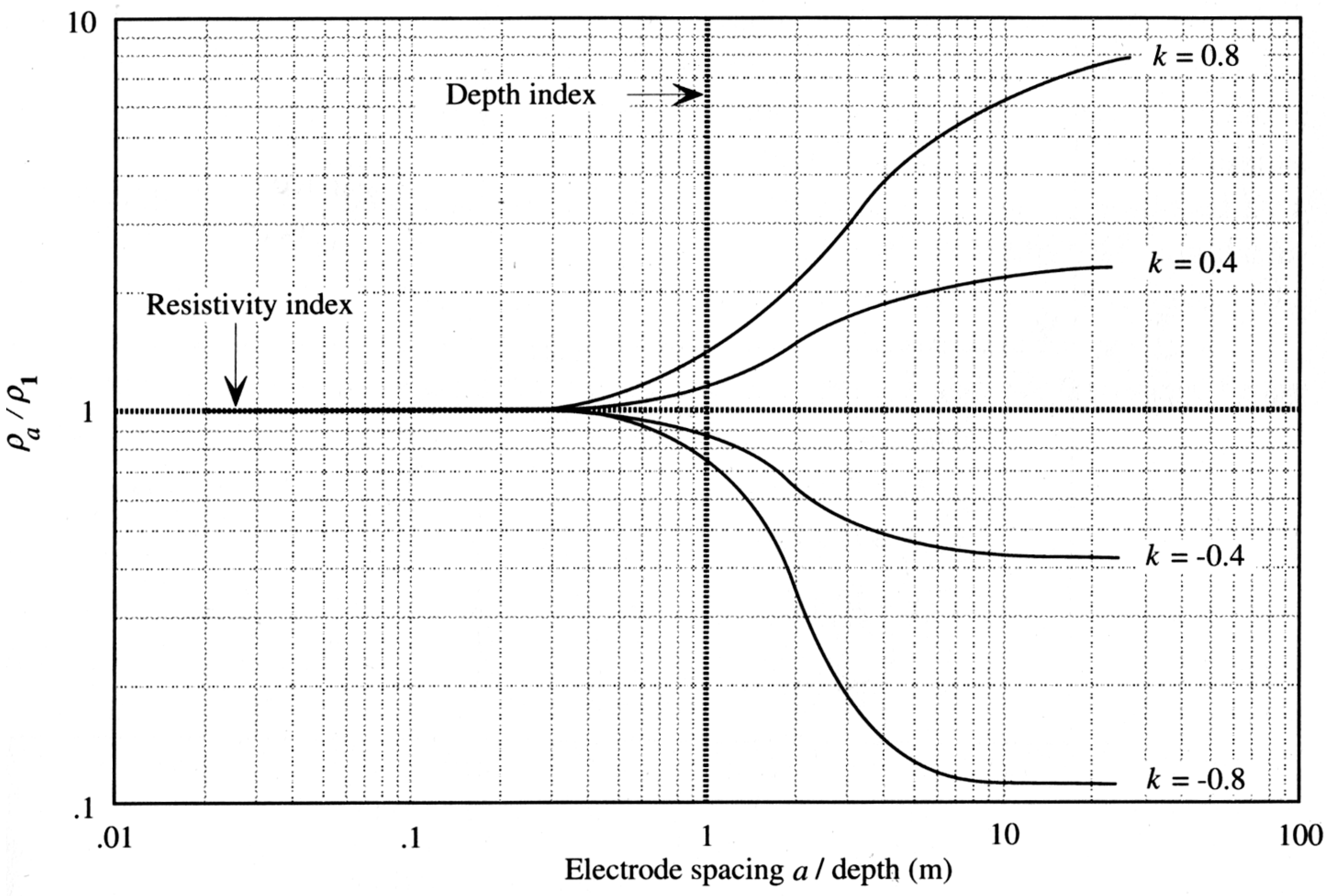
- Plot apparent resistivity as a function of the log of some measure of electrode separation.
  - Wenner – *a spacing*
  - Schlumberger – AB/2
  - Dipole-Dipole – *n spacing*
- Asymptotes:
  - Short spacings << h_1, $\rho_a=\rho_1$.
  - Long spacings >> total thickness of overlying layers, $\rho_a=\rho_n$
- To get $\rho_a=\rho_{true}$ for intermediate layers, layer must be thick relative to depth.



(Sharma 1997)

Solutions for a Wenner Array for two layers





$$k = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$$

Solutions for a Wenner Array for two layers

- Simple for two layer case.
  - Plot data at same scales as master curves.
  - Overlie shallow-layer resistivity asymptote with ‘1’ on master curves.
  - Determine depth to layer, and resistivity of lower layer by comparing scaled master-curve values to data values
- Gets rapidly more difficult as more layers added.

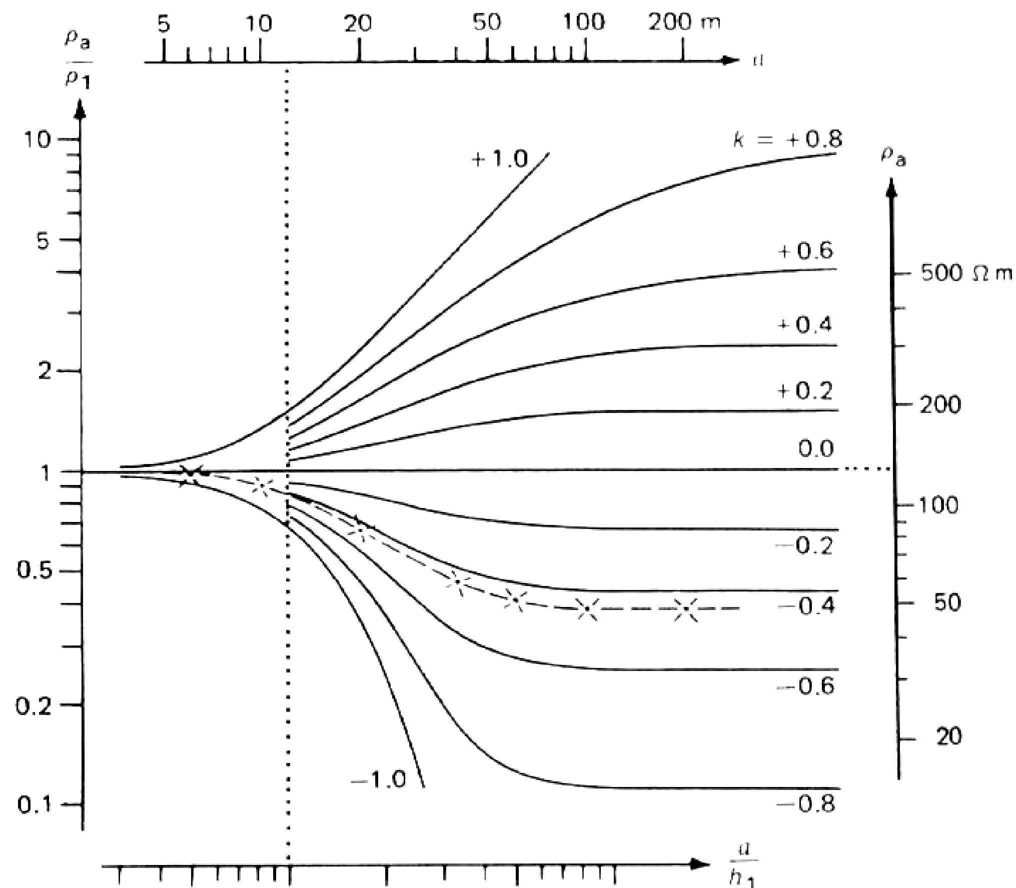


Fig. 6.16 Example of the interpretation of a field curve (dashed line with crosses) by matching it with a set of master two-layer resistivity curves (for explanation see text).

(Sharma 1997)

Equivalence: several models produce the same results

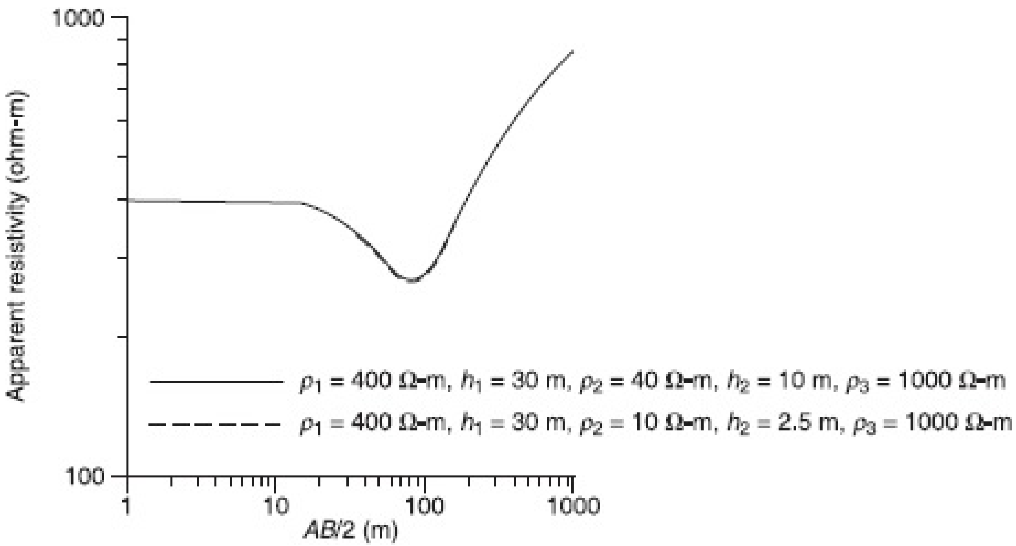
- Ambiguity in physics of 1D interpretation such that different layered models basically yield the same response.

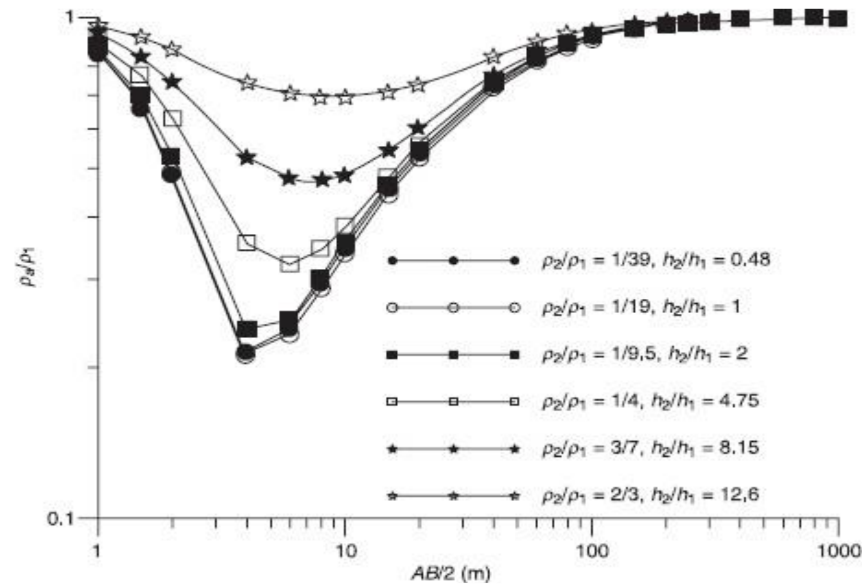
- Different Scenarios:
  - Conductive layers between two resistors, where longitudinal conductance (σ h) is the same.
  - Resistive layer between two conductors with same transverse resistance (ρ h).

The principle of equivalence states that two three-layer geoelectric sections of *H*–type ($\rho 1 > \rho 2 <$ p3), or of *A*-type ($\rho 1 < \rho 2 < \rho 3$), may be equivalent if the thickness of the second layer is relatively thin and conducting. The c$S_2\left(=\frac{h_2}{\rho_2}\right)$nt flow in the intermediate layer will tend to be more focused and will be more or less parallel to this layer. The value of longitudinal Conductance ( ) is equal in both the sections.

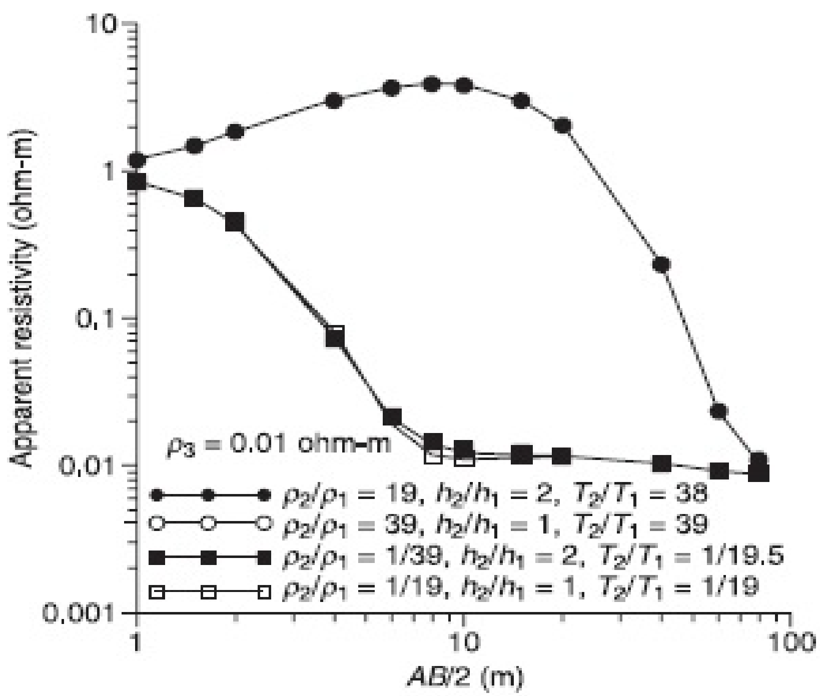
It also states that the two three-layer section of *K*–type ($\rho 1 < \rho 2 > \rho 3$), or of *Q*–type ($\rho 1 > \rho 2 > \rho 3$), may be equivalent if the thickness of the second layer is relatively small and resistivity much larger than the top and bottom layers. The value of transverse resistance $T2(=h2\rho 2)$ is equal in both the sections (*T*–equivalence). In such a case, the electric current will be repelled due to the presence of the intermediate resistive layer and will try to follow the shortest route to the lower layer.

[Figure 3.62](#) shows the equivalence of *H*–type curves for S_2 = 1/4 where a low resistivity layer is sandwiched between two high resistivity layers of same longitudinal conductance with exactly same
response.

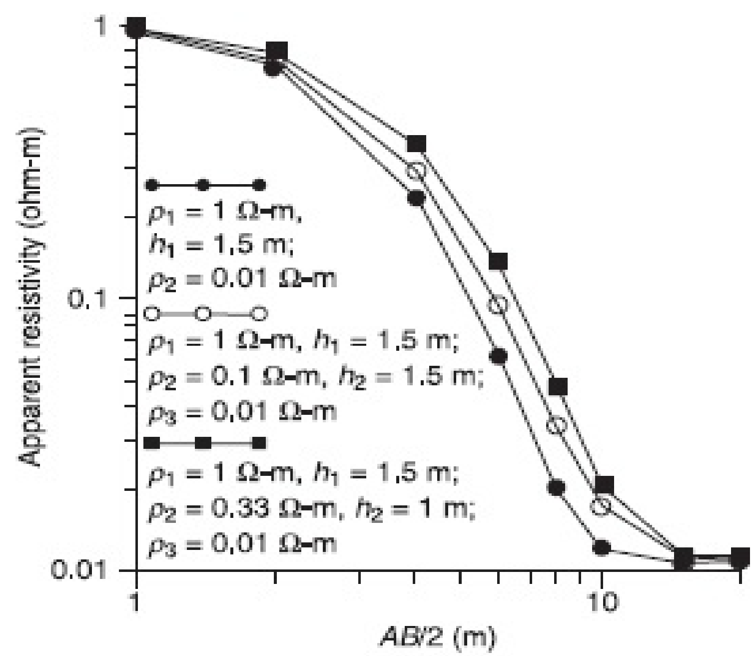




The given Figure shows a case of suppression. A two-layer descending-type curve has been computed with the following layer parameters: h_1 = 1.5 m, ρ_1 = 1 ohm-m, and ρ_2 = 0.01 ohm-m. An intermediate layer has been added with the following parameters: h_2 = 1.5 m, ρ_2 = 0.1 ohm-m, which shows a resistivity contrast of 10 times with both top and bottom layers. The curves are nearly coincident. In the next case, the intermediate layer has been replaced with the following parameters: h_2 = 1.0 m, ρ_2 = 0.33 ohm-m. The resistivity contrast with the first layer in this case is 3 times only, whereas with the third layer, the resistivity contrast is 33 times. These three curves follow each other closely and the effect of the second layer is not discernible. It is a case of suppression of the intermediate layer.

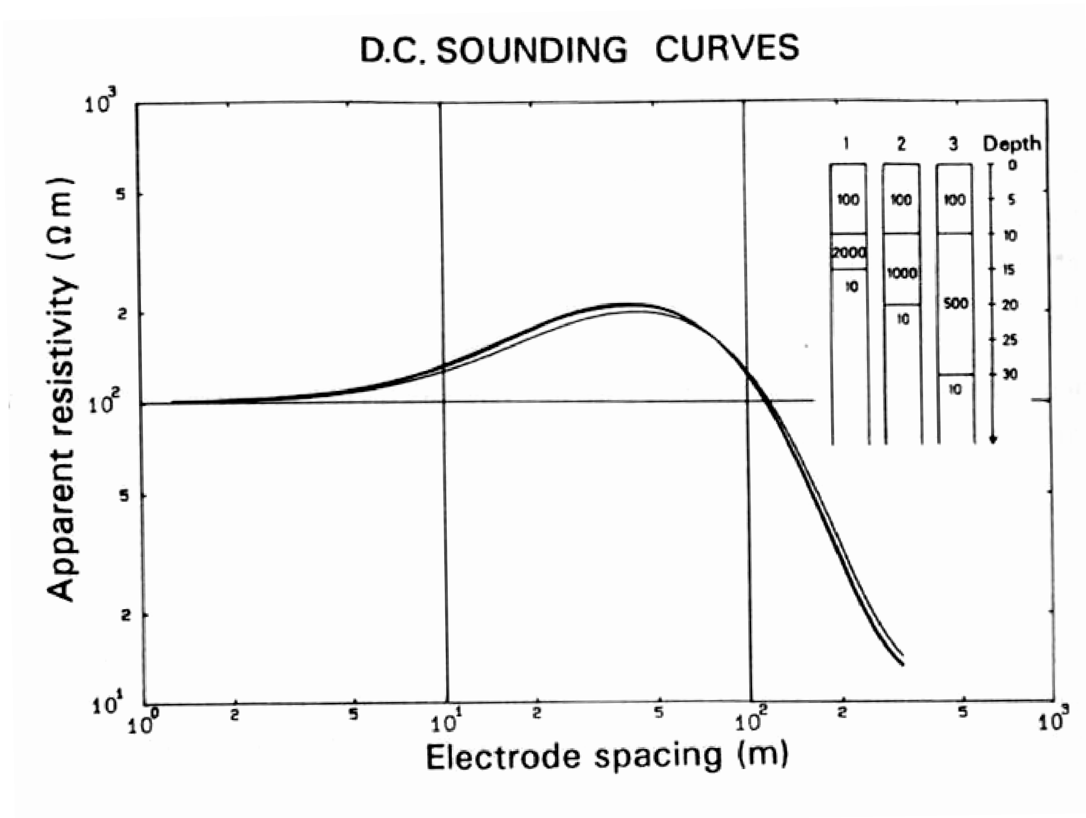


(a)



(b)

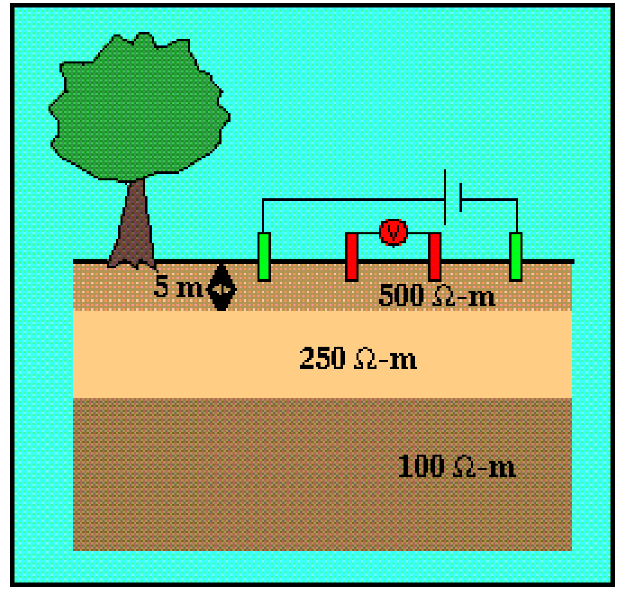
Equivalence: several models produce the same results

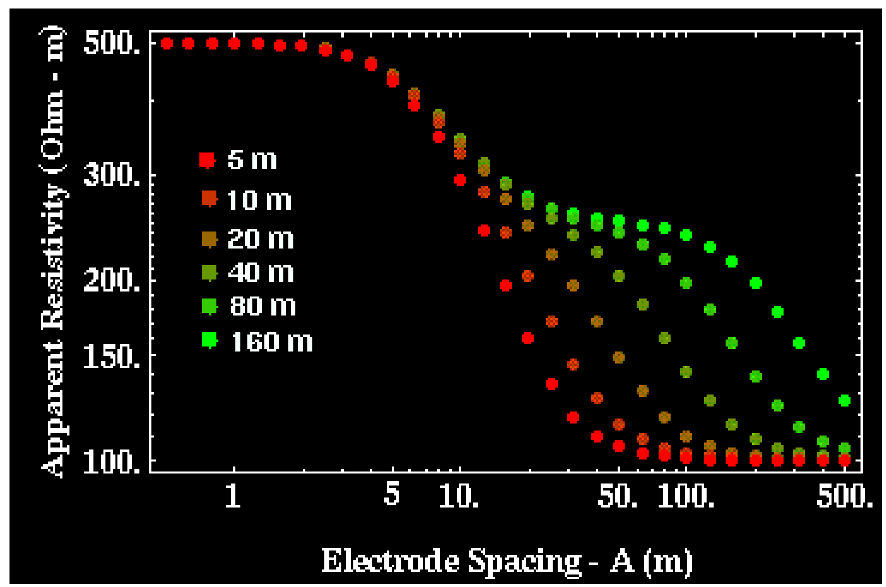


- Although ER cannot determine unique parameters, can determine range of values.
- Also exists in 2D and 3D, but much more difficult to quantify. In these multidimensional cases simply referred to as *non-uniqueness*.

Suppression

- Principle of *suppression:* Thin layers of small resistivity contrast with respect to background will be missed.
- Thin layers of greater resistivity contrast will be detectable, but equivalence limits resolution of boundary depths, etc.

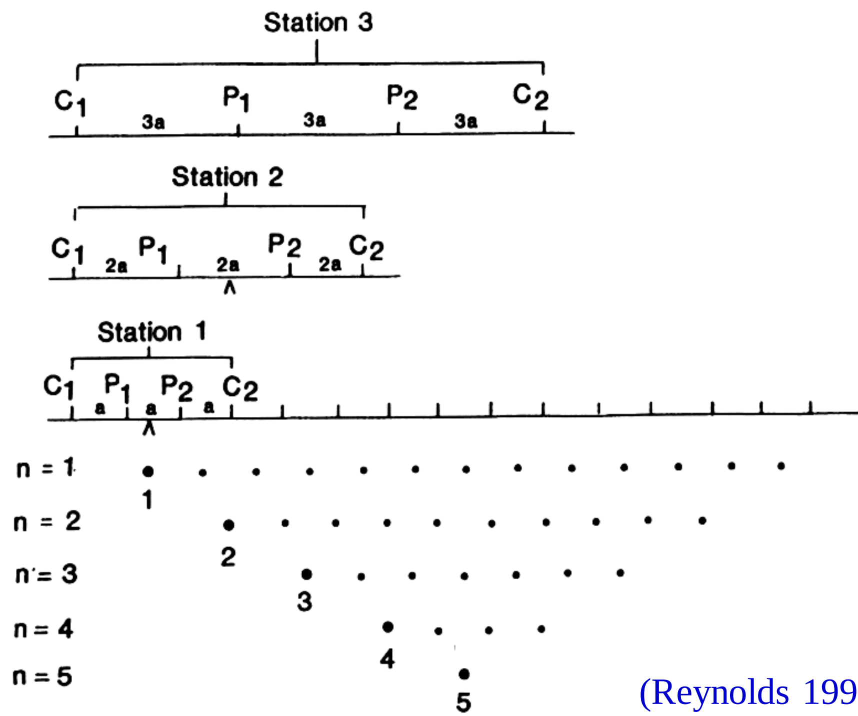




Combined Sounding and Profiling

- Increase electrode separation as well as make measurements at multiple locations along the horizontal axis.
- Provides data for two dimensional interpretation of subsurface.
- Data often plotted in *pseudo-section* for qualitative analysis.

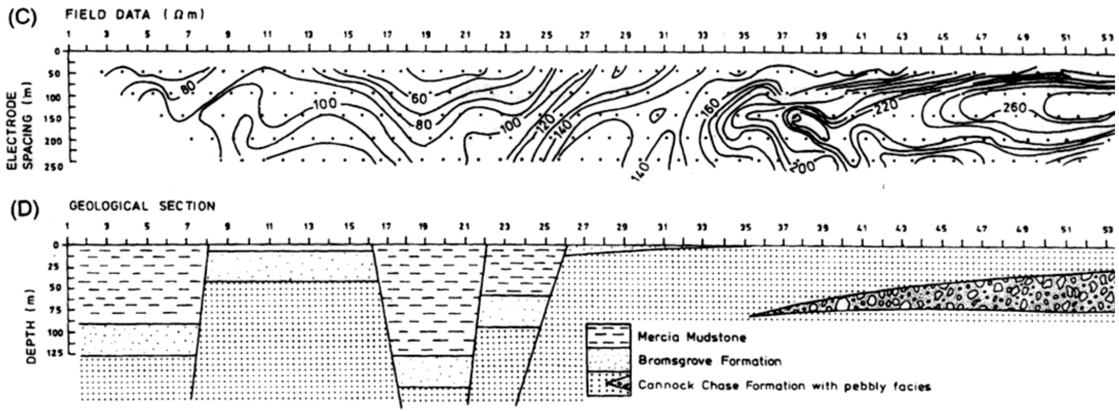
Wenner Pseudo-Section



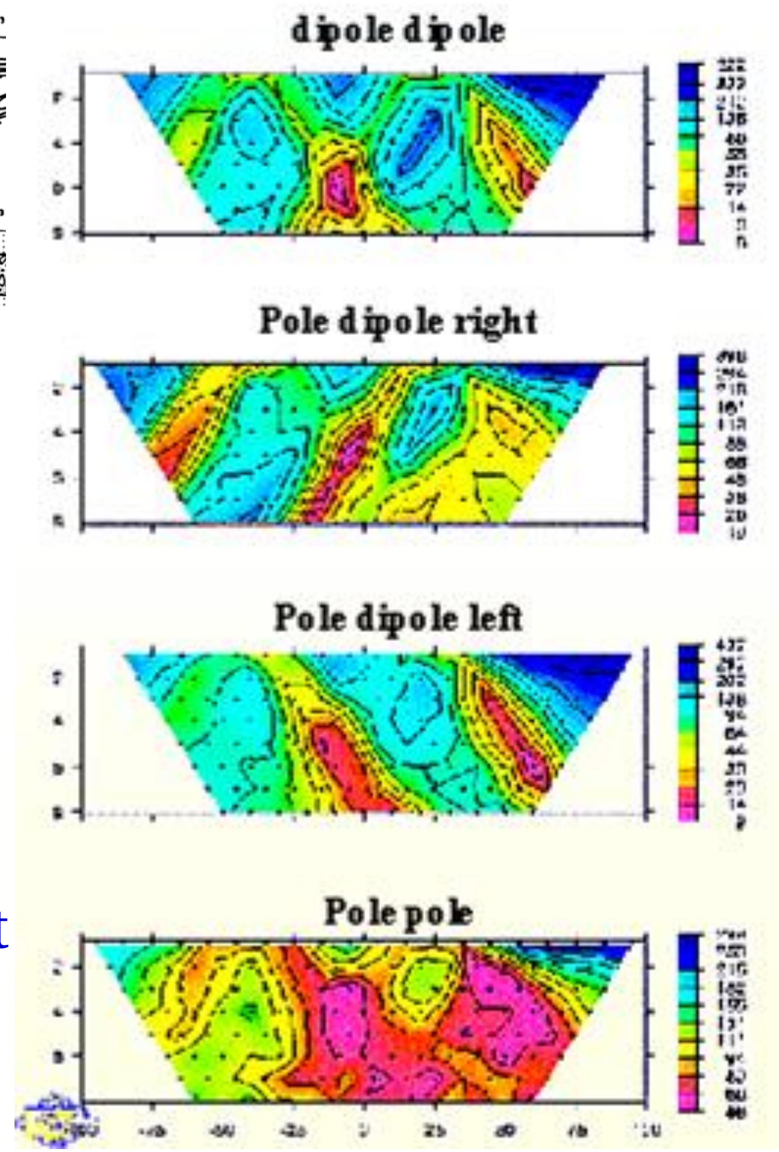
(Reynolds 1997)

Wenner: h=a/2
Schlumberger: h=L/3
Dipole Dipole: h=n a

Pseudo-Sections



(Reynolds 1997)



- Can sometimes be used to qualitatively assess geology

- <u>Warning</u>: Can also prove to be very difficult to interpret directly, with different arrays yielding very different results.

Measurement Systems

Transmitter

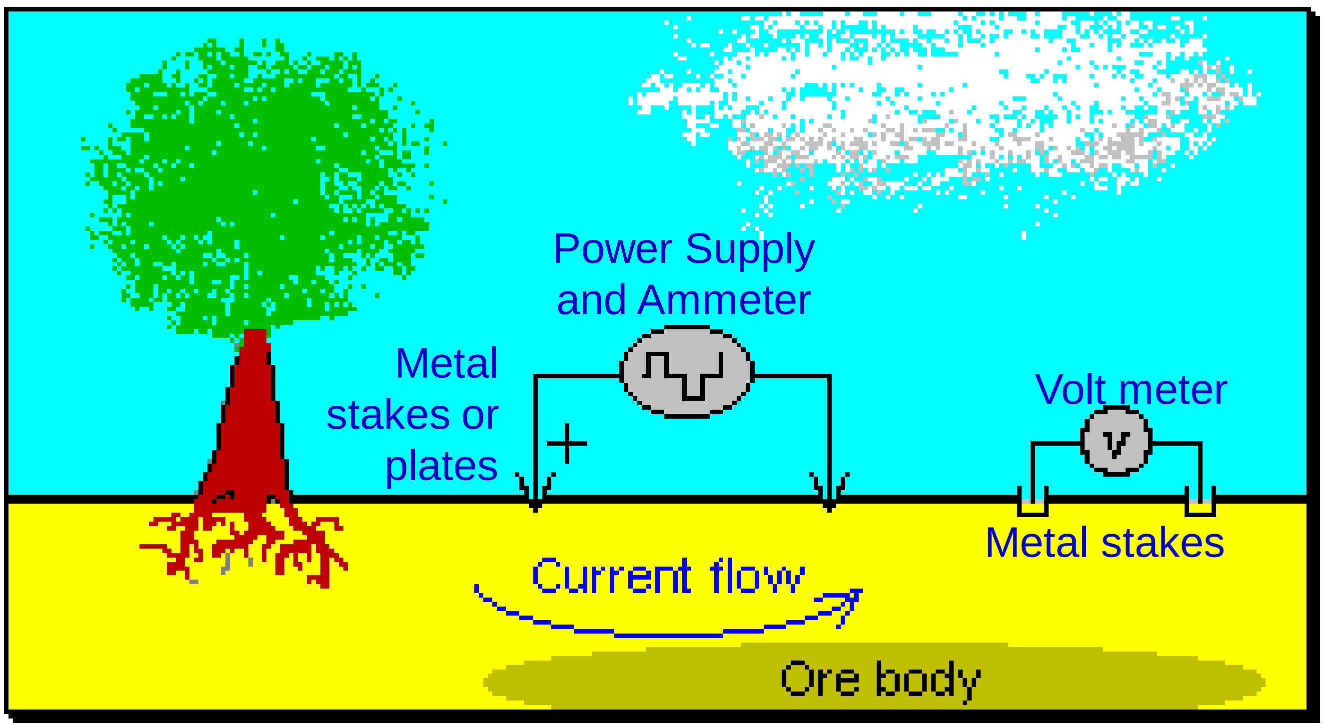
- Power Supply
  - DC
  - AC (more common)

•Ammeter

•Metal electrodes

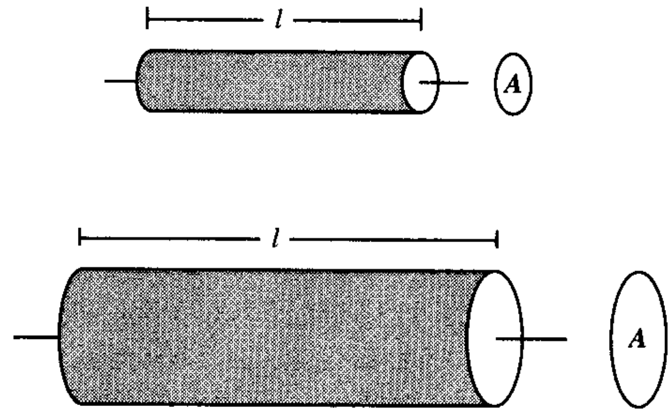
Receiver

- Voltmeter
- Metal Electrodes



Resistivity

Resistance includes length and area
We want resisitivity ρ [ohm m] because:
- It is a material property
- No geometry included



$$R = \rho \frac{L}{A} [\text{ohm}]$$

↑ length → ↑ resistance
↑area → ↓resistance

Conductivity σ [siemens/m] or [mhos/m]:

$$\sigma = \frac{1}{\rho} [\text{mhos m}]$$

It is the ability of the electrical charge to move through the material

More general form of Ohm's law

$$i = \frac{1}{R} V = \frac{A}{\rho} \frac{V}{l}$$

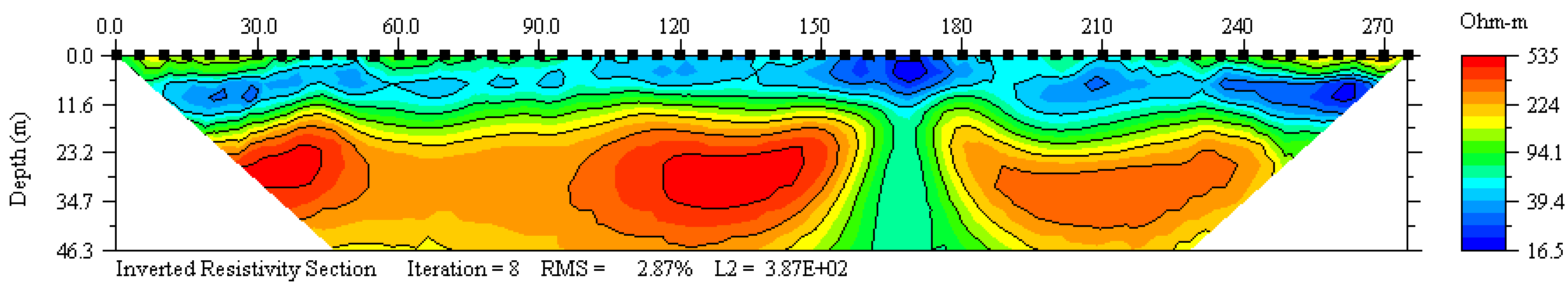
When looking at a solid, Ohm's law can be written as:

$$i = \frac{A}{\rho} \frac{\Delta V}{\Delta l}$$

And in 3-D we use vectors: $$I = \frac{A}{\rho} gradV$$

Resistivity of Geologic Materials

- The resistivity of the subsurface depends upon:
  - The presence of certain metals
    - Especially metallic ores
  - The temperature of the subsurface
    - Geothermal energy!
  - The presence of archeological features
    - Graves, fire pits, post holes, etc…
  - Amount of groundwater present
    - Amount of dissolved salts
    - Presence of contaminants
    - % Porosity and Permeability



A resistivity profile

Archie's Law

- Porous, water-bearing rocks / sediments may be ionic conductors. Their "formation resistivity" is defined by *Archie's Law*:

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

$\phi \equiv$ porosity

$s_w \equiv$ water saturation

$a \approx 0.5 - 2.5$

$n \approx 2$ if $s_w \geq 0.3$

$m \equiv$ cementation ≈ 1.3 (Tertiary) $-$ 2.0 (Palaeozoic)

  – Archie's law is an empirical model
    - Note the exponents…what does this imply about the range of resistivity of geologic materials?

General Rules of Thumb For Resistivity

Highest R

Igneous Rocks

Why? Only a minor component of pore water

Metamorphic Rocks

Why? Hydrous minerals and fabrics

Sedimentary Rocks

Why? Abundant pore space and fluids

Lowest R

Clay: super low resistivity

General Rules of Thumb For Resistivity

Highest R

Older Rocks

Why? More time to fill in fractures and pore space

Younger Rocks

Why? Abundant fractures and/or pore space

Lowest R