Metodi Geoelettrici

Metodi geoelettrici

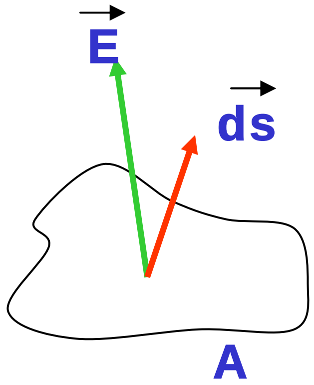
A Cura di

dott. Torrese Patrizio

Università degli Studi di Pavia

Dipartimento di Scienze della Terra

$$\vec{E} = \frac{\vec{F}}{q} = k\frac{q}{r^2}\vec{r}$$



$$E = \frac{1}{4\pi\varepsilon}\cdot\frac{q}{r^2}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots\ldots + \vec{E}_n$$

$$\Phi_E = \int_A \vec{E}\,d\vec{s}$$

per una superficie chiusa :

$$\Phi_E = \oint_s \vec{E}\,d\vec{s}$$

$$\Phi_E = \oint_s \vec{E}\,d\vec{s} = \frac{q}{\varepsilon} \qquad \Rightarrow \qquad \varepsilon\oint_s \vec{E}\,d\vec{s} = q$$

con $q = 0$ $\quad \varepsilon\oint_s \vec{E}\,d\vec{s} = 0$ $\quad$ essendo $\varepsilon \neq 0$ $\quad \oint_s \vec{E}\,d\vec{s} = 0$

$div\vec{E} = 0$ $\quad$ dove $\quad div = \lim_{V\to 0}\frac{1}{V_E}\oint \vec{E}\,d\vec{s}$

$$\int_V div\vec{E}\,dV = 0$$

$$I = \frac{Q}{t};$$

$$I = \int_A \vec{J}\,d\vec{a}; \qquad \vec{J} = \frac{\vec{I}}{A};$$

$$\vec{J} = \frac{1}{\rho}\vec{E} \qquad \text{e se} \quad div\vec{E} = 0$$

$$div\vec{J} = 0$$

sappiamo anche $\vec{E} = -gradV$

$$div\left(-\frac{1}{\rho}gradV\right) = \left(grad\left(\frac{1}{\rho}\right)gradV + \frac{1}{\rho}divgradV\right) = 0$$

$$\nabla^2 V = \frac{\delta^2 V}{\delta x^2} + \frac{\delta^2 V}{\delta y^2} + \frac{\delta^2 V}{\delta z^2} = 0$$

$$\frac{\delta^2 V}{\delta x^2} + \frac{\delta^2 V}{\delta y^2} = -\frac{\delta^2 V}{\delta z^2}$$

$$\frac{\delta^2 V}{\delta r^2} + \frac{1}{r}\frac{\delta V}{\delta r} = 0$$

la soluzione di questa equazione risulta :

$$V = \frac{c}{r}; \qquad \text{dove} \quad c = \text{costante};$$

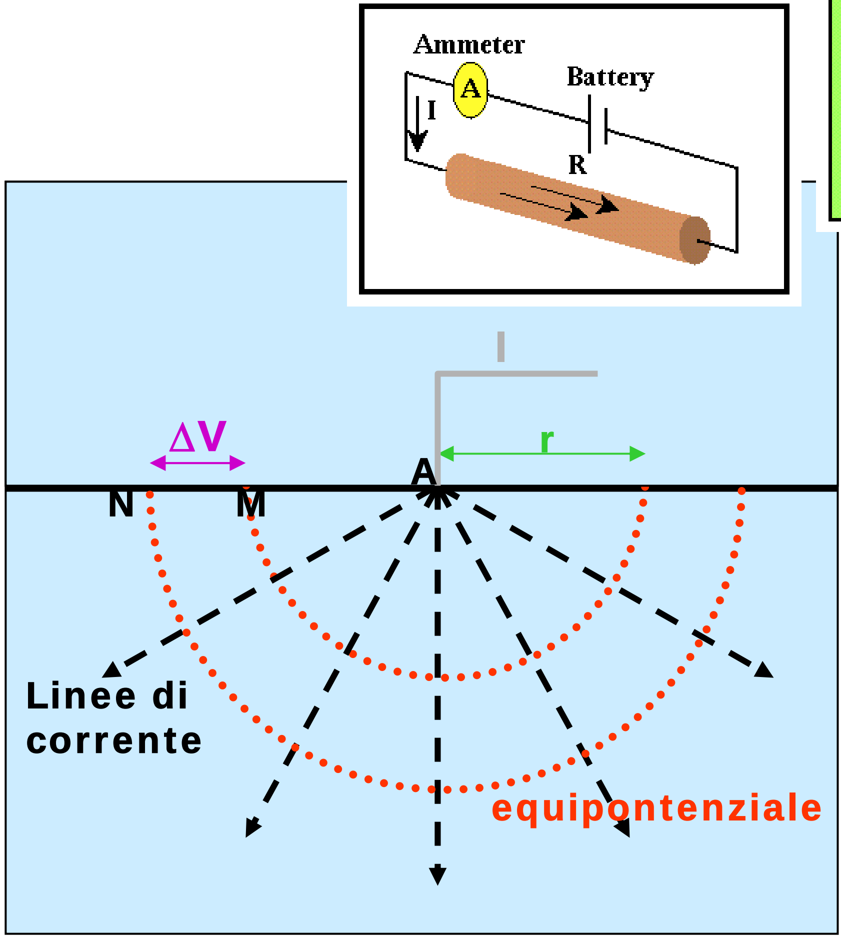
$$\vec{E} = -\frac{dV}{dr} \qquad \text{e} \qquad -dV = \vec{E}dr;$$

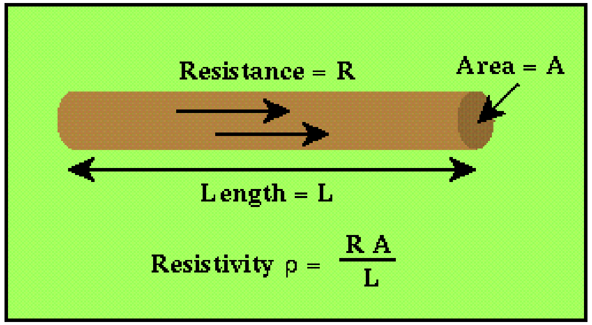
$$\vec{E} = \rho\vec{J} \qquad \text{e} \qquad -dV = \rho\vec{J}dr;$$

$$J = \frac{I}{2\pi r^2} \qquad \text{e} \qquad -dV = \rho\frac{I}{2\pi r^2}dr;$$

$$V = -\int_{\infty}^{r} \rho\frac{I}{2\pi r^2}dr = \frac{\rho I}{2\pi r}$$

Legge di Ohm





By Colorado
School of Mines

$$\Delta V = R \cdot I$$

$$\frac{\Delta V}{I} = R = \rho \frac{l}{s} = \rho K$$

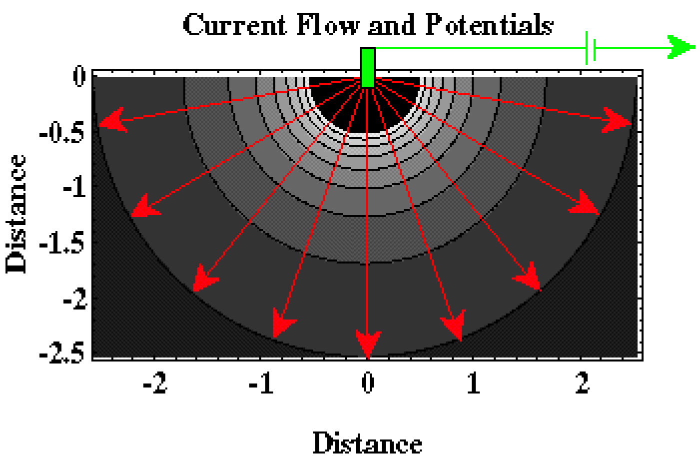
R = resistenza (ohm);

ρ = resistività (ohm · m);

l = lunghezza
s = sezione
} conduttore lineare

k = coeff. geometrico del conduttore

Material	Resistivity (Ohm-meter)
Air	Infinite
Pyrite	3 x 10^-1
Galena	2 x 10^-3
Quartz	4 x 10^10 - 2 x 10^14
Calcite	1 x 10^12 - 1 x 10^13
Rock Salt	30 - 1 x 10^13
Mica	9 x 10^12 - 1 x 10^14
Granite	100 - 1 x 10^6
Gabbro	1 x 10^3 - 1 x 10^6
Basalt	10 - 1 x 10^7
Limestones	50 - 1 x 10^7
Sandstones	1 - 1 x 10^8
Shales	20 - 2 x 10^3
Dolomite	100 - 10,000
Sand	1 - 1,000
Clay	1 - 100
Ground Water	0.5 - 300
Sea Water	0.2

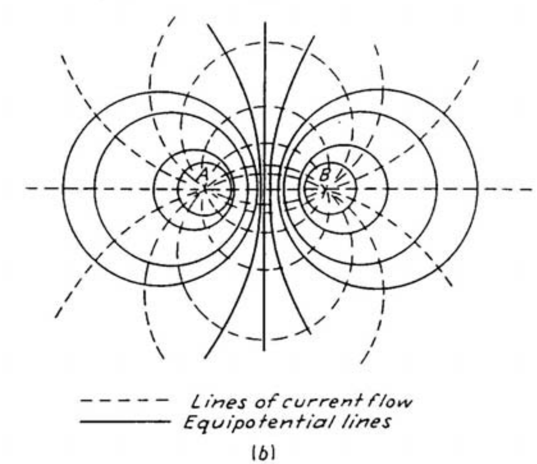


By Colorado School of Mines

Resistività e resistività apparente

Resistività e resistività apparente

In genere il sottosuolo non è elettricamente omogeneo ed isotropo; pertanto quando in esso si immette corrente, una qualsiasi causa di variazione di conducibilità, ne altera il flusso provocando di conseguenza, una anomala distribuzione del potenziale rispetto a quella che si avrebbe per un sottosuolo omogeneo.



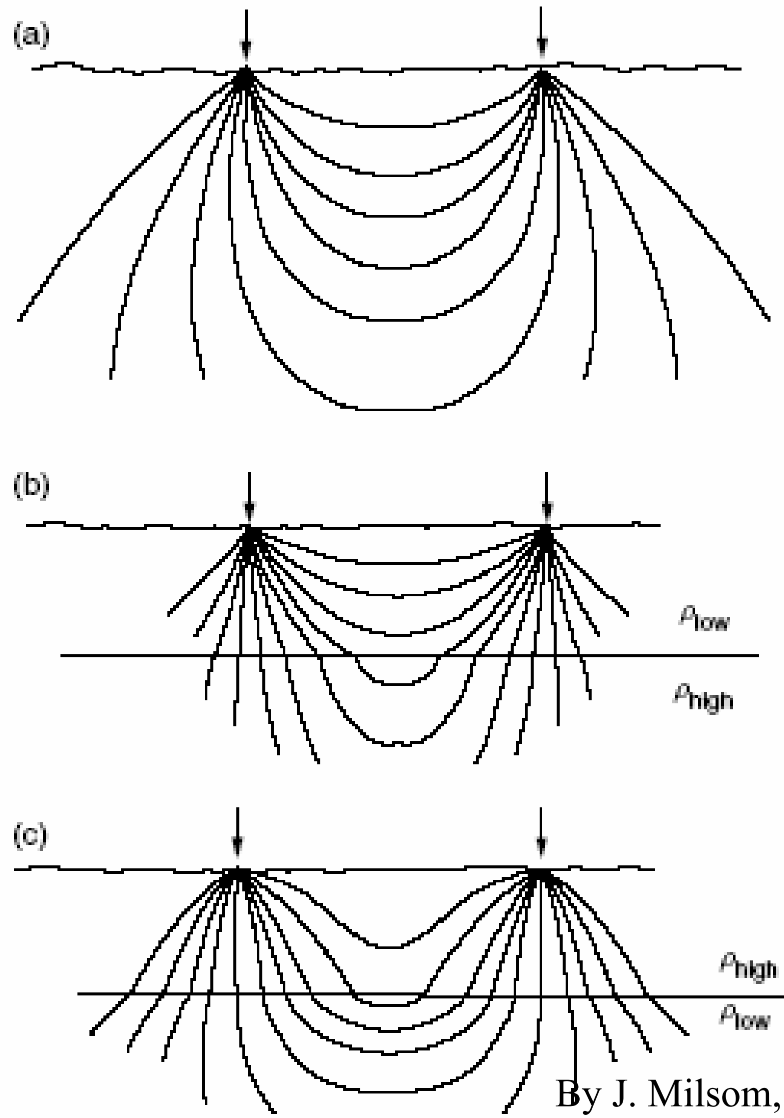
Di conseguenza il valore di resistività che si misura nella realtà è anomalo rispetto al valore che si misurerebbe rispetto ad una distribuzione uniforme del potenziale. Esso prende il nome di RESISTIVITA' APPARENTE e si indica con r_a.

Depth, lateral investigation

Current flow patterns for
(a) uniform half-space;
(b) two-layer ground with lower resistivity in upper layer;
(c) two-layer ground with higher resistivity in upper layer.

AB distance: depth investigation

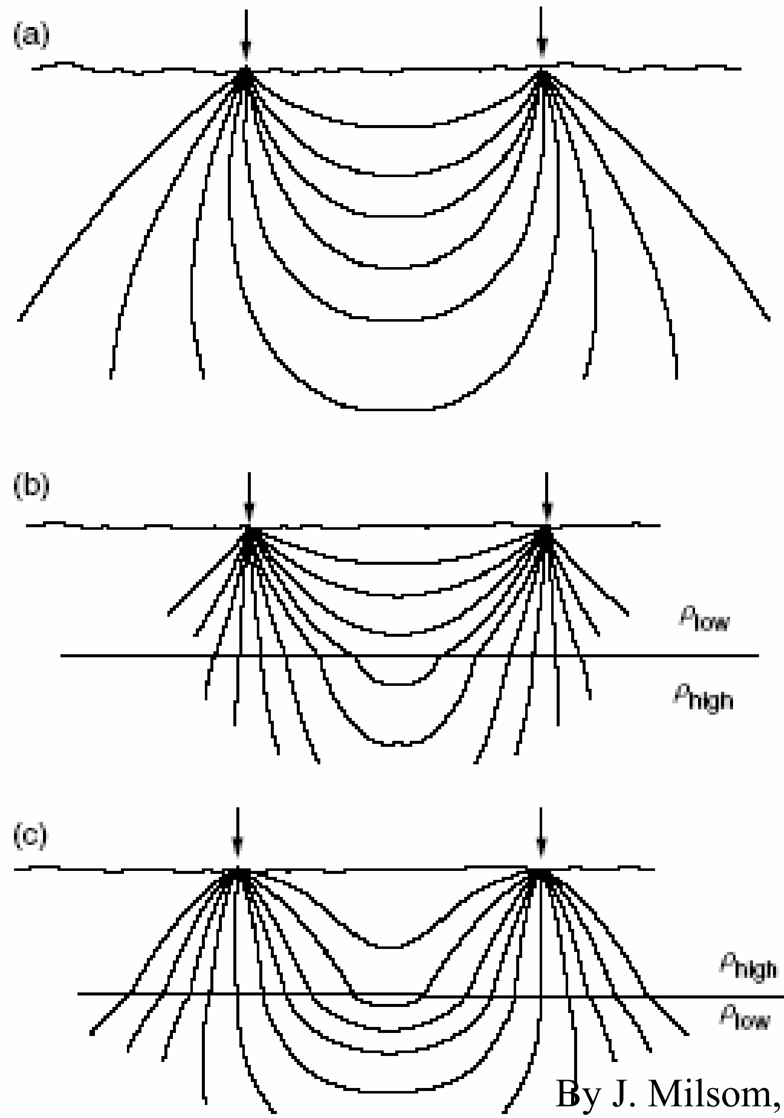
MN distance: lateral investigation



By J. Milsom, 2003

Depth, lateral investigation

depth penetration is almost impossible to define because the depth to which a given fraction of current penetrates depends on the layering as well as on the separation between the current electrodes.



By J. Milsom, 2003

Ohm law

$V = \rho I / 2\pi a$ Legge di Ohm

for the electric potential *V* at a distance *a* from a point electrode at the surface of a *uniform half-space* (homogeneous ground) of resistivity *ρ* (referenced to a zero potential at infinity).

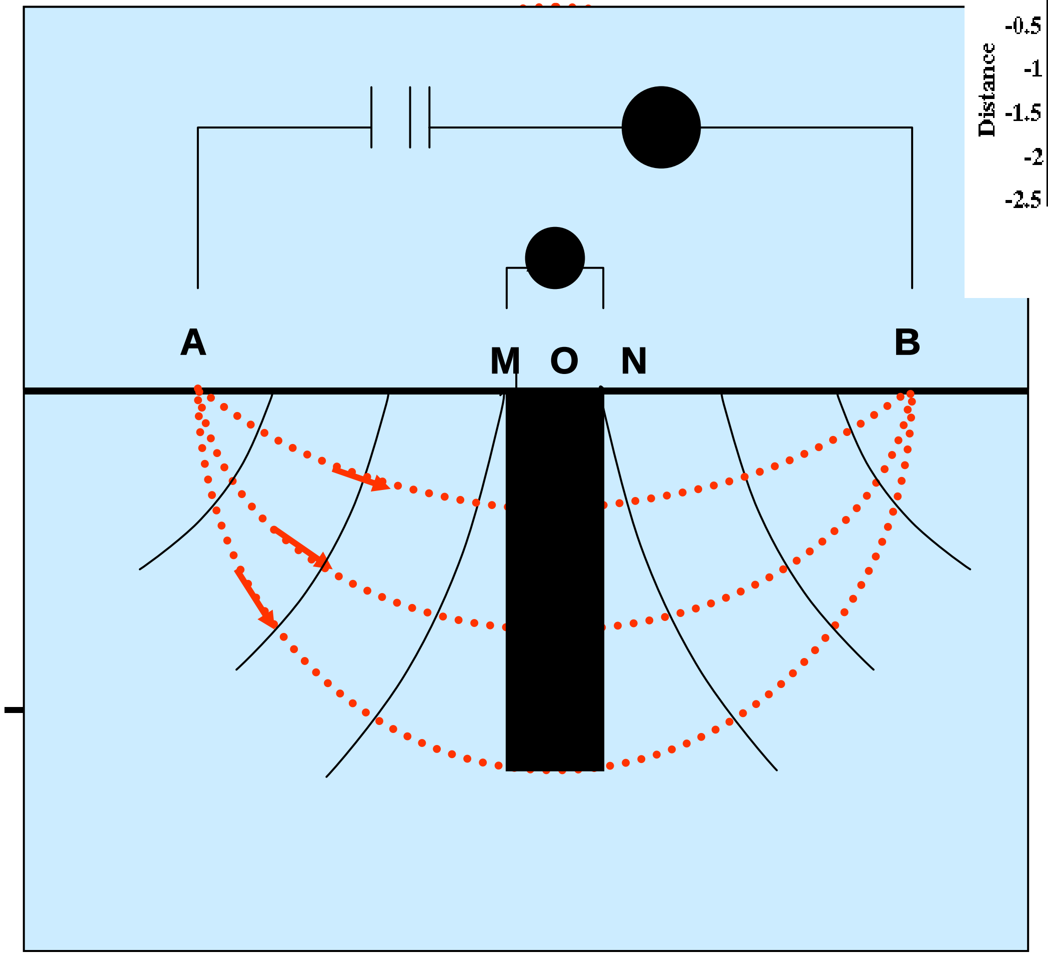
For arrays, the potential at any voltage electrode is equal to the sum of the contributions from the individual current electrodes. In a four-electrode survey over homogeneous ground:

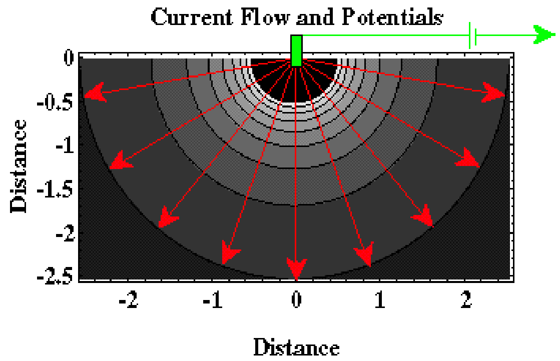
$$V = I\rho(1/[Ma] - 1/[Na] - 1/[Mb] + 1/[Nb])/2\pi = I\rho/k$$

where *V* is the voltage difference between electrodes M and N due to a current *I* flowing between electrodes a and b, and the quantities in square brackets represent inter-electrode distances.

Misura al centro dello stendimento

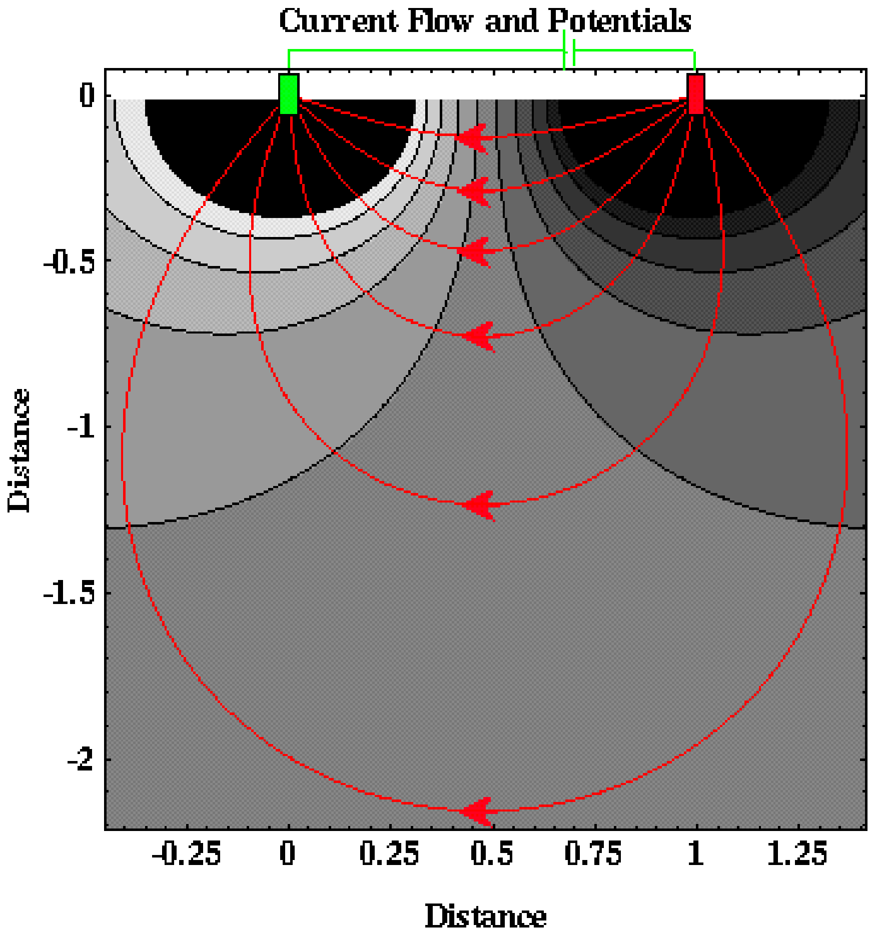
R=AO





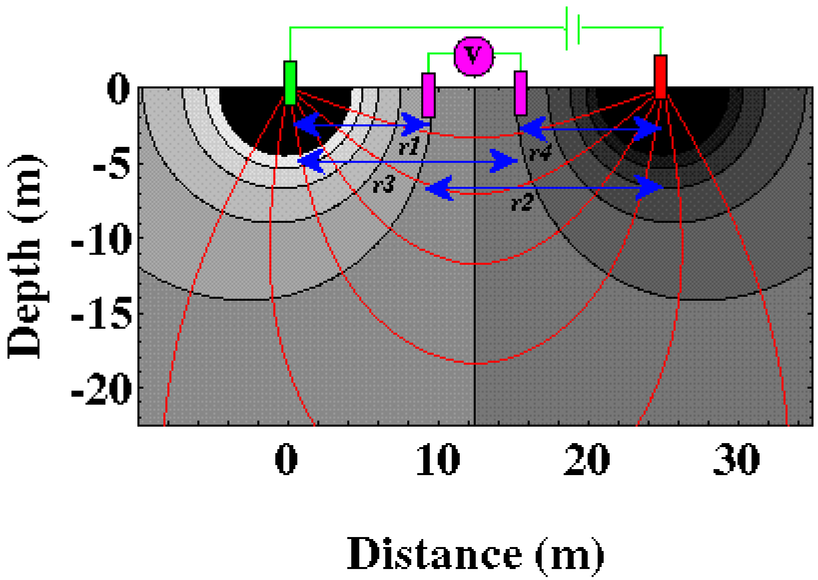
$$V = \frac{\rho I}{2\pi r}$$

By Colorado School of Mines

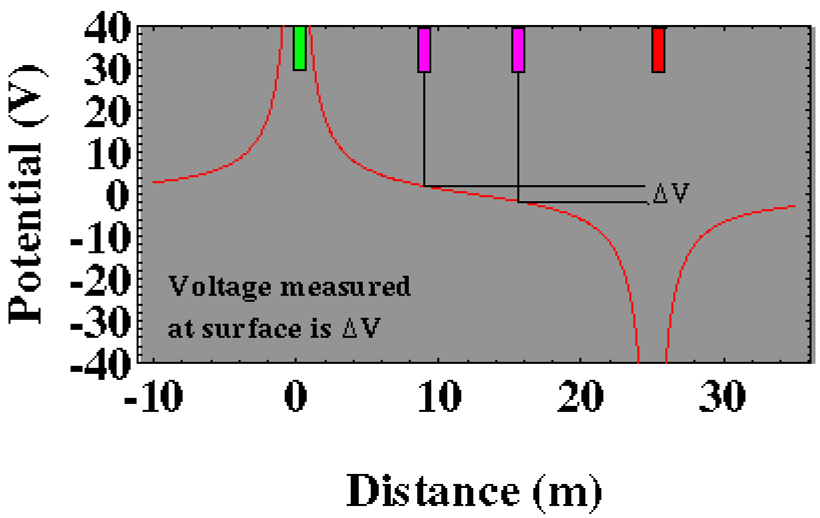


Current Path	% of Total Current
1	17
2	32
3	43
4	49
5	51
6	57

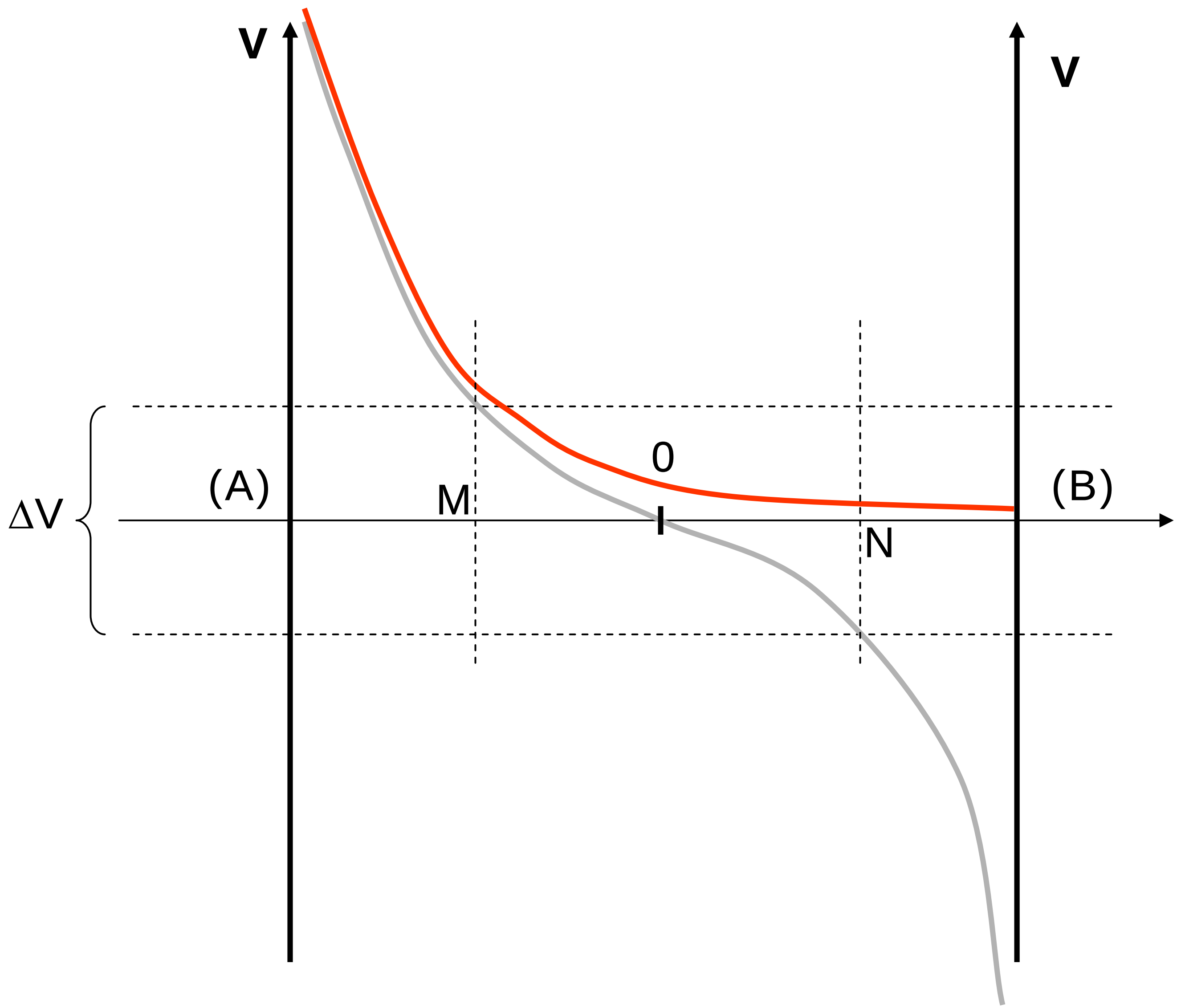
By Colorado School of Mines

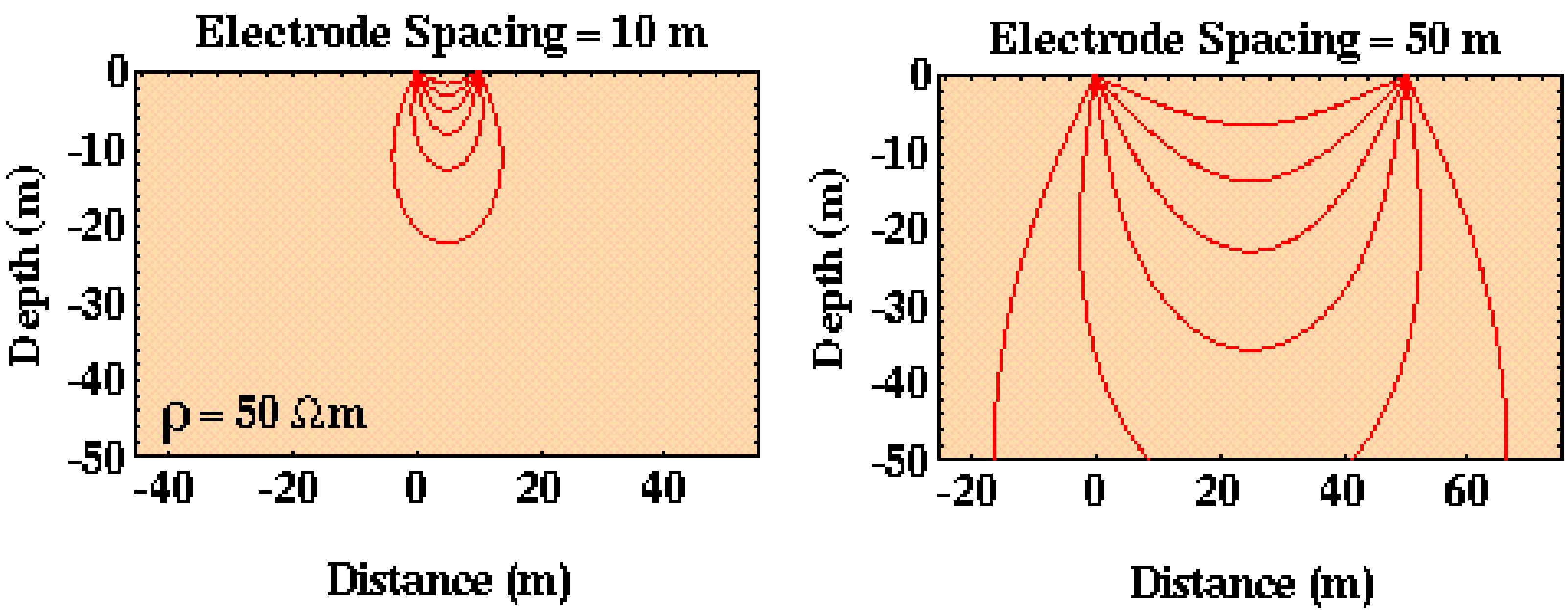


$$\rho_a = \frac{2\pi\Delta V}{i}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}\right)}\right]$$

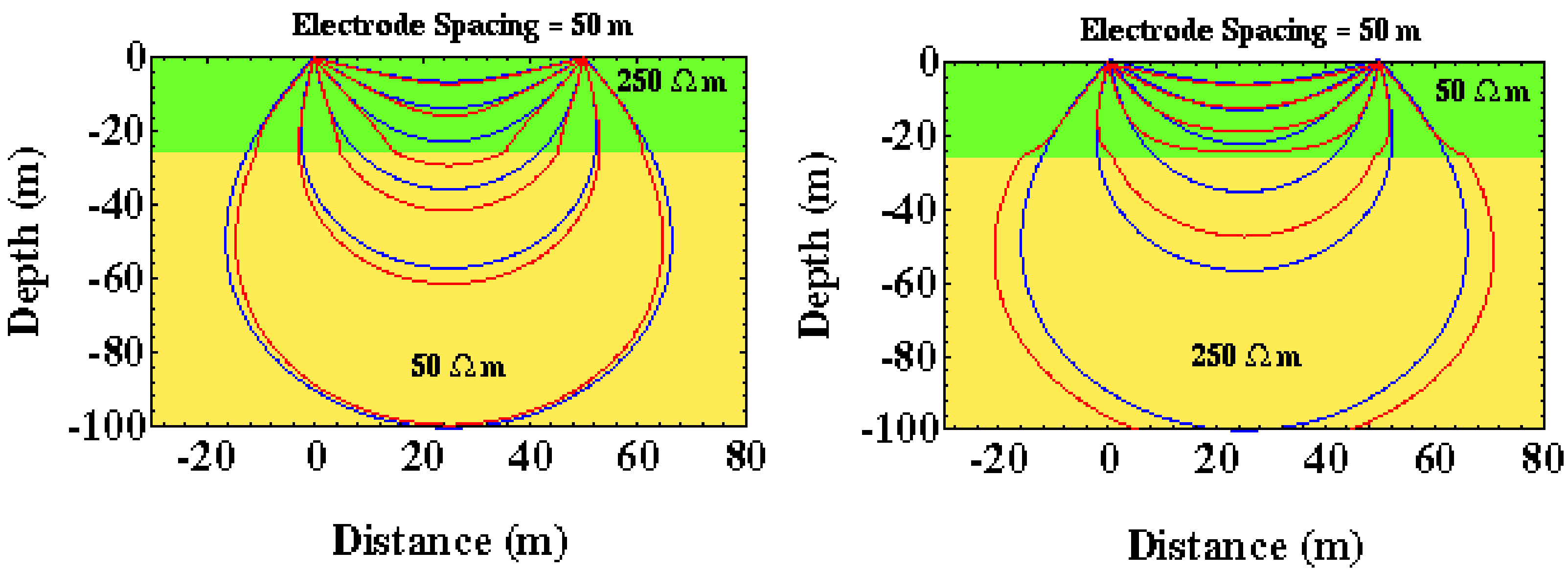


By Colorado
School of Mines

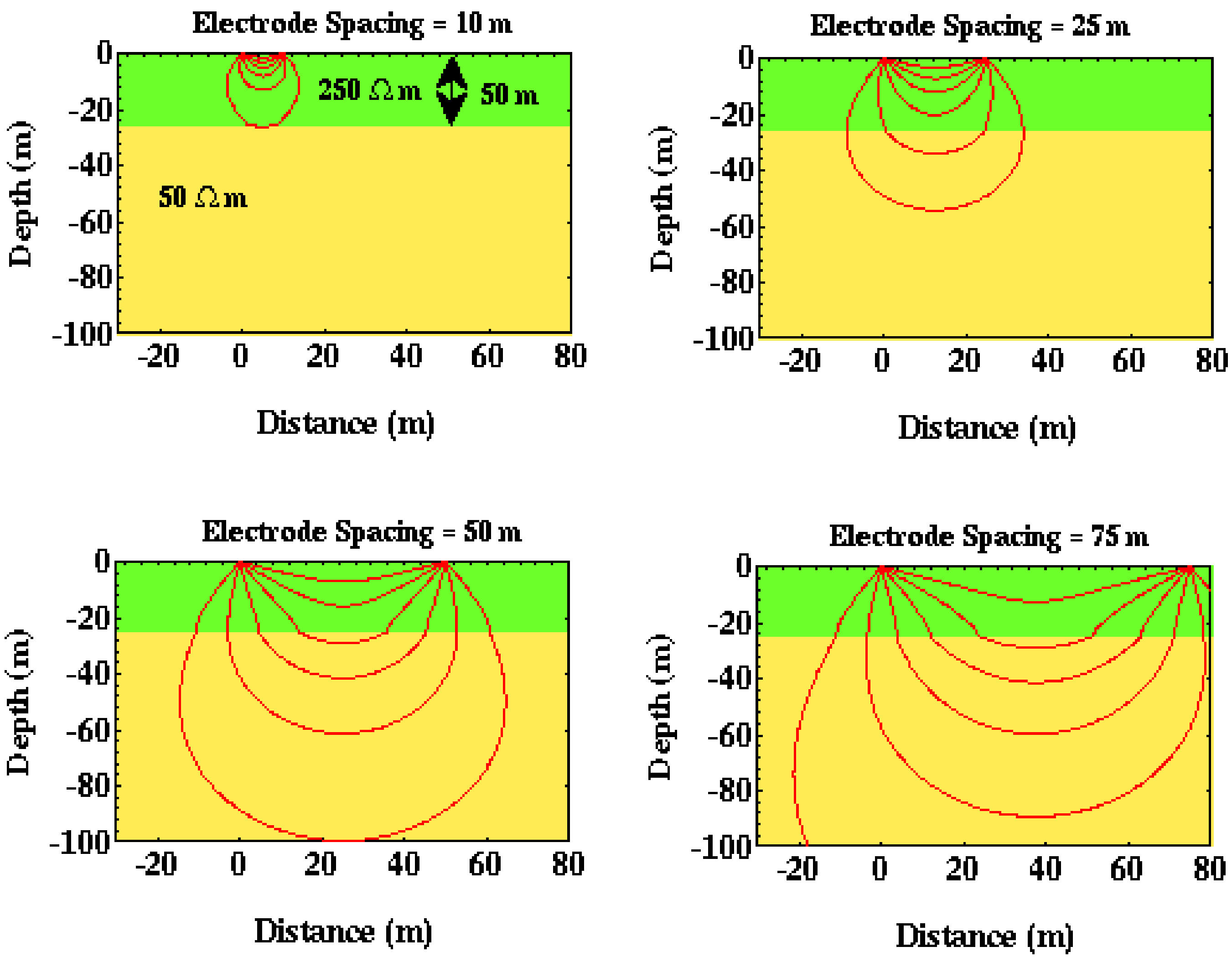

V
V
ΔV
(A)
M
0
I
N
(B)



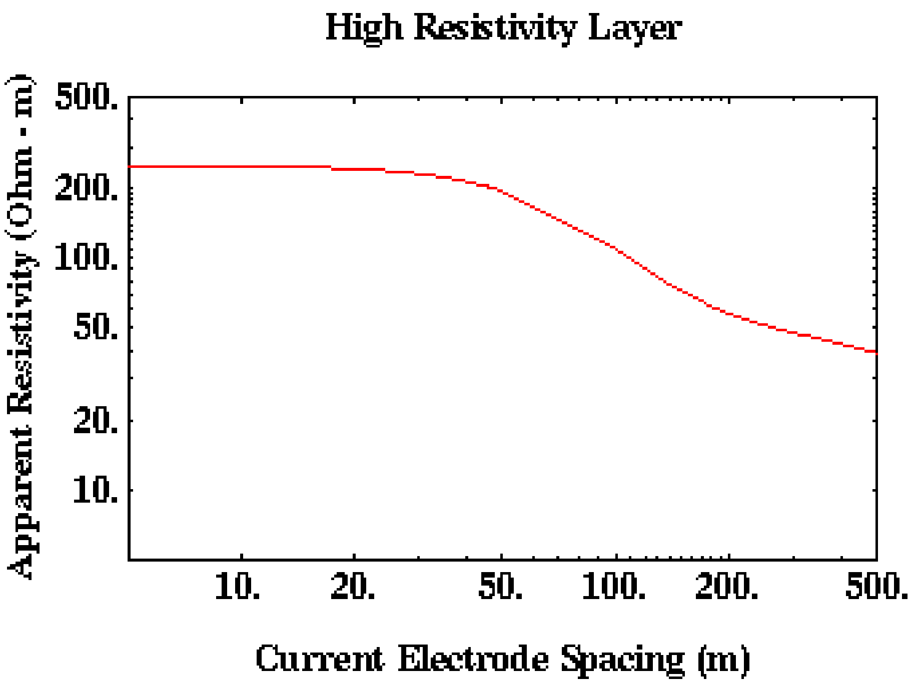
By Colorado
School of Mines



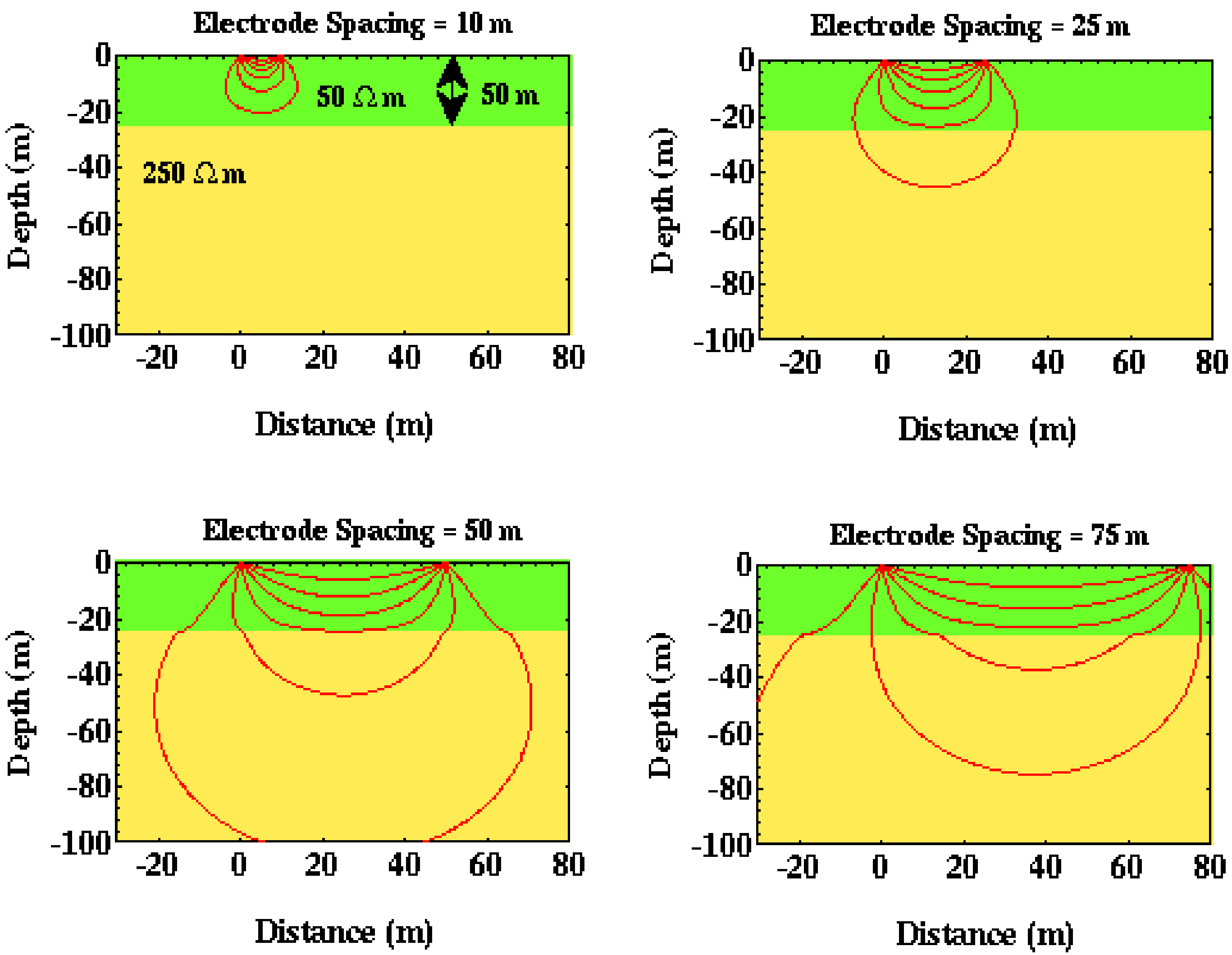
By Colorado
School of Mines



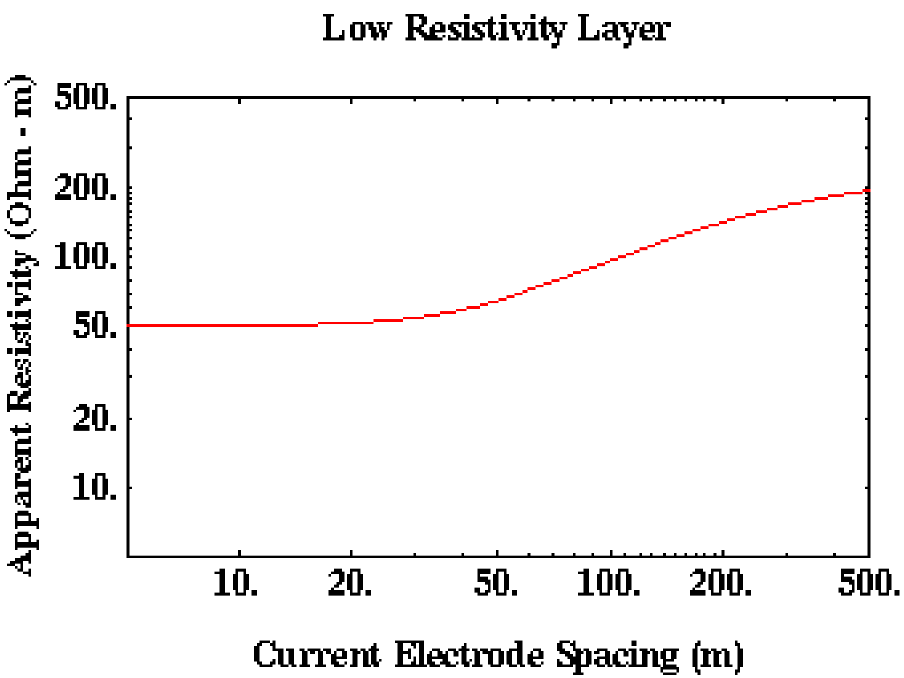
By Colorado School of Mines



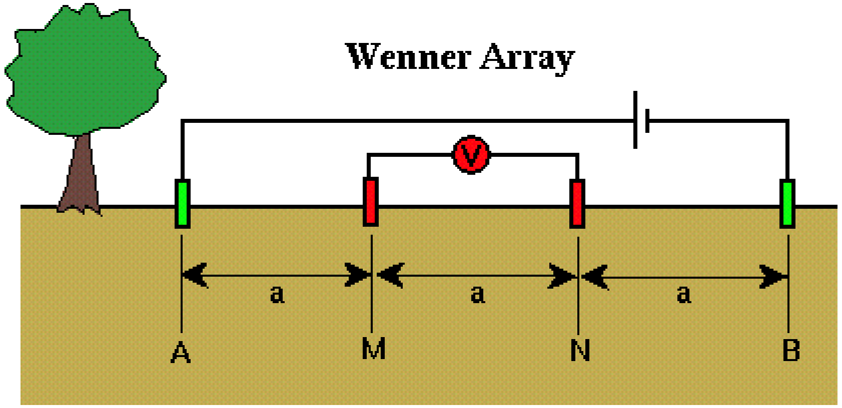
By Colorado
School of Mines



By Colorado School of Mines

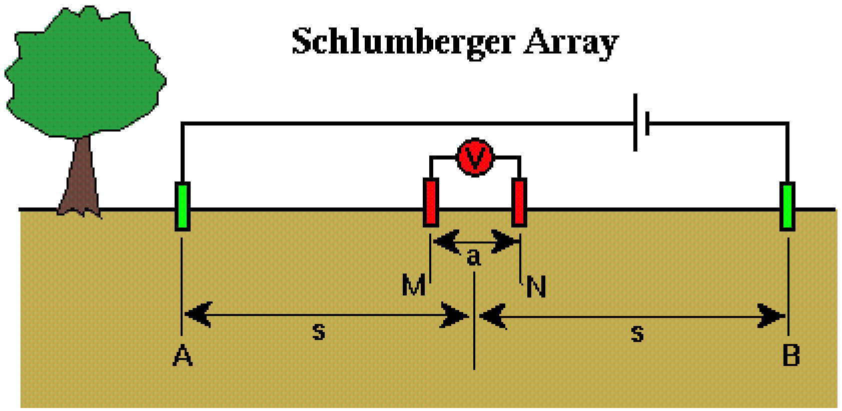


By Colorado
School of Mines



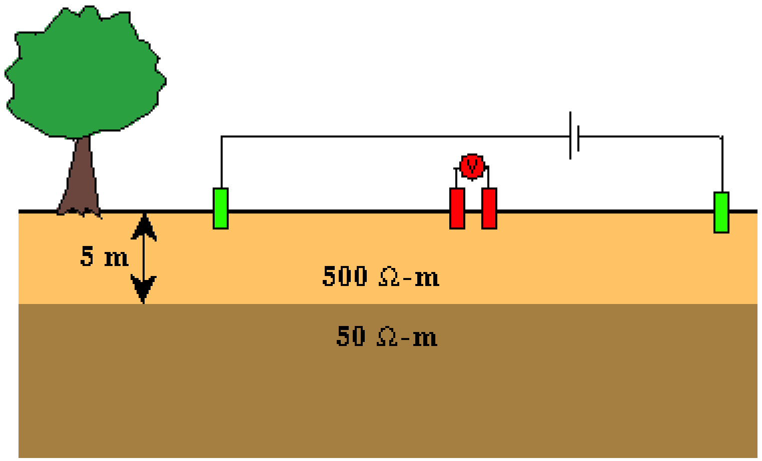
$$\rho_a = 2\pi a \frac{\Delta V}{i}$$

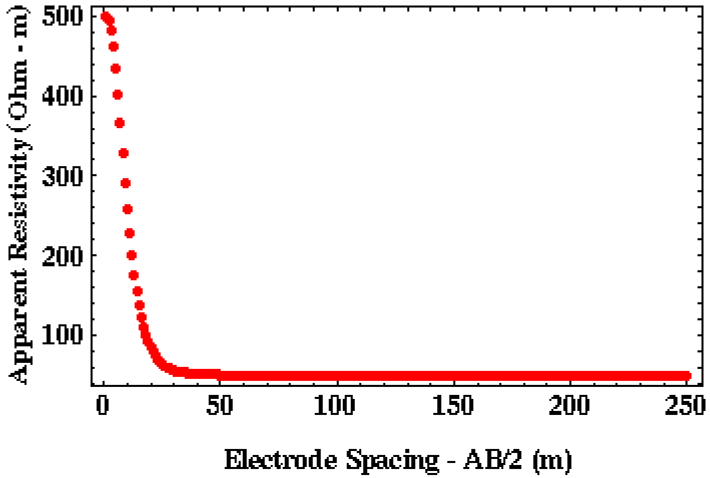
By Colorado School of Mines

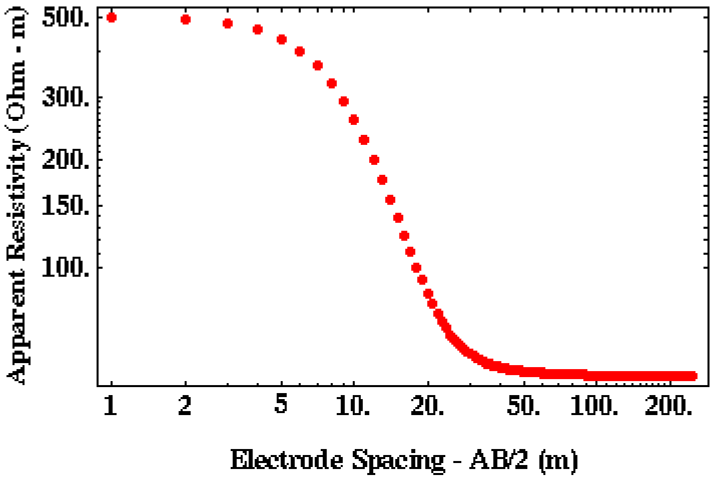


$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a} \frac{\Delta V}{i}$$

By Colorado
School of Mines

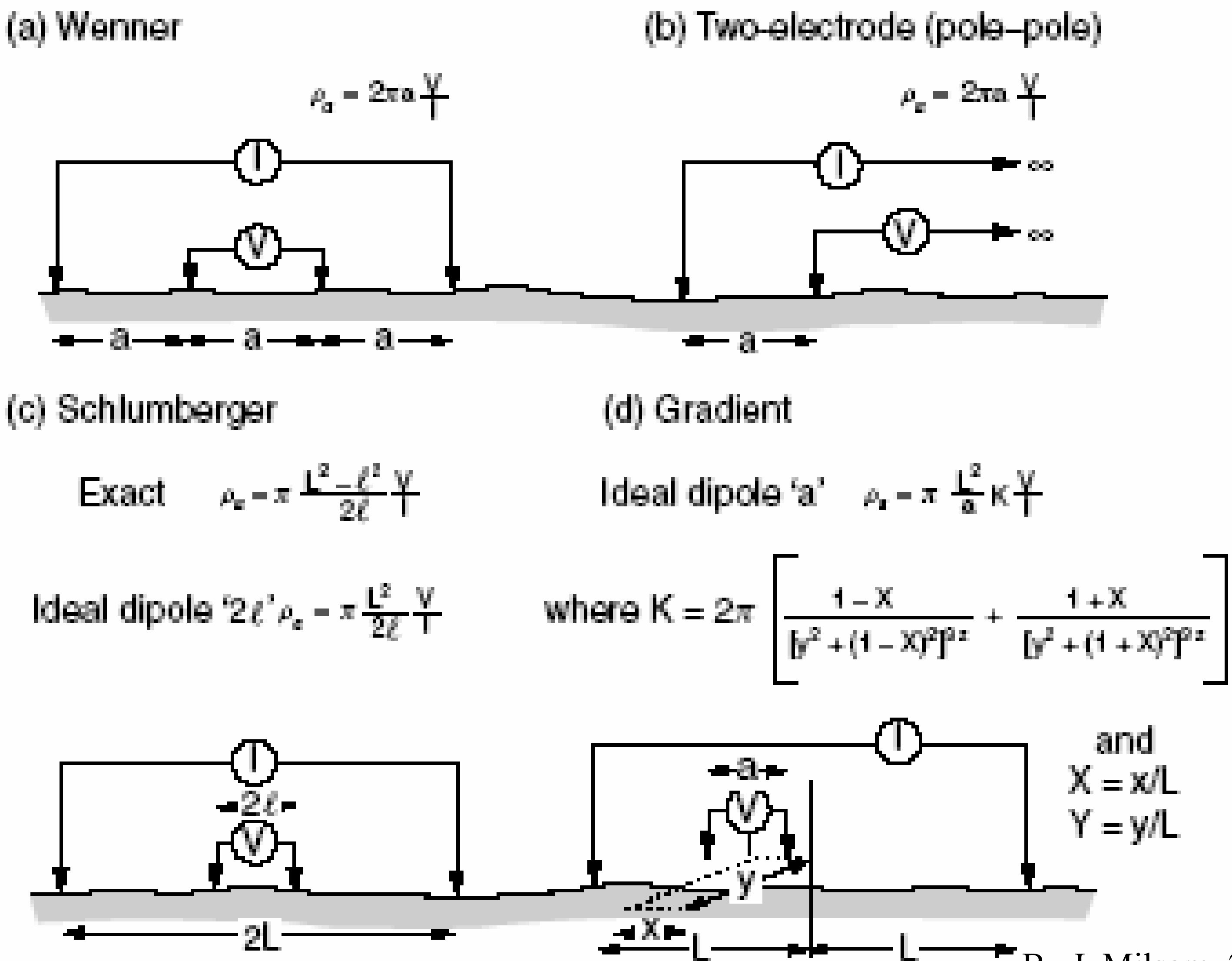






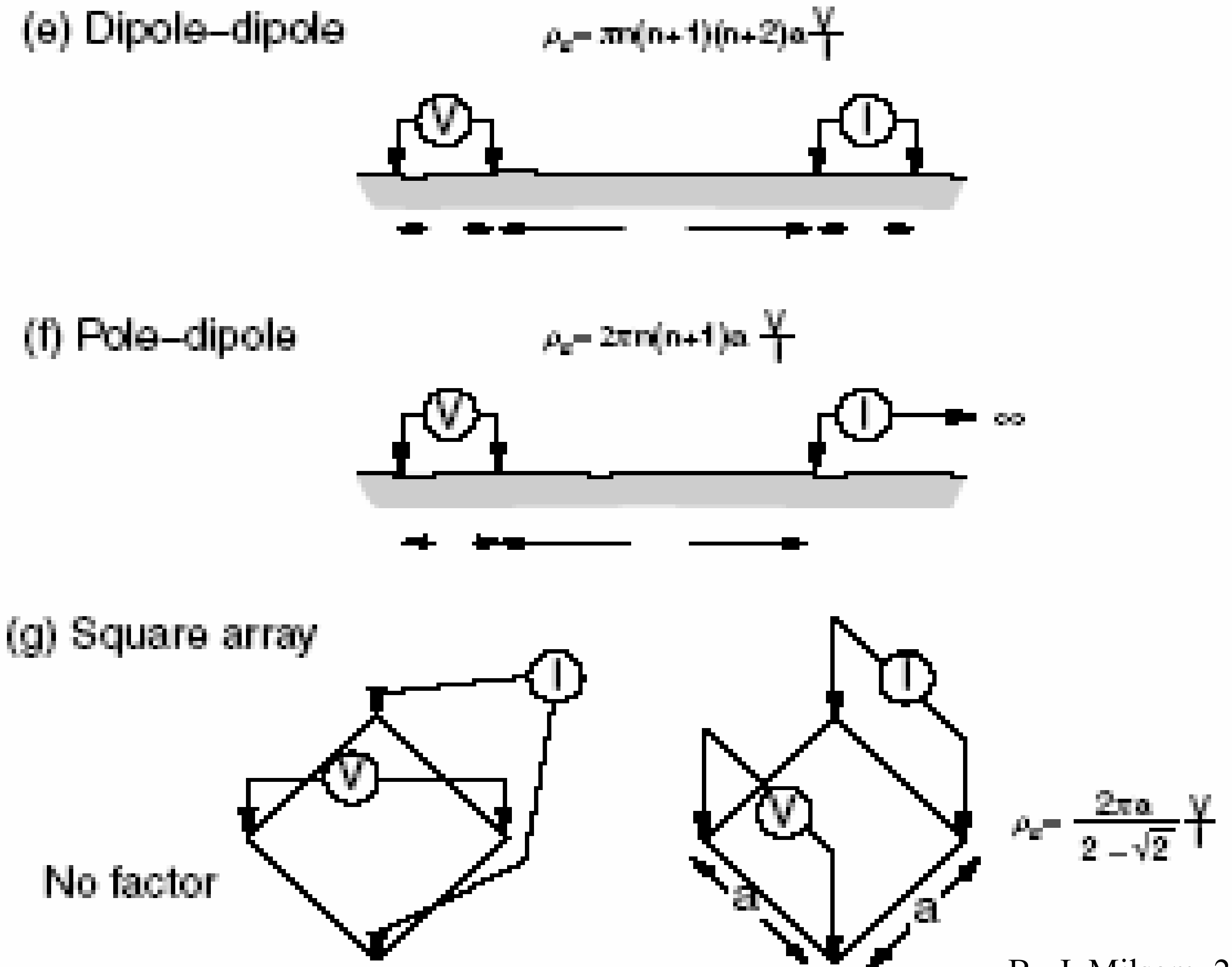
By Colorado
School of Mines

Arrays



By J. Milsom, 2003

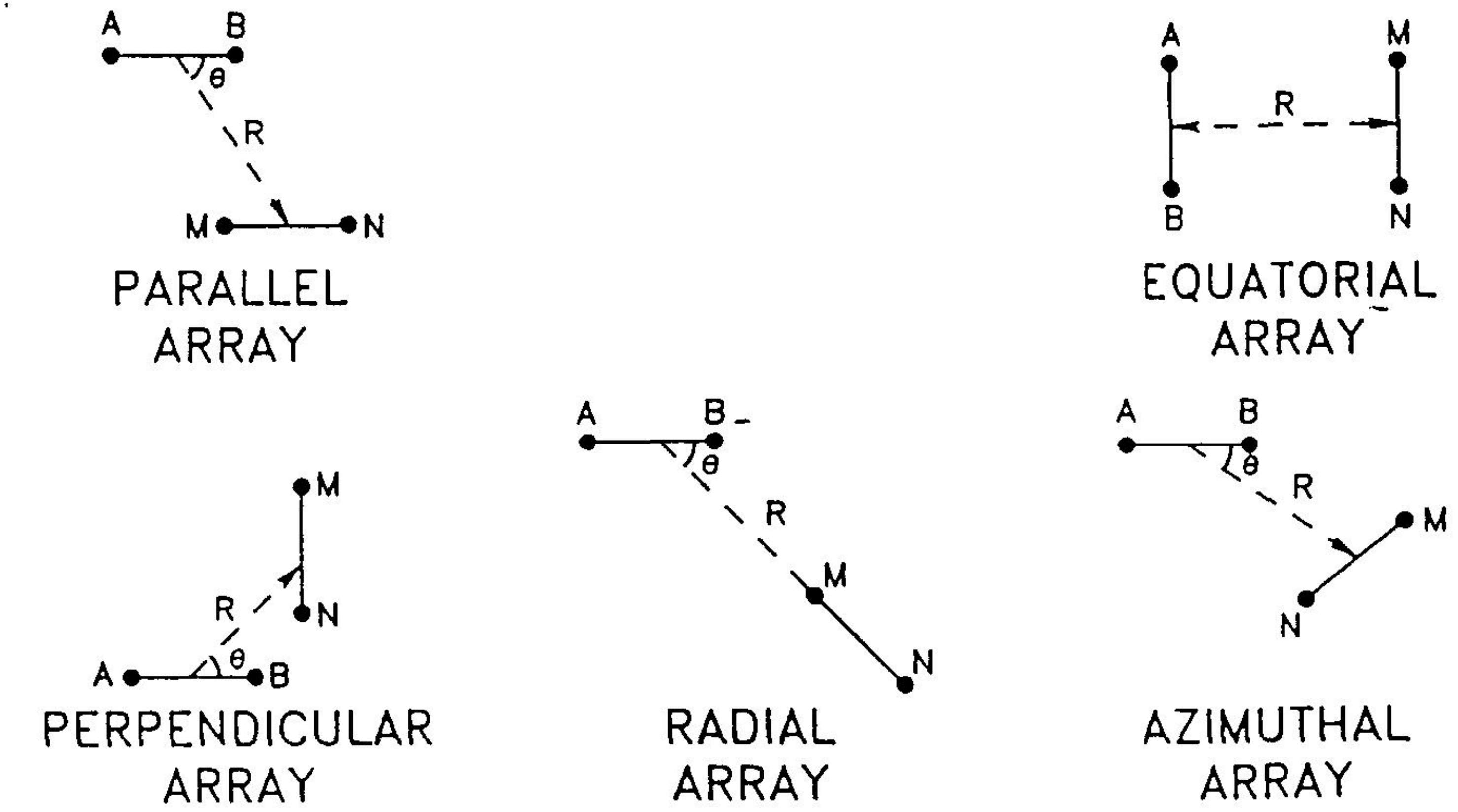
Arrays



By J. Milsom, 2003

Arrays dipolari per alcune configurazioni non assiali

Arrays dipolari per alcune configurazioni non assiali



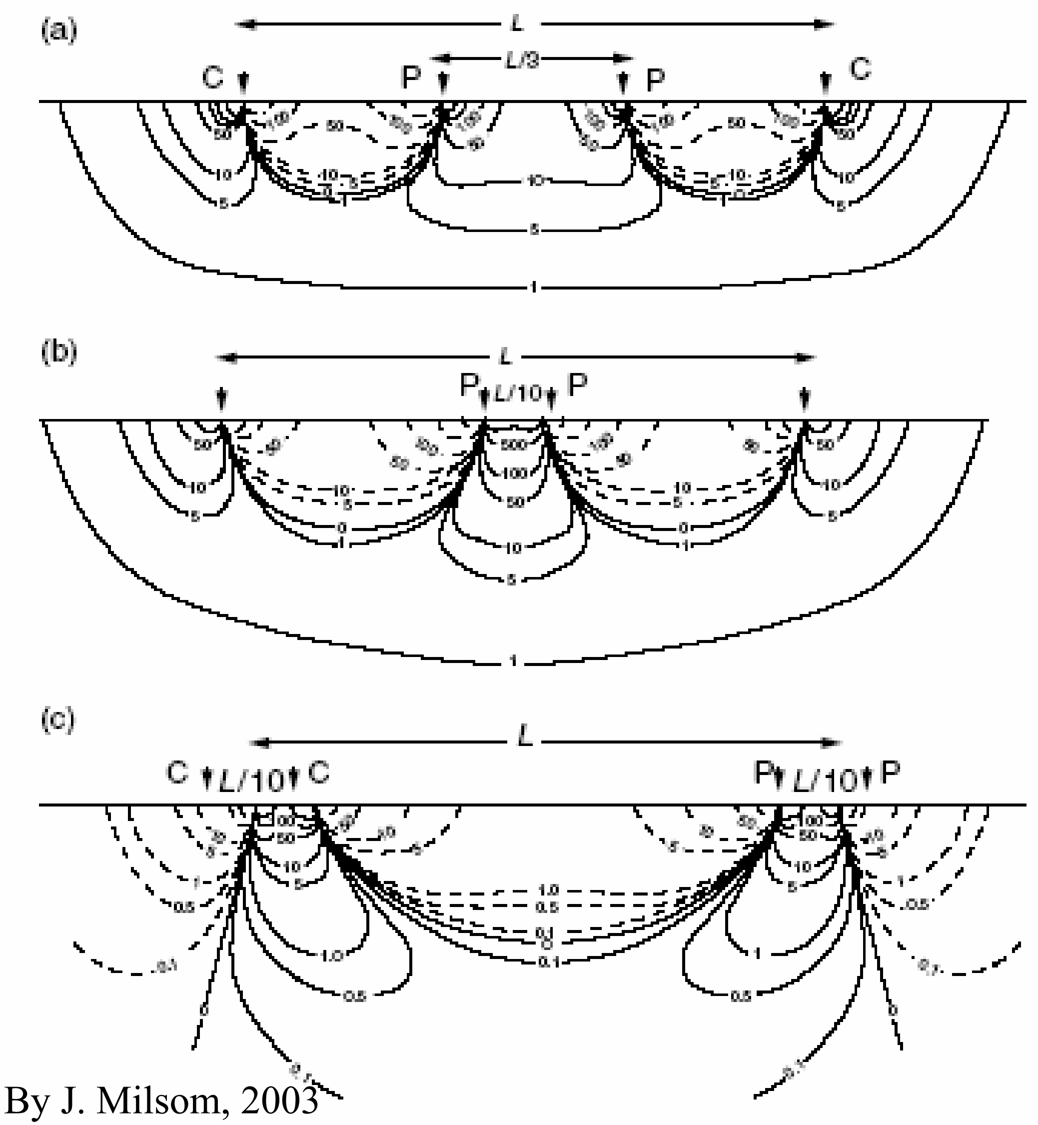
Raggio di penetrazione dei dispositivi dipolo-dipolo

$$r = \sqrt{\left(\frac{AB}{2}\right)^2 + R^2}$$

Electric field geometry

Signal contribution sections for
(a) Wenner;
(b) Schlumberger
(c) dipole–dipole arrays.

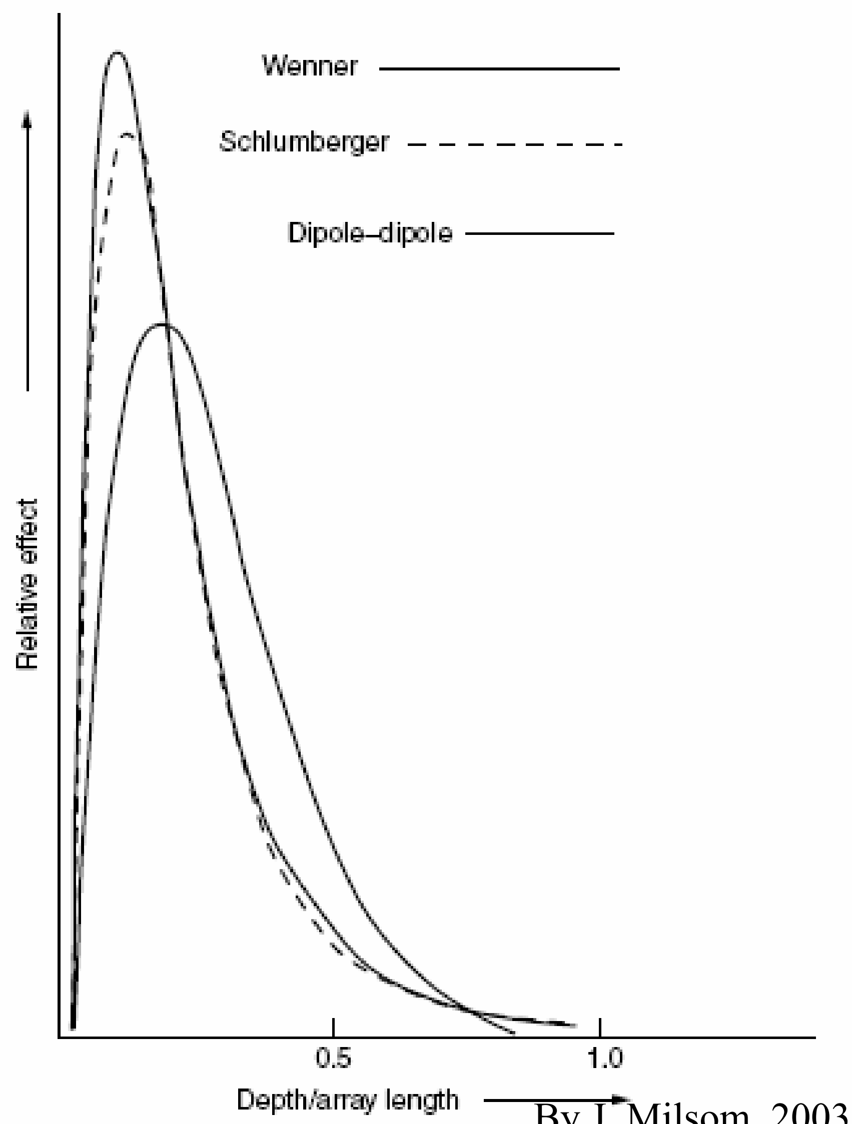
Contours show relative contributions to the signal from unit volumes of homogeneous ground. Dashed lines indicate negative values.



By J. Milsom, 2003

Voltage, depth

Relative effect of a thin, horizontal high-resistance bed in otherwise homogeneous ground. The areas under the curves have been made equal, concealing the fact that the voltage observed using the Schlumberger array will be somewhat less, and with the dipole–dipole array very much less, than with the Wenner array.



By J. Milsom, 2003

Arrays considerations

Wenner: - the best vertical resolving power (the most sharply peaked curves),locates flatlying interfaces more accurately;
- the least penetrative array;

Arrays considerations

Schlumberger:
- good vertical resolving power;
- best for depth sounding;
- small signal strength (the voltages measured are always less than those for a Wenner array of the same overall length);

Arrays considerations

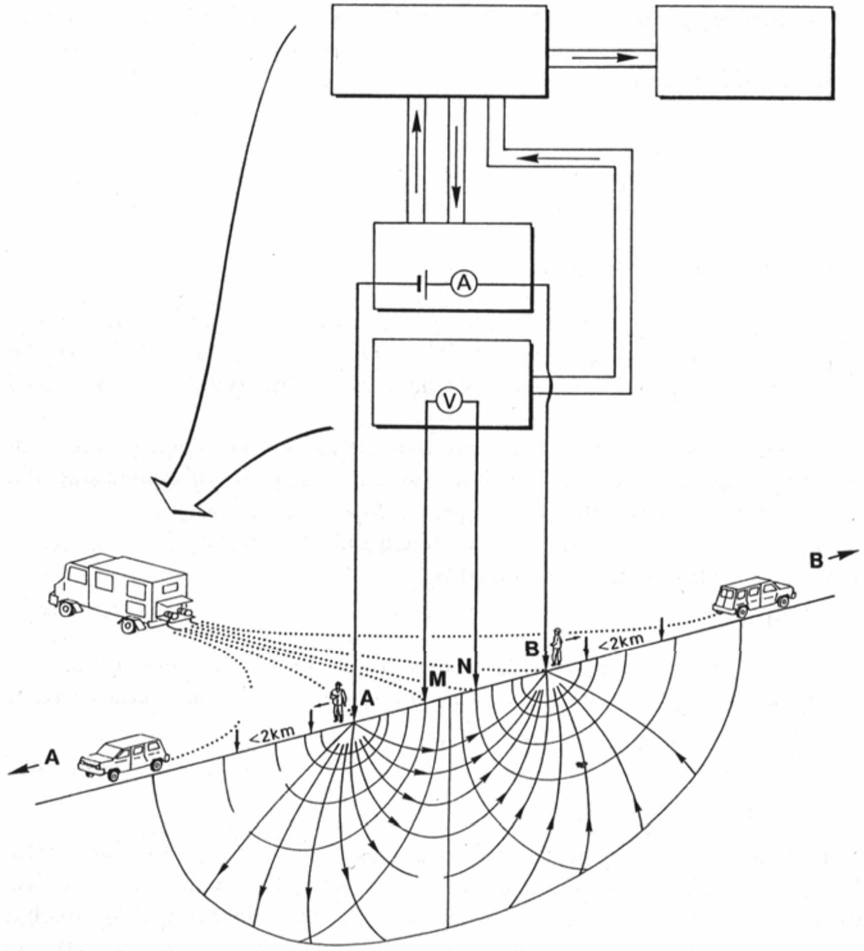
Dipole- dipole: - poor vertical resolution (signal-contribution contours for the dipole–dipole array are near vertical in some places at considerable depths,

- Best horizontal resolution (best suited to mapping lateral changes);
- the most penetrative array;
- complete separation of current and voltage circuits reduces the vulnerability to inductive noise.
- small signal strength (is smaller than for the Wenner by a factor of three)
- mainly used in IP work, where induction effects must be avoided at all costs. Four electrodes have to be moved and the observed voltages are usually very small;
- best for depth pseudo-sections, much used in IP surveys;

Noise

Noise due to induction in the cables and also to natural voltages, which may vary with time and so be incompletely cancelled by reversing the current flow and averaging. Large separations and long cables should be avoided if possible, but the most effective method of improving signal/noise ratio is to increase the signal strength (physical limits to the amount of current any given instrument can supply to the ground).

To cancel telluric and SP noise, ‘DC’ measurements are taken with current reversed at intervals of the order of a few seconds, while the ‘high’ frequencies are usually kept below 10 Hz to minimize electromagnetic induction.


A
V
B
M
N
A
B
<2km
<2km
A
B

Profili di resistività (SEO)

- Profili convenzionali (Wenner, Schumberger,…)
- Profili tripolari
- Profili rettangolo

Scelta dell'apertura AB

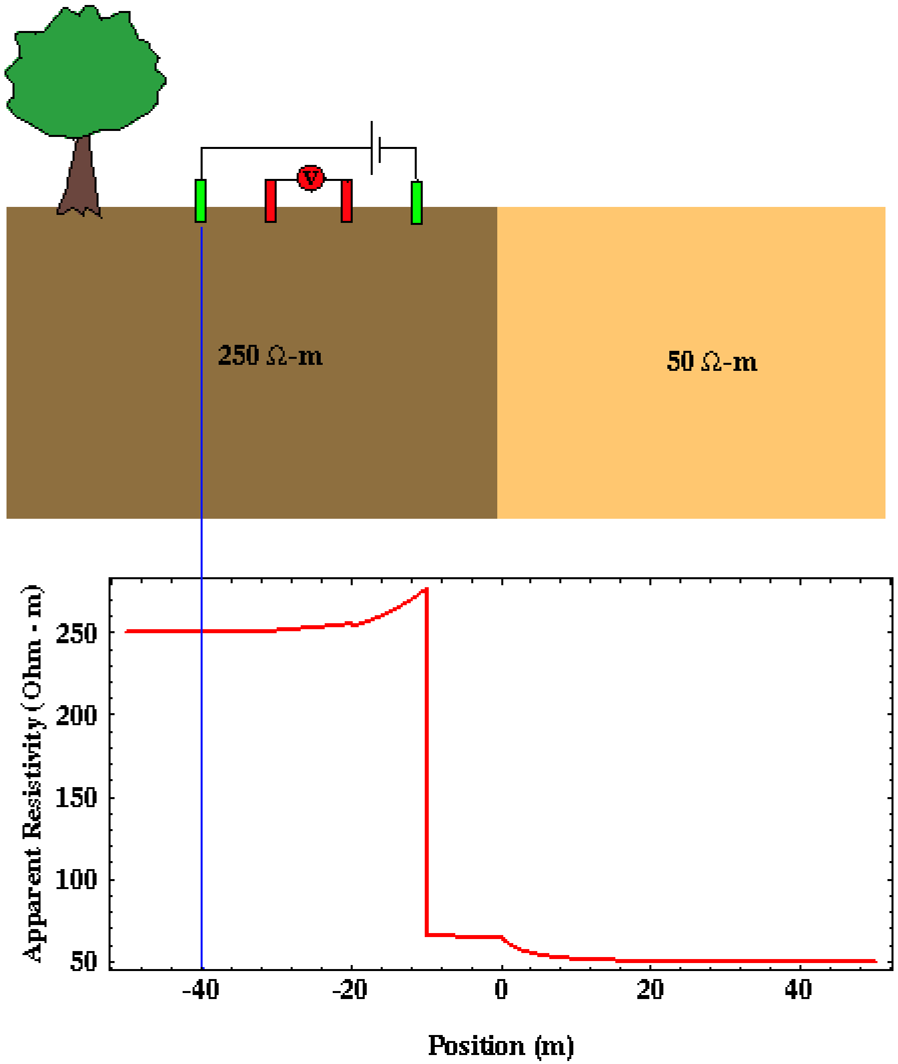
Scelta dell'MN

- Profili multielettrodici

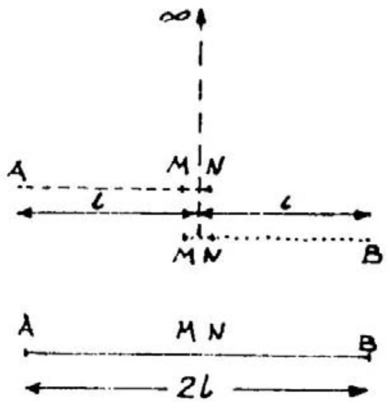
Colpo di presa

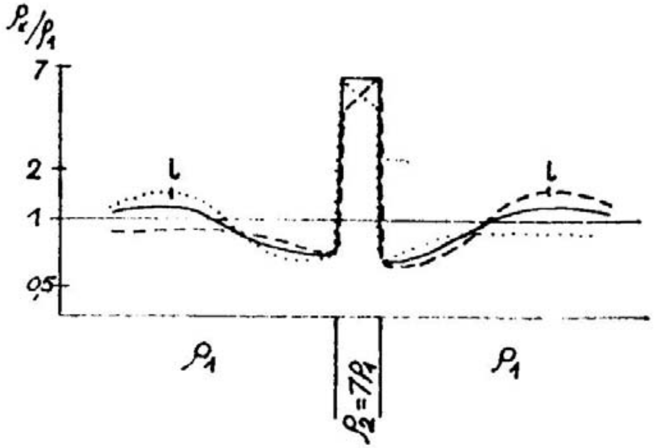
Disposizione e scelta del tipo di array

a seconda della problematica e del contesto

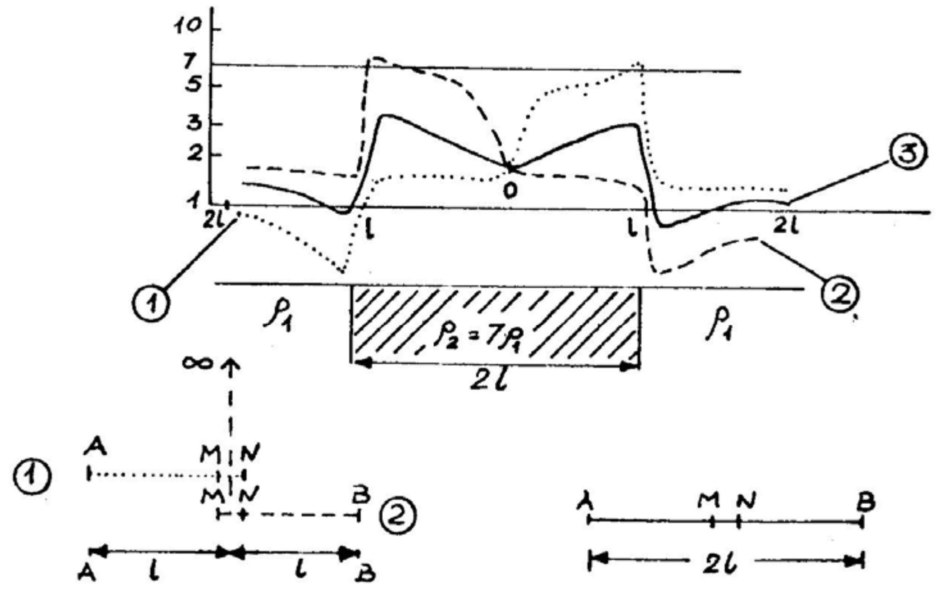


By Colorado
School of Mines

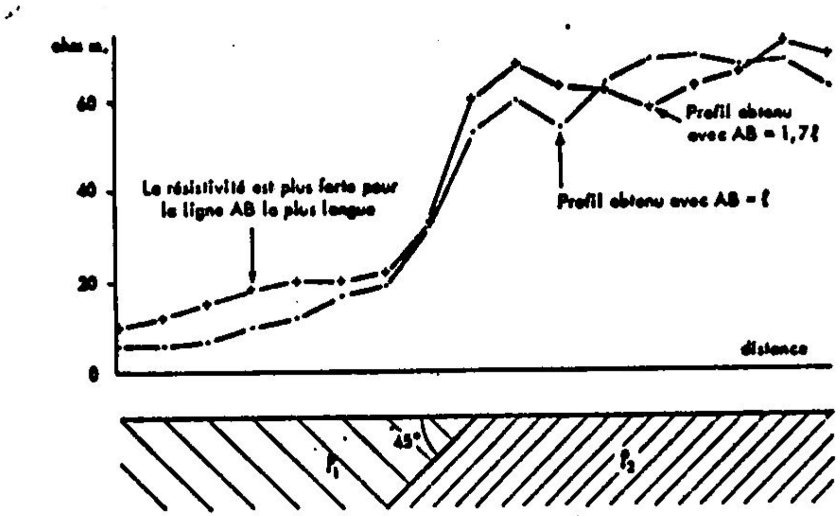




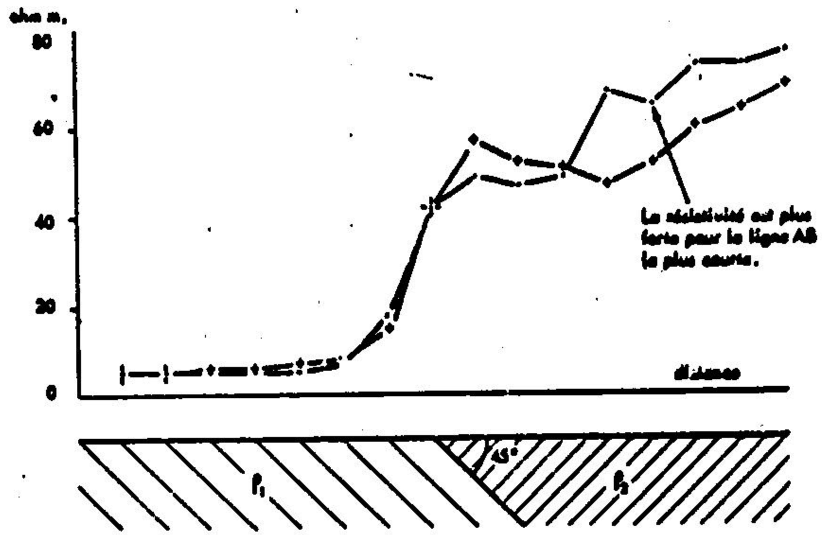
Profili convenzionali



Profili multielettrodici



Biseau conducteur ($\rho_1 < \rho_2$)



Biseau résistant ($\rho_1 < \rho_2$)

Profili rettangolo

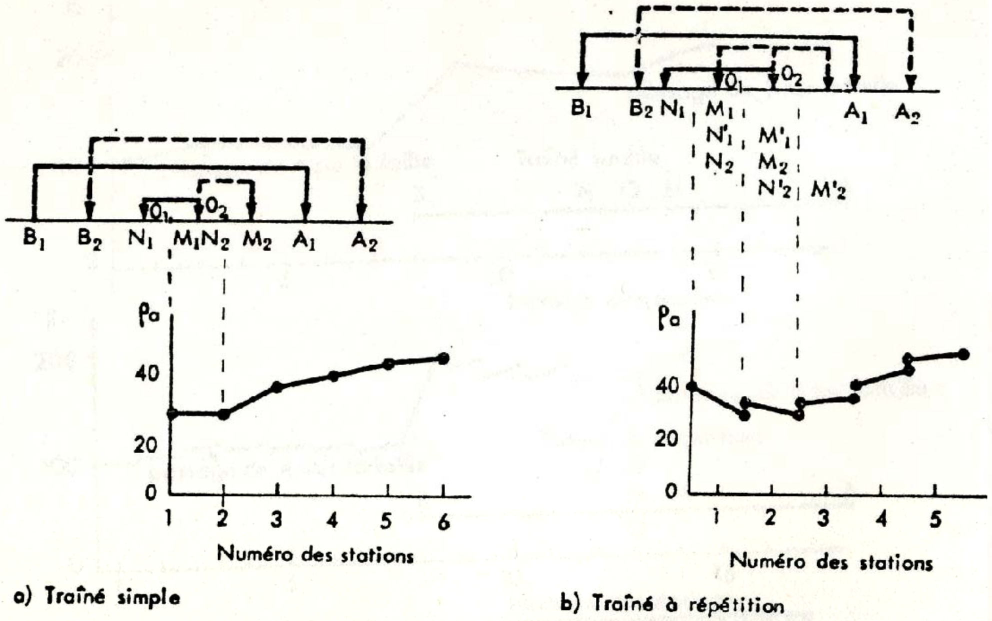


Fig. 62. — *Réalisation des profils de résistivité avec une ligne AB mobile.*

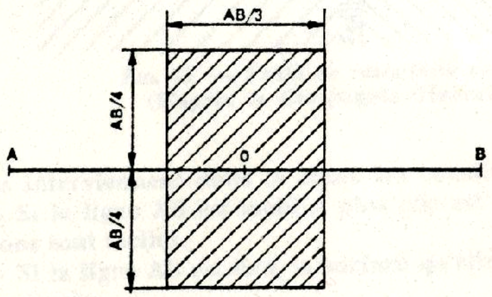


Fig. 63.

***Réalisation des profils de résistivité avec une ligne AB fixe.* Le rectangle hachuré représente la zone qui peut être prospectée à partir d'une position donnée de la ligne AB.**

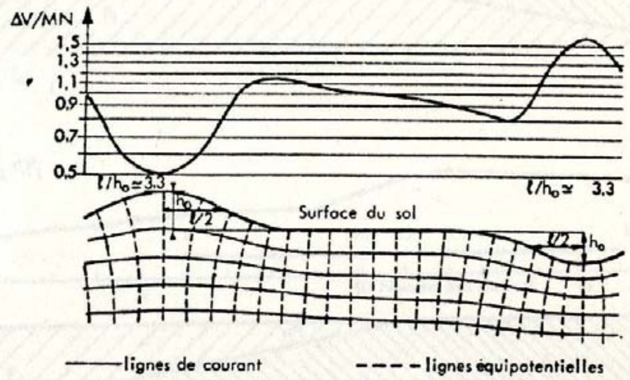
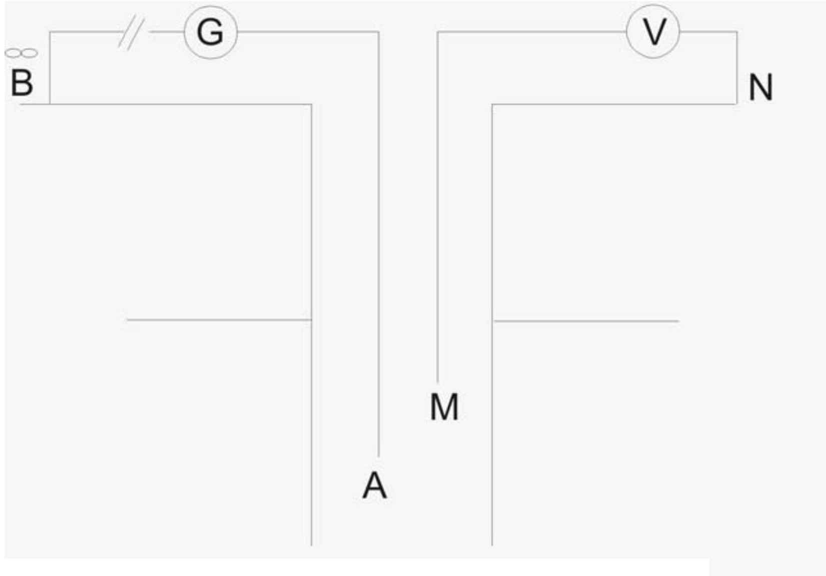
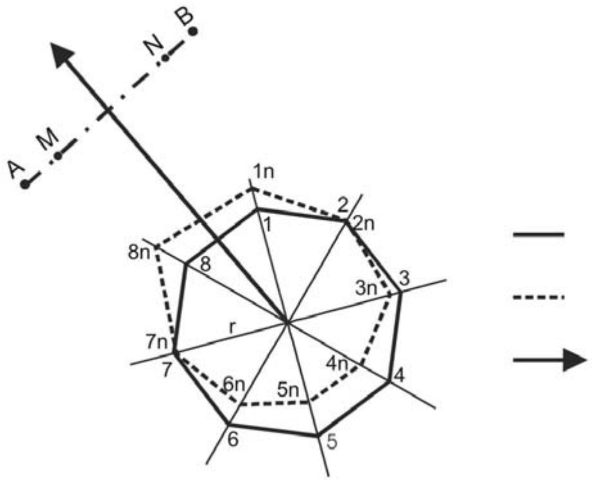


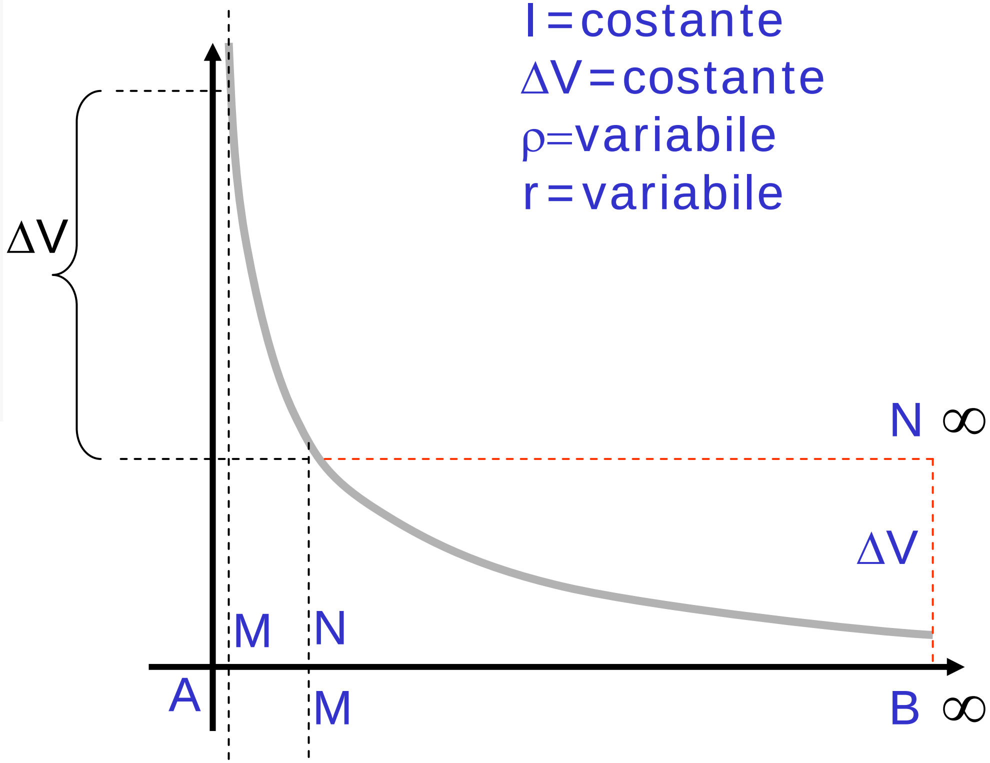
Fig. 64. — ***Influence de la topographie.* Cas d'un terrain homogène.**
(D'après G. Kunetz.)

Sondaggio gradiente e determinazione della velocità di falda





I=costante
ΔV=costante
ρ=variabile
r=variabile



$$\Delta V = \frac{\rho\, I\, MN}{2\pi}$$

Resistivity Depth-sounding (SEV)

Resistivity depth-soundings investigate layering, using arrays in which the distances between some or all of the electrodes are increased systematically;

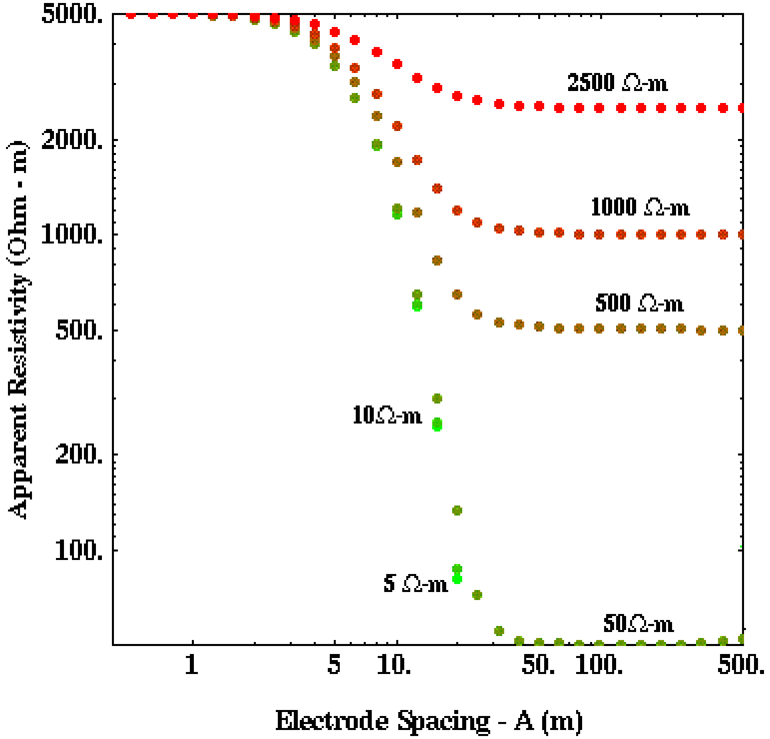
Apparent resistivities are plotted against expansion on log-log paper and matched against type curves.

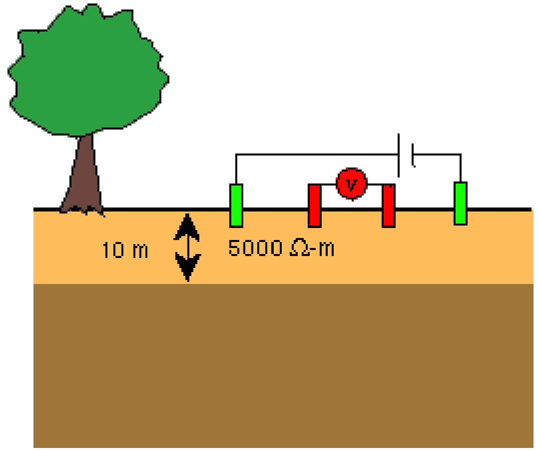
Expansion is still generally in steps that are approximately or accurately logarithmic. The half-spacing sequence 1, 1.5, 2, 3, 5, 7, 10,15 . . . is convenient, but some interpretation programs require exact logarithmic spacing.

Resistivity Depth-sounding

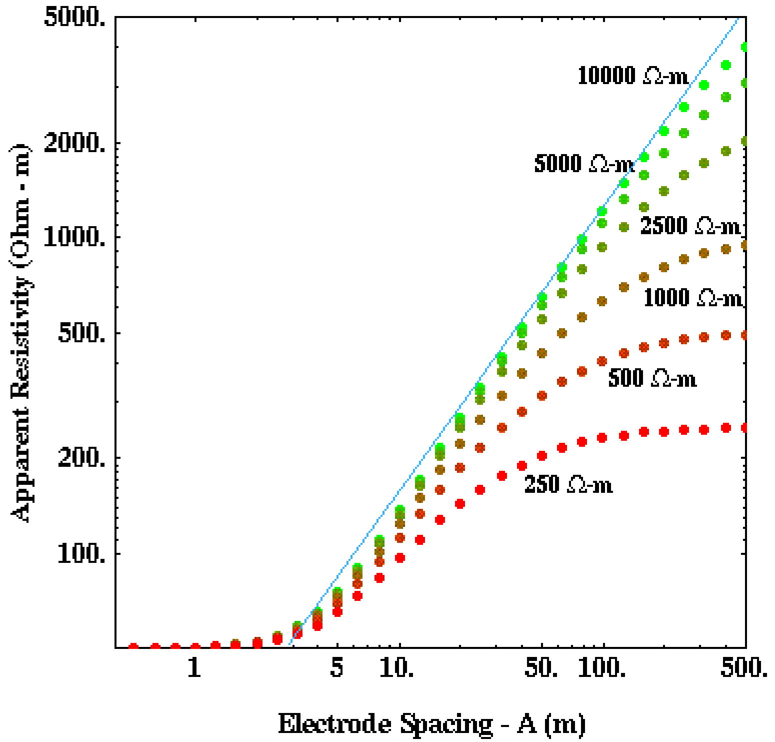
In principle a Schlumberger array is expanded by moving the outer electrodes only, but the voltage will eventually become too small to be accurately measured unless the inner electrodes are also moved farther apart.

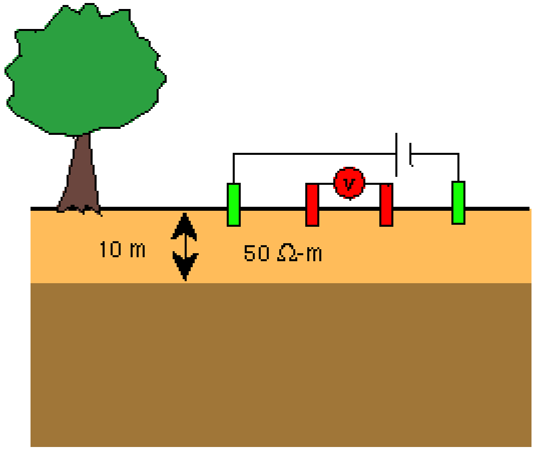
Even if the ground actually is divided into layers that are perfectly internally homogeneous, the segments will not join smoothly because the approximations made in using the dipole equation are different for different *l/L* ratios. This effect is generally less important than the effect of ground inhomogeneities.





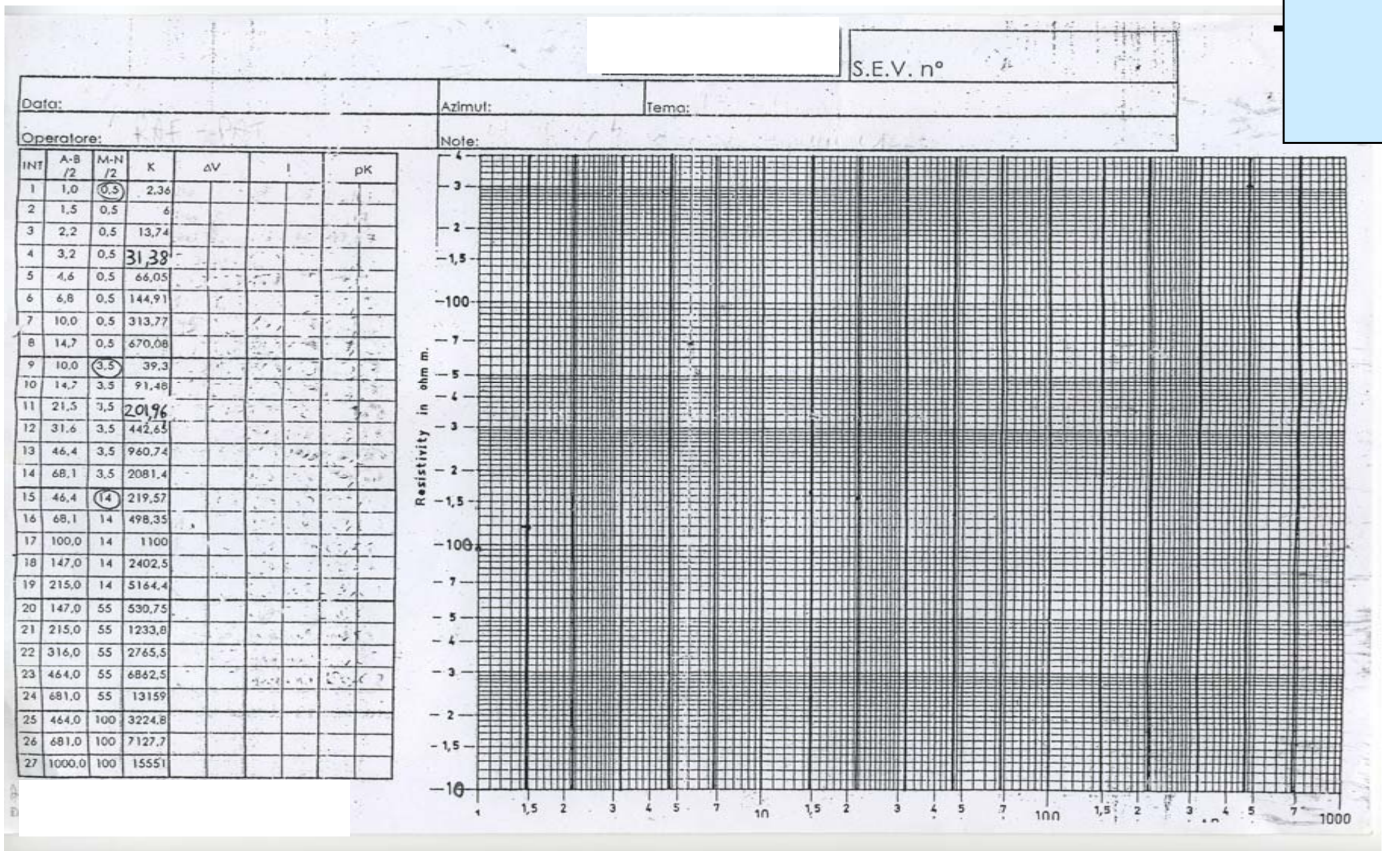
By Colorado School of Mines





By Colorado School of Mines

Sondaggio verticale (SEV)



S.E.V. n°

Data:

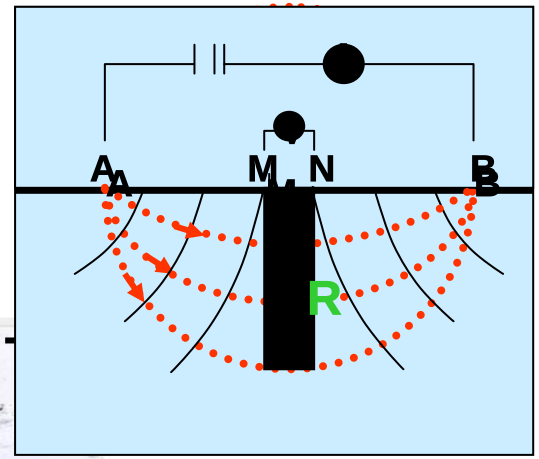
Azimut:

Tema:

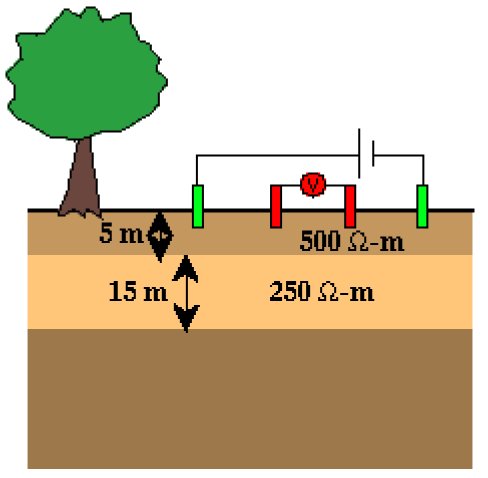
Operatore:

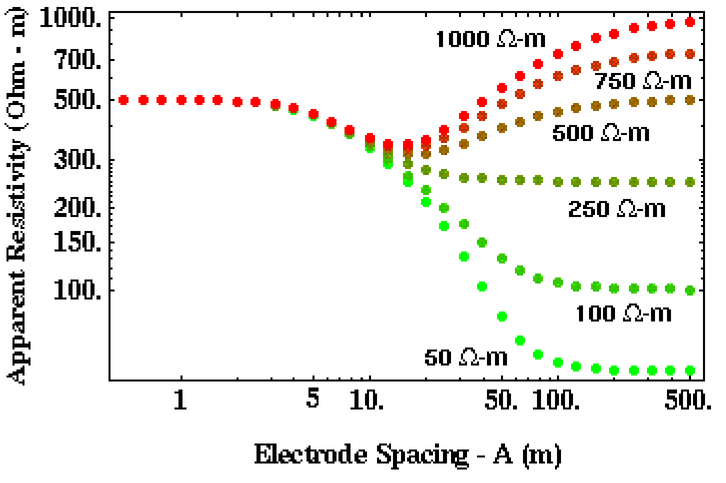
Note:

INT	A-B /2	M-N /2	K	ΔV	I	ρK
1	1,0	0,5	2,36			
2	1,5	0,5	6			
3	2,2	0,5	13,74			
4	3,2	0,5	31,38			
5	4,6	0,5	66,05			
6	6,8	0,5	144,91			
7	10,0	0,5	313,77			
8	14,7	0,5	670,08			
9	10,0	3,5	39,3			
10	14,7	3,5	91,48			
11	21,5	3,5	201,96			
12	31,6	3,5	442,65			
13	46,4	3,5	960,74			
14	68,1	3,5	2081,4			
15	46,4	14	219,57			
16	68,1	14	498,35			
17	100,0	14	1100			
18	147,0	14	2402,5			
19	215,0	14	5164,4			
20	147,0	55	530,75			
21	215,0	55	1233,8			
22	316,0	55	2765,5			
23	464,0	55	6862,5			
24	681,0	55	13159			
25	464,0	100	3224,8			
26	681,0	100	7127,7			
27	1000,0	100	15551			

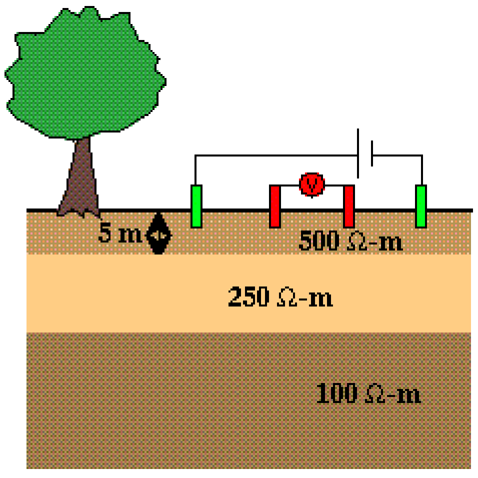


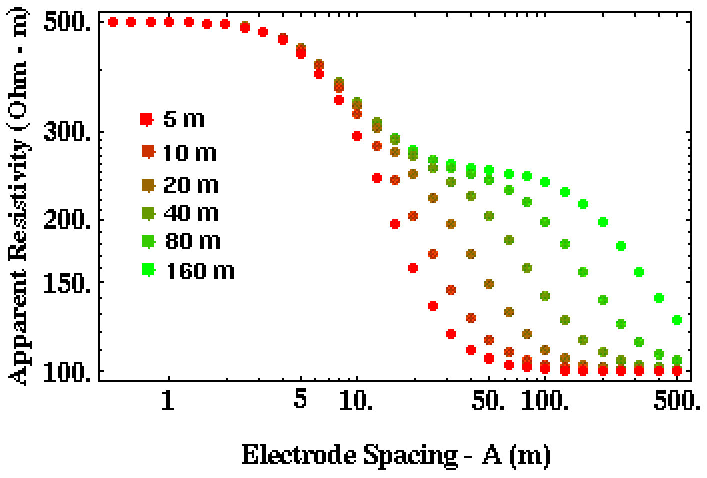
Acquisizione dati





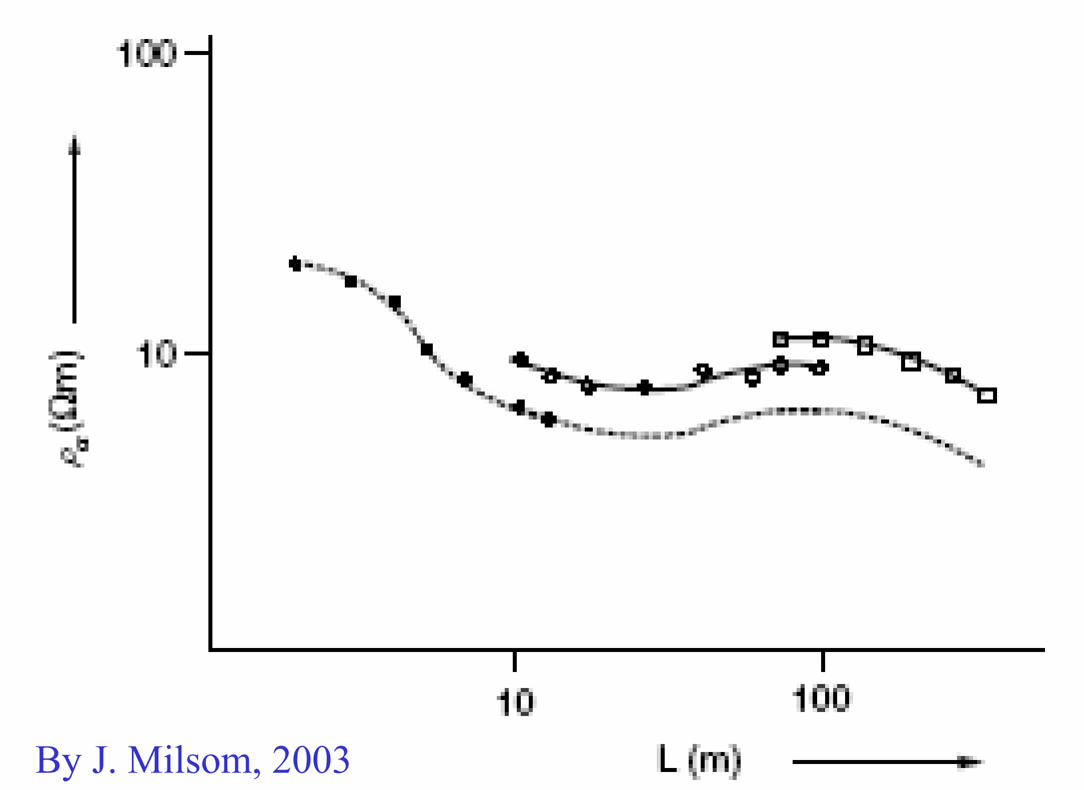
By Colorado
School of Mines





By Colorado School of Mines

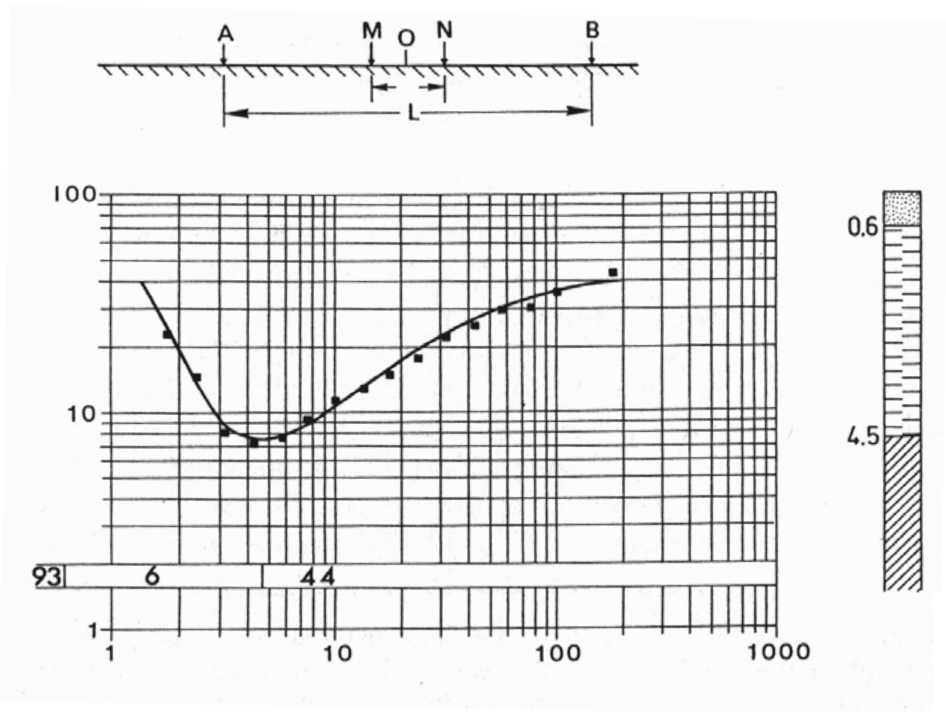
Resistivity Depth-sounding



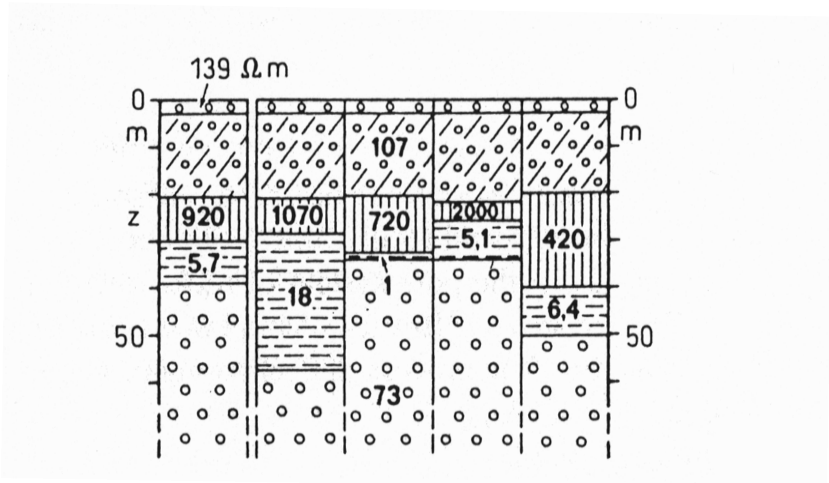
By J. Milsom, 2003

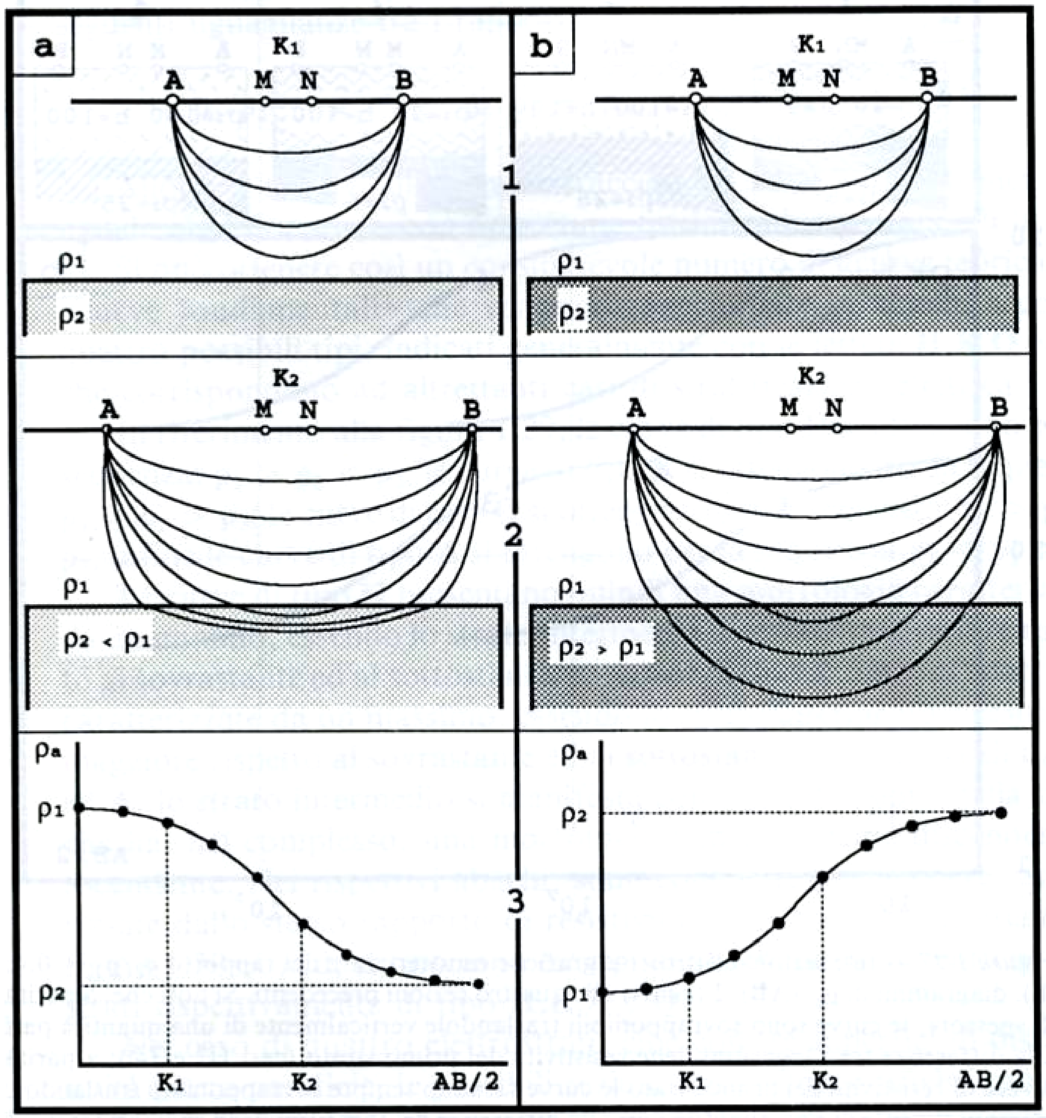
Construction of a complete Schlumberger depth-sounding curve (dashed line) from overlapping segments obtained using different innerelectrode separations.

Esempio di SEV



Esempio di sezione elettrostratigrafica ottenuta da SEV





Esempio di situazione a due strati:

a) caso in cui $r_1 > r_2$

b) caso in cui $r_1 < r_2$

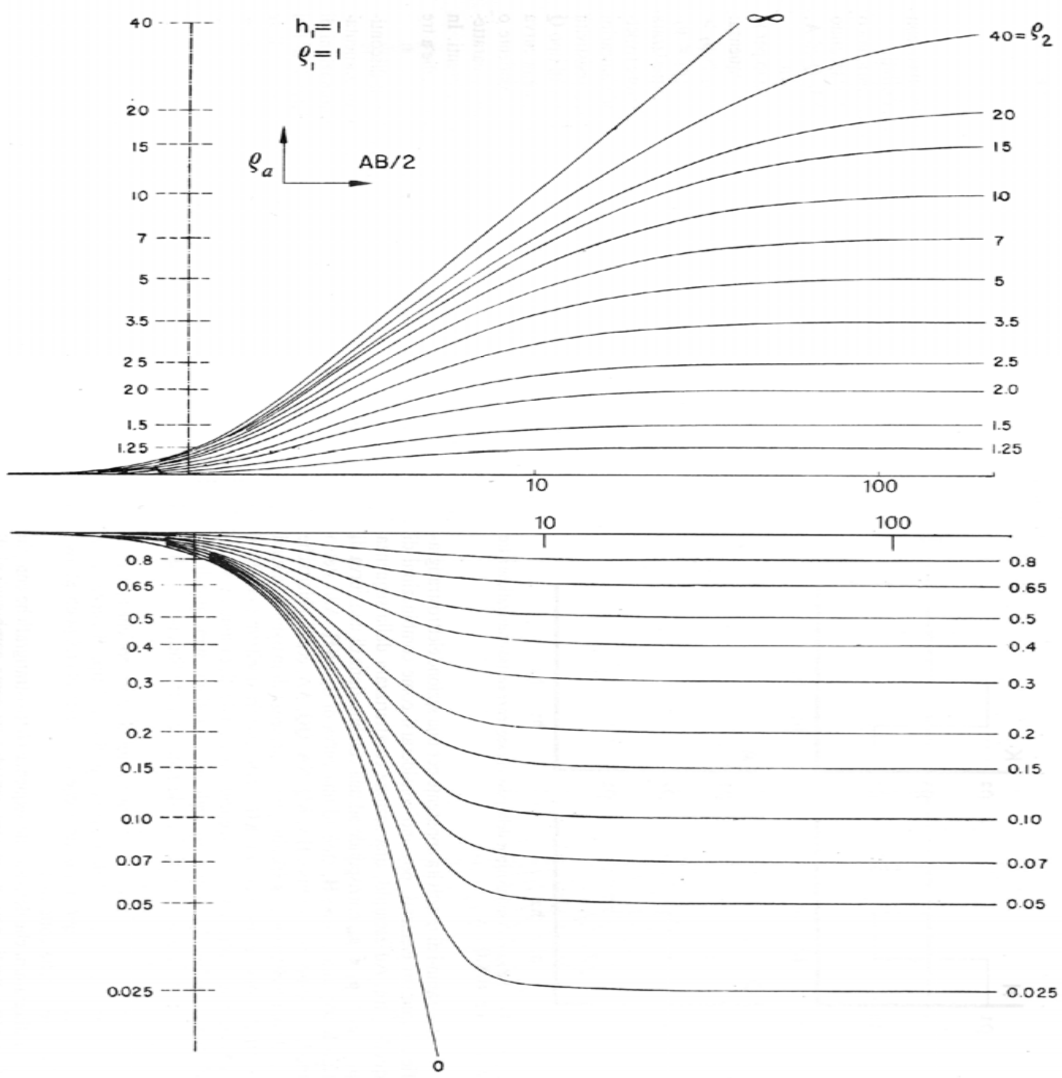


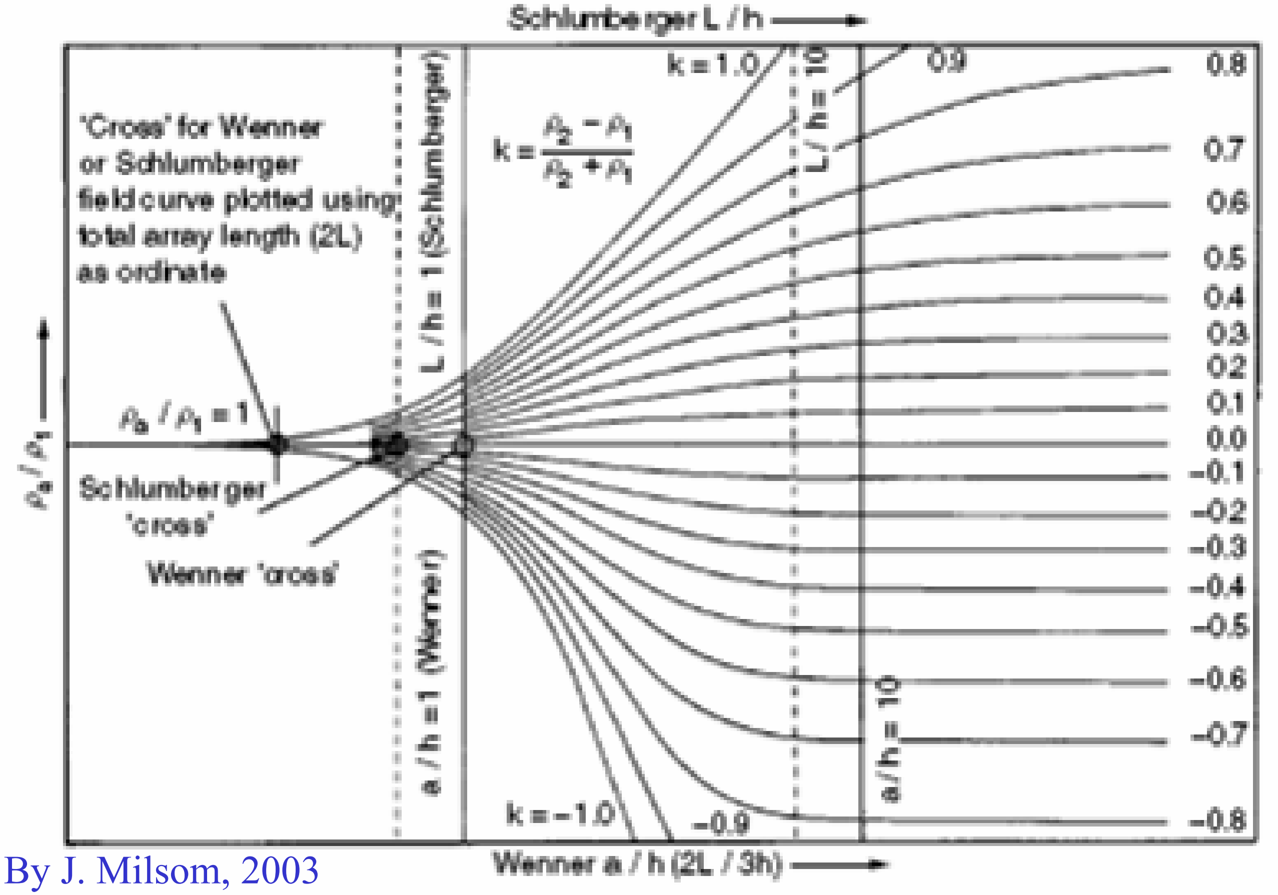
Figura 1.28b — Abaco di curve teoriche a due strati ($\rho_2 < \rho_1$). (da Orellana E., Mooney H.M., 1966, modificato).

Abaco di curve teoriche a due strati ($\rho_2 > \rho_1$)

Situazione a 2 strati

Situazione a 2 strati

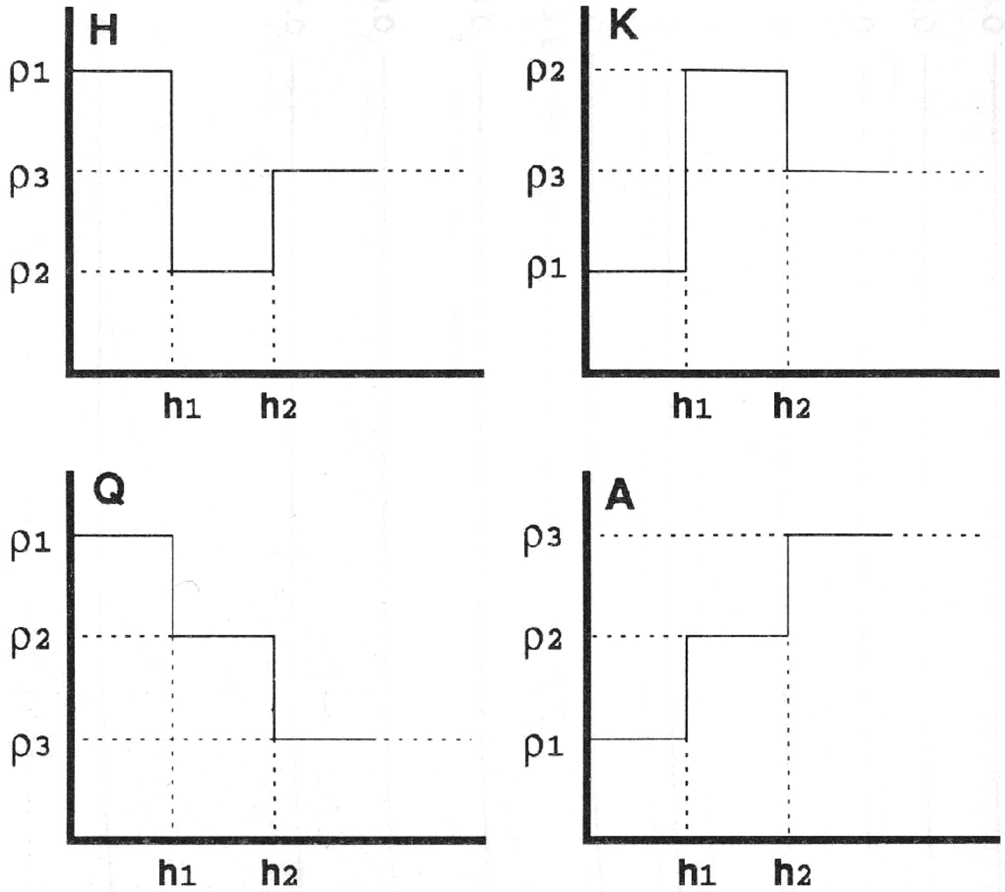
Abaco di curve teoriche a due strati ($\rho_2 < \rho_1$)



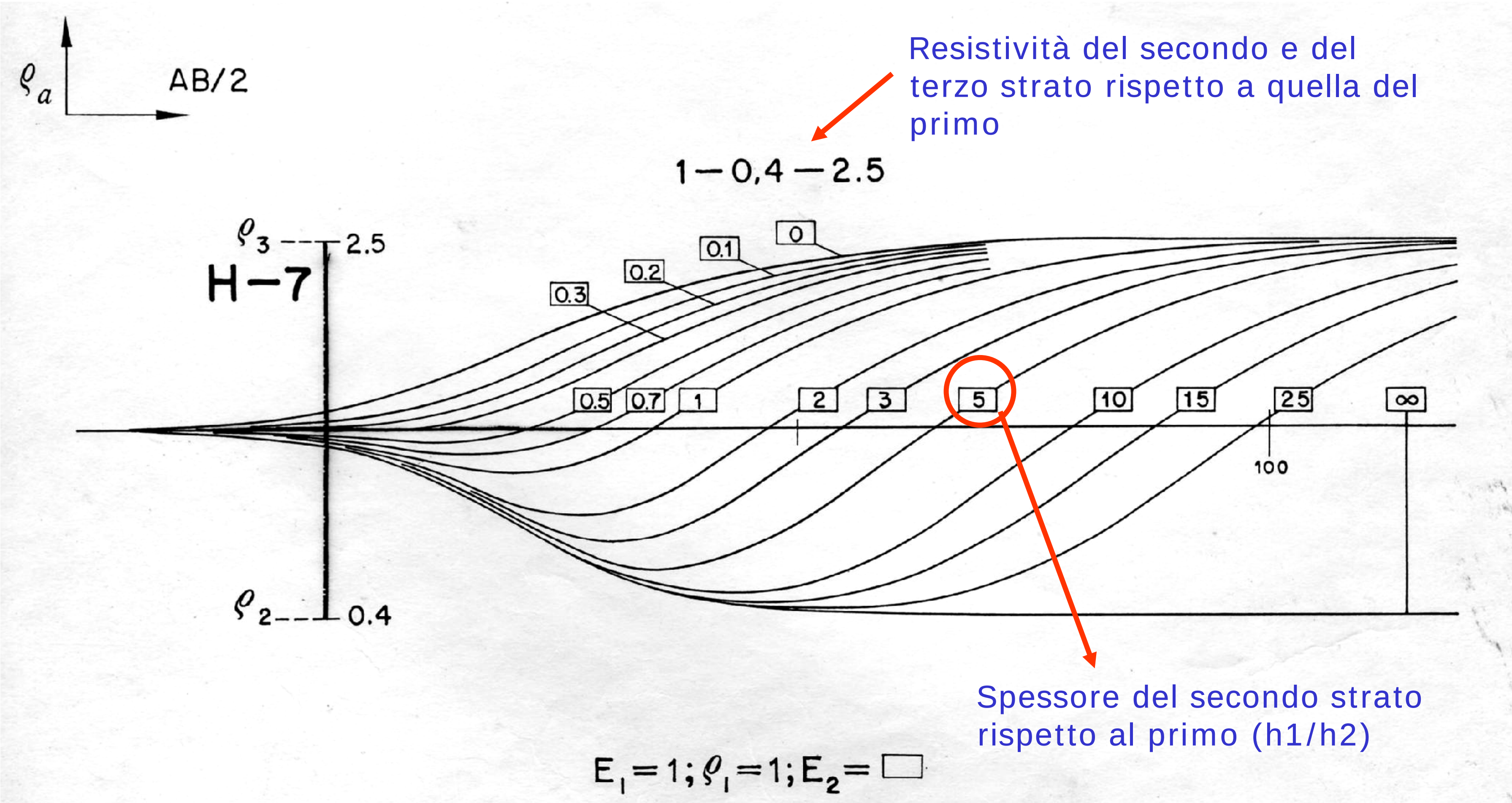
By J. Milsom, 2003

Two layer apparent resistivity type curves for the Wenner array

Tipi di curve a 3 strati



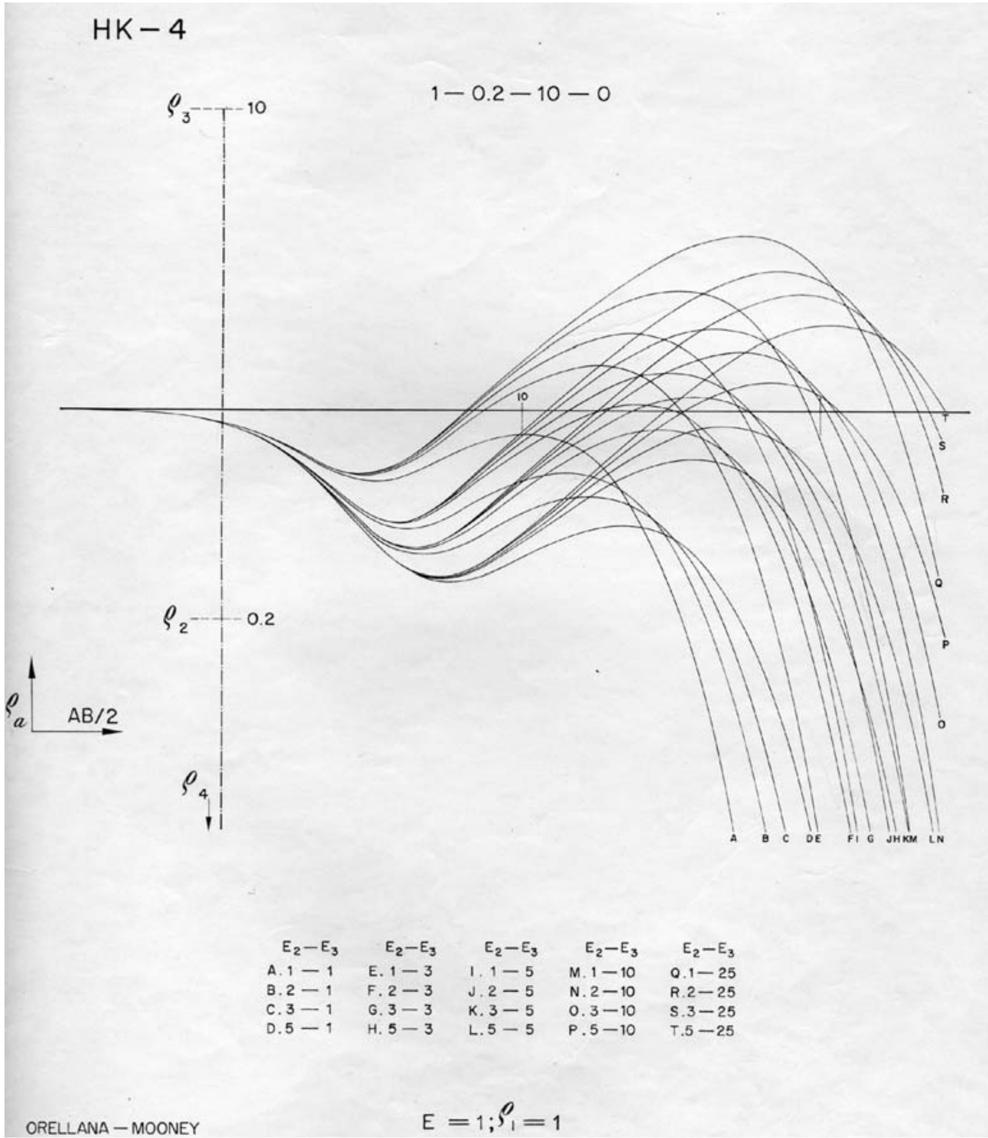
Abachi a 3 strati



Resistività del secondo e del terzo strato rispetto a quella del primo

Spessore del secondo strato rispetto al primo (h1/h2)

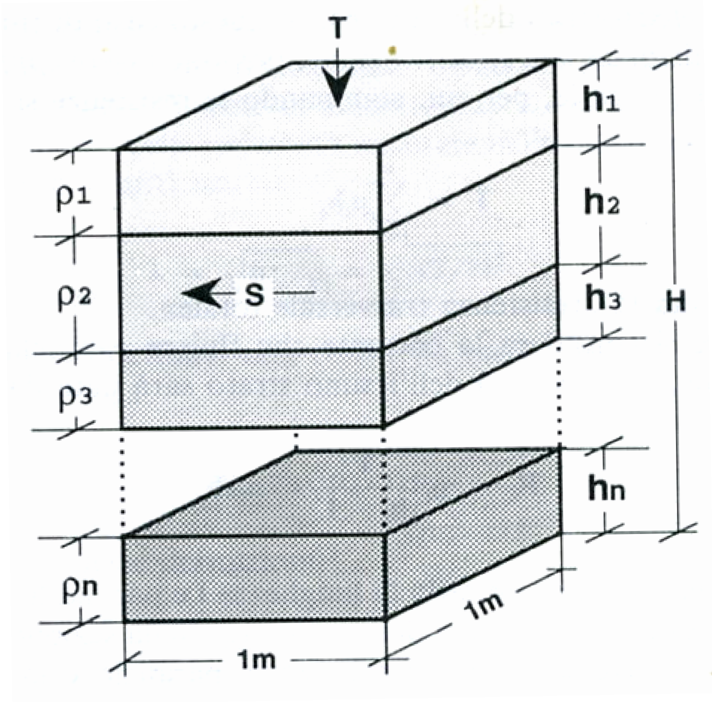
Abachi a 4 strati



Resistenza trasversale

$$T = \sum_{i=1}^{n} \rho_i h_i$$

Resistenza trasversale unitaria $R_i = \rho_i h_i$



Conduttanza longitudinale

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$$

Conduttanza longitudinale unitaria $\frac{1}{R_i'} = \frac{h_i}{\rho_i}$

⇩

Coefficiente di anisotropia

$$\lambda = \frac{\sqrt{ST}}{H}$$ dove $H = \Sigma h_i$

Resistività media $\rho_m = \sqrt{(T/S)}$

Legge dell'equivalenza

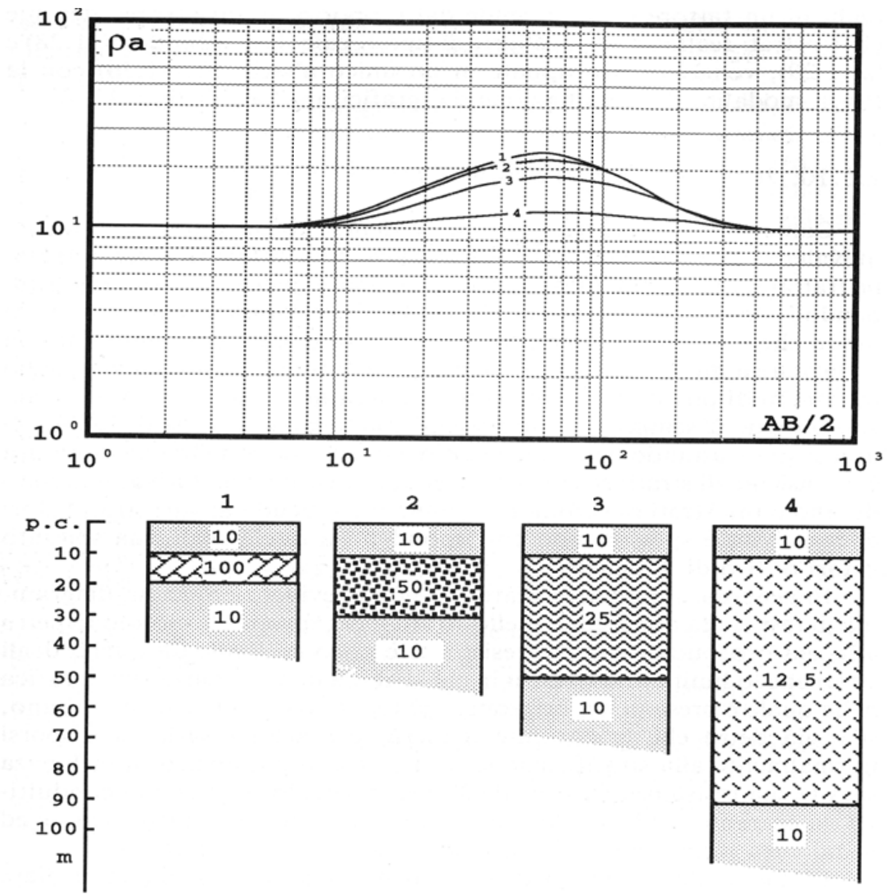


Figura 1.40a — Confronto tra curve di tipo **K** caratterizzate da identico valore di **T** per lo strato intermedio. I valori di **ρ** (in Ohm·m) e **h** (in m) sono riportati nel testo.

1)	$\rho_2 = 100$	$h_2 = 10$	$T = 1000$
2)	$\rho_2 = 50$	$h_2 = 20$	$T = 1000$
3)	$\rho_2 = 25$	$h_2 = 40$	$T = 1000$
4)	$\rho_2 = 12.5$	$h_2 = 80$	$T = 1000$

Date due situazioni di curve a tre strati ed ipotizzando che:

H1=h1'

ρ1=ρ1'

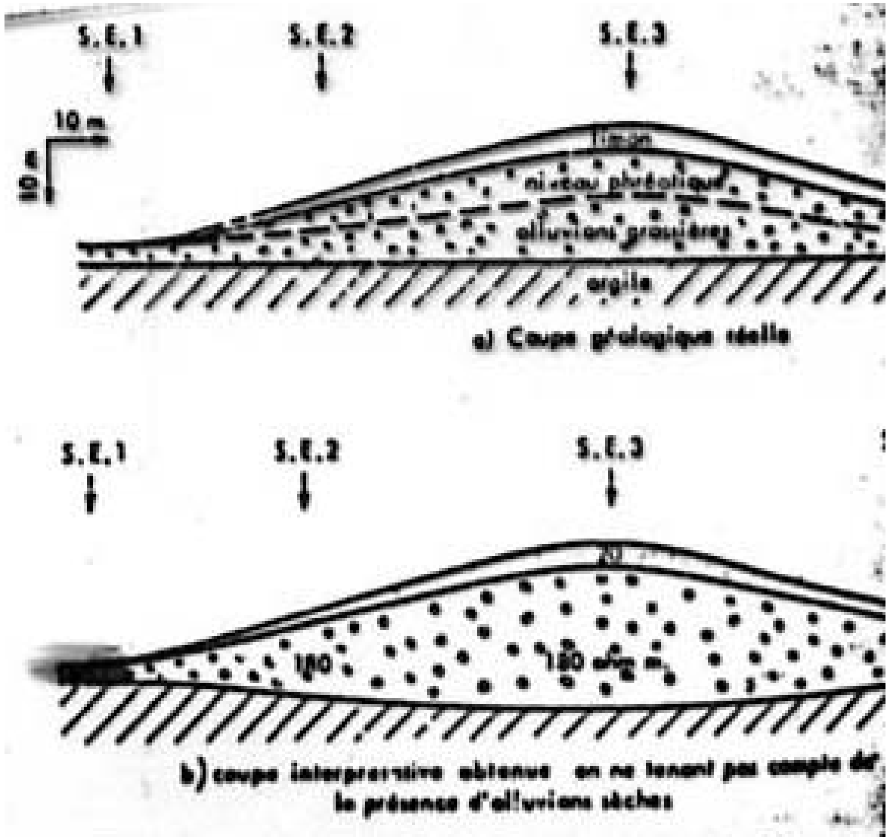
ρ3=ρ3'

Nel caso che, il secondo strato sia "piccolo", qualora, per le curve di tipo K e Q le resistenze trasversale T e T' del secondo strato siano uguali, le curve risulteranno indistinguibili. Per le curve di tipo A e H ciò si verifica quando le conduttanze longitudinali S e S' del secondo strato coincidono. Nel caso di tre strati "piccolo" significa che il rapporto h2/h1<0,4; nel caso di più strati un qualsiasi strato diventa piccolo quando il rapporto:

h2/Σh1 x λ <0,4.

Legge della soppressione degli strati

Nelle curve di tipo A e Q, se il secondo strato è piccolo la curva risulta coincidente con una curva a due strati. Il margine di errore provocato da questa soppressione è di discreta entità.



Situazioni equivalenti

Fattore di formazione - rocce non argillose

$$F = \frac{\rho}{\rho_a}$$

$$F = \frac{\alpha}{pm}$$

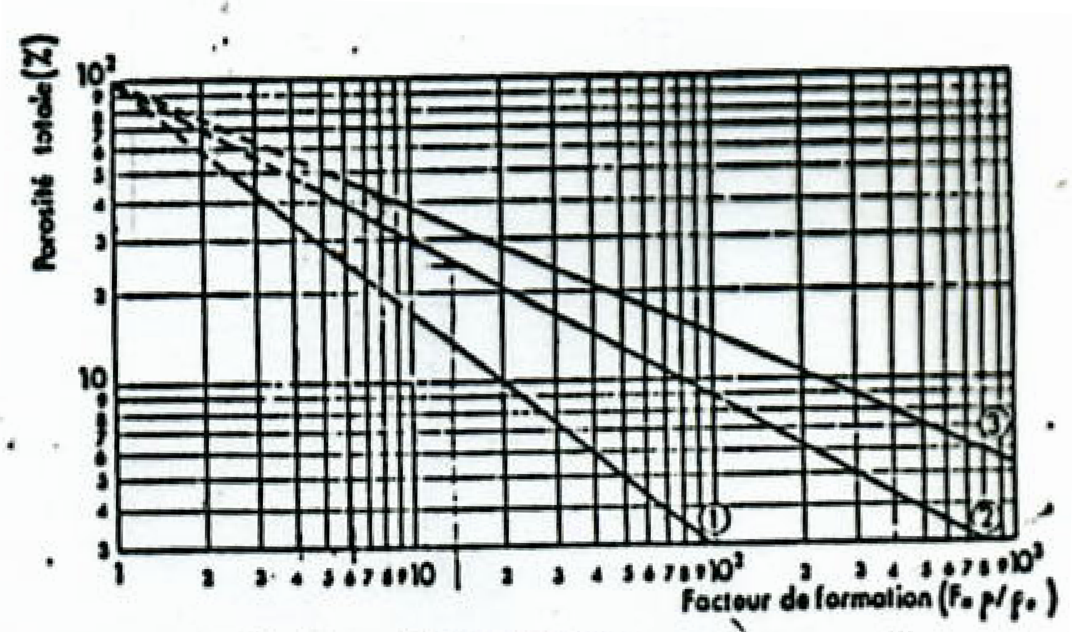


Fig. 138. — Courbes donnant la porosité totale d'une formation aquifère saturée non argileuse en fonction du facteur de formation F.

Courbe 1 : formation meuble.
Courbe 2 : roche consolidée à porosité d'interstices.
Courbe 3 : roche consolidée à porosité de fissures.

il fattore di formazione è inversamente proporzionale alla porosità

Abaco che mette in relazione la porosità totale con il fattore di formazione per tipi di rocce differenti

Rocce argillose

$$\frac{1}{\rho} = \frac{a}{\rho_{ar}} + \frac{1-a}{\rho_a}$$

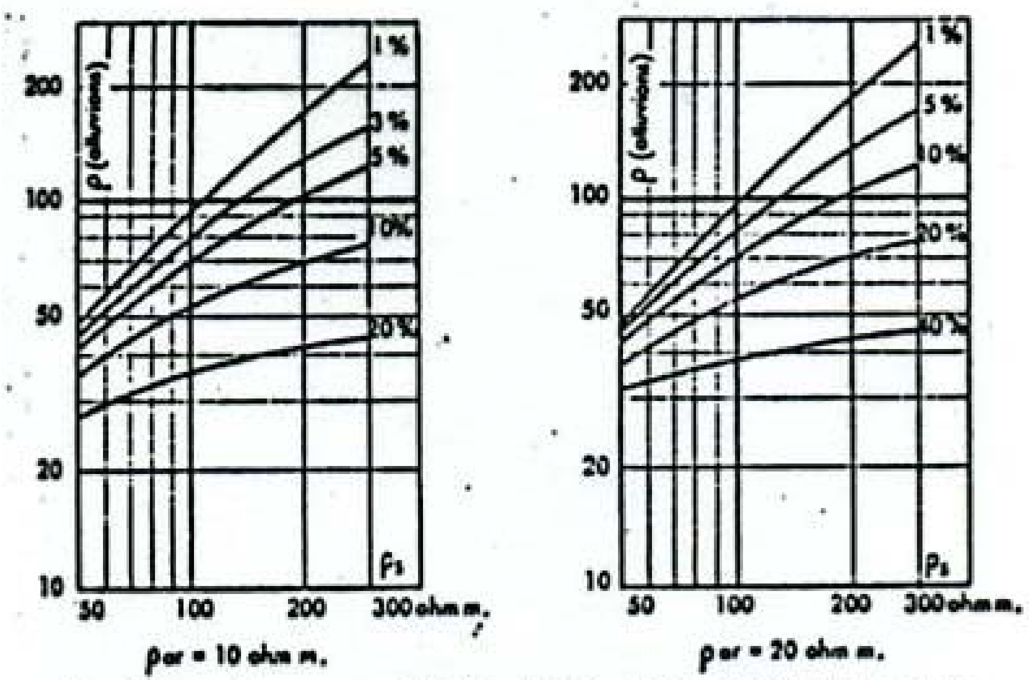


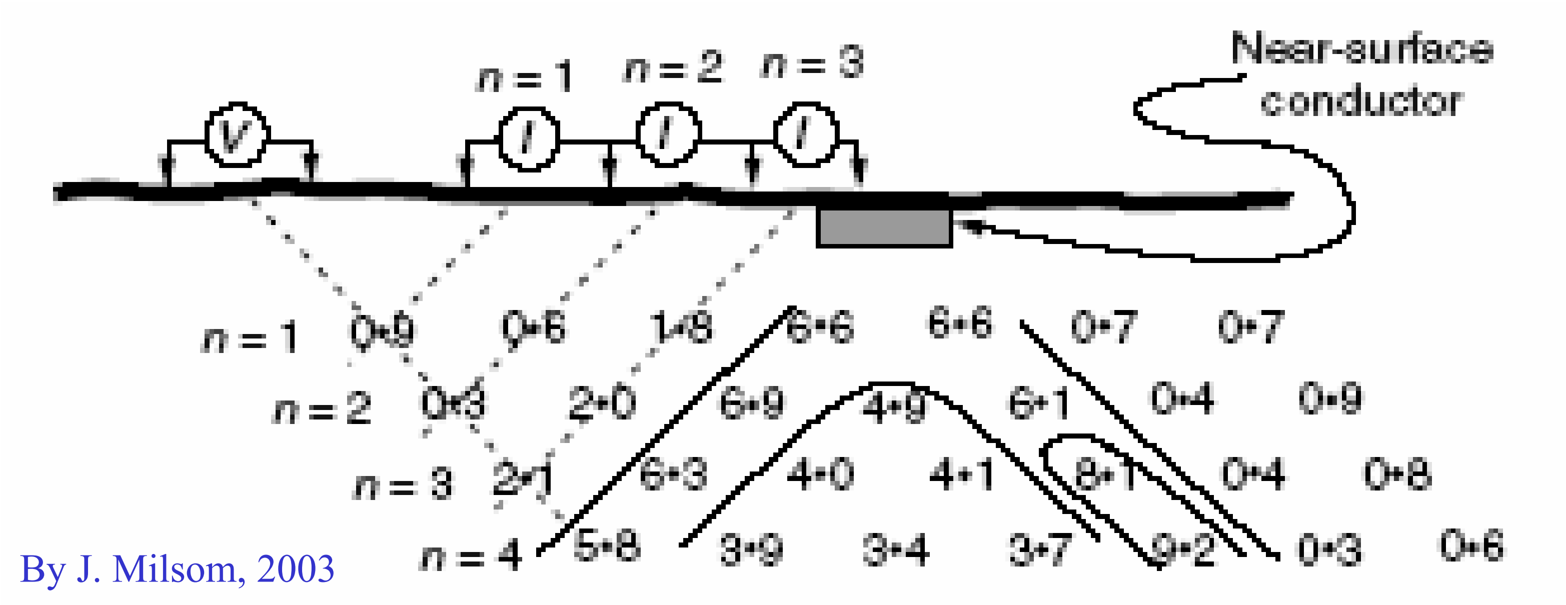
FIG. 130. — *Abaques pour la détermination de la résistivité des sables (ρs) d'alluvions formées d'une alternance de strates de sables et d'argiles* (les pourcentages indiqués sur les courbes se rapportent aux argiles).

Per le rocce argillose non si può utilizzare il fattore di formazione perché il comportamento di queste è equivalente a quello di un elettrolita debole ed il rapporto r/r_a (F) può risultare minore di 1.

Nel caso di rocce costituite da sabbie ed argille, qualora si conosca il valore di resistività dei due mezzi allo stato puro, è possibile prevedere la resistività delle relative miscele.

Resisitivity pseudo-sections

The relationships between the positions of highs on pseudosections and source body locations are even less simple with dipole–dipole than with Wenner arrays. In particular, the very common *pant's leg* anomaly is usually produced by a near-surface body with little extent in depth; every measurement made with either the current or the voltage dipole near the body will record high chargeability.



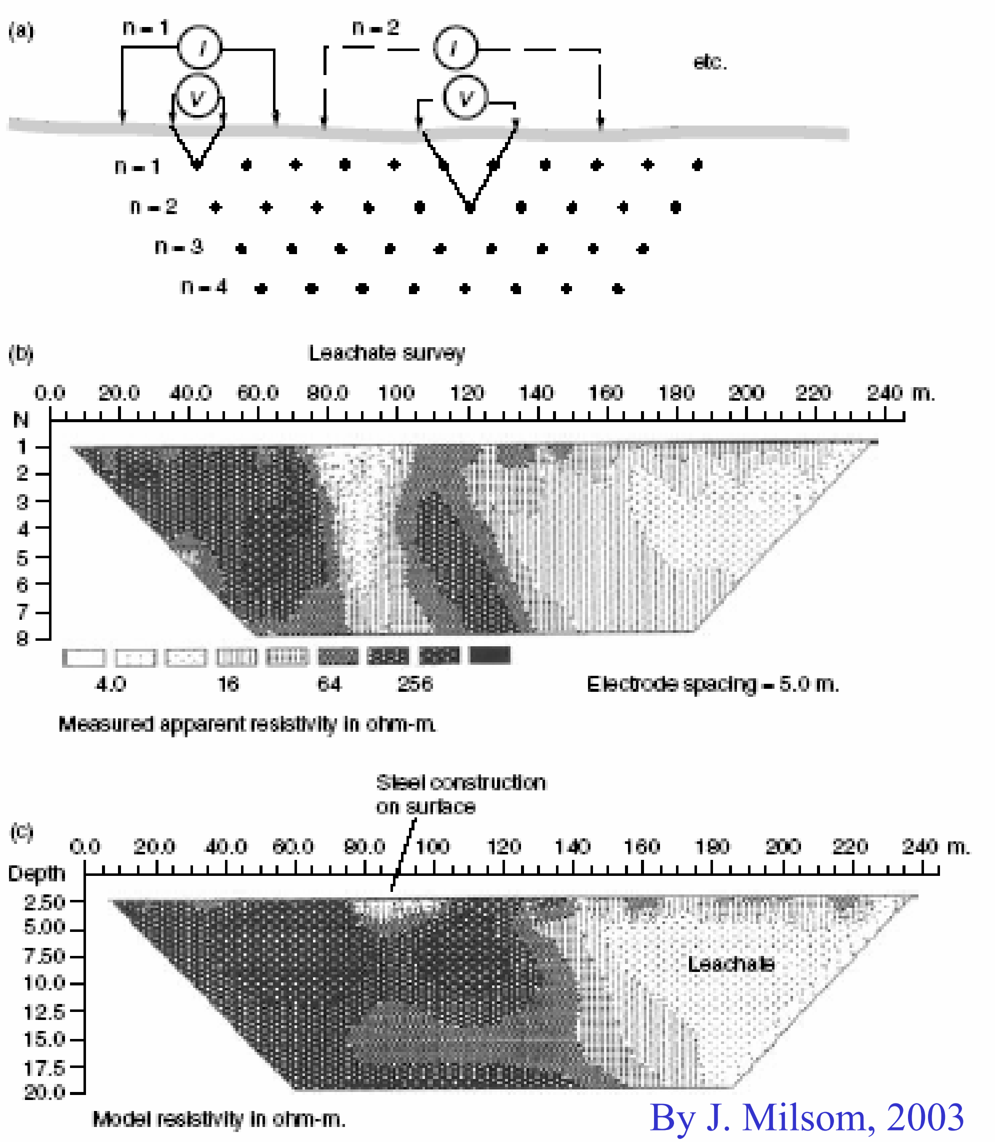
By J. Milsom, 2003

Resisitivity pseudo-sections

Wenner array pseudo-sections.

(a) Plotting system;
(b) 'raw' pseudo-section;
(c) pseudo-section after inversion.

The low-resistivity (white) area at about 90 m was produced by a metal loading bay and railway line, i.e. by a source virtually at the ground surface.

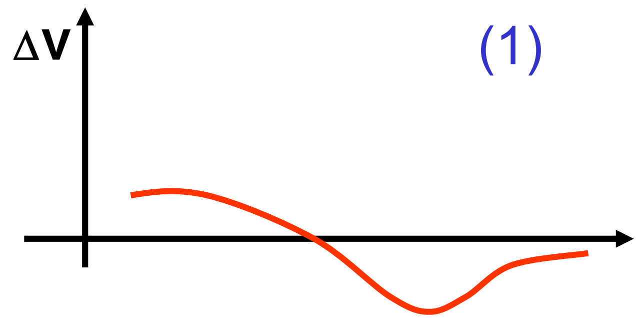


By J. Milsom, 2003

Potenziali spontanei

ΔV costante | ΔV ciclicamente variabile | ΔV variabile

- Potenziale di mineralizzazione (red-ox) (1)
- Potenziale di membrana (2)
- Potenziale di elettrofiltrazione (3)



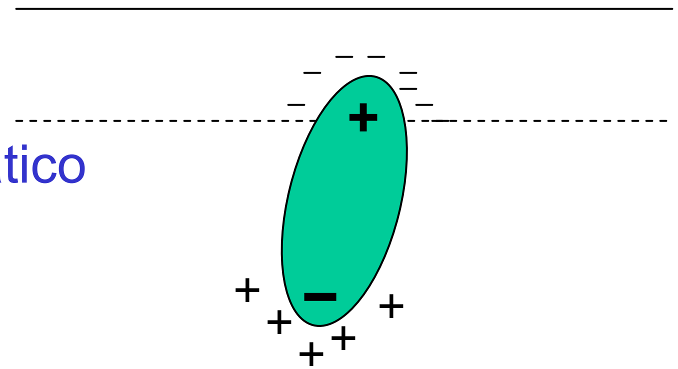
(1)

(1)

mineralizzazione

$$DV_0 = \frac{RT}{nF} L_N \frac{C_0}{C_r}$$

Livello idrostatico



Potenziali spontanei

(2*a*)

membrana cationica

$$\Delta V_a = \frac{RT}{nF} L_n \frac{C_0}{C_1}$$

(2*b*)

diffusione

$$\Delta V_d = \frac{RT}{nF} \frac{L_a - L_c}{L_a + L_c} L_n \frac{C_1}{C_2}$$

(3)

elettrofiltrazione

- Utilizzo sonde impolarizzabili

$$\Delta V_{ef} = \frac{k \Delta P \varepsilon \rho}{4 \pi \eta}$$

IP Surveys (Induced polarzation)

IP surveys are perhaps the most useful of all geophysical methods in mineral exploration, being the only ones responsive to low-grade disseminated mineralization.

IP Surveys

Membrane polarization

Membrane polarization

The surfaces of clays and some other platey or fibrous minerals are negatively charged and cause *membrane polarization* in rocks with small pore spaces. Positive ions in the formation waters in such rocks congregate near the pore walls, forming an *electrical double layer*. If an electric field is applied, the positive ion clouds are distorted and negative ions move into them and are trapped, producing concentration gradients that impede current flow. When the applied field is removed, a reverse current flows to restore the original equilibrium.

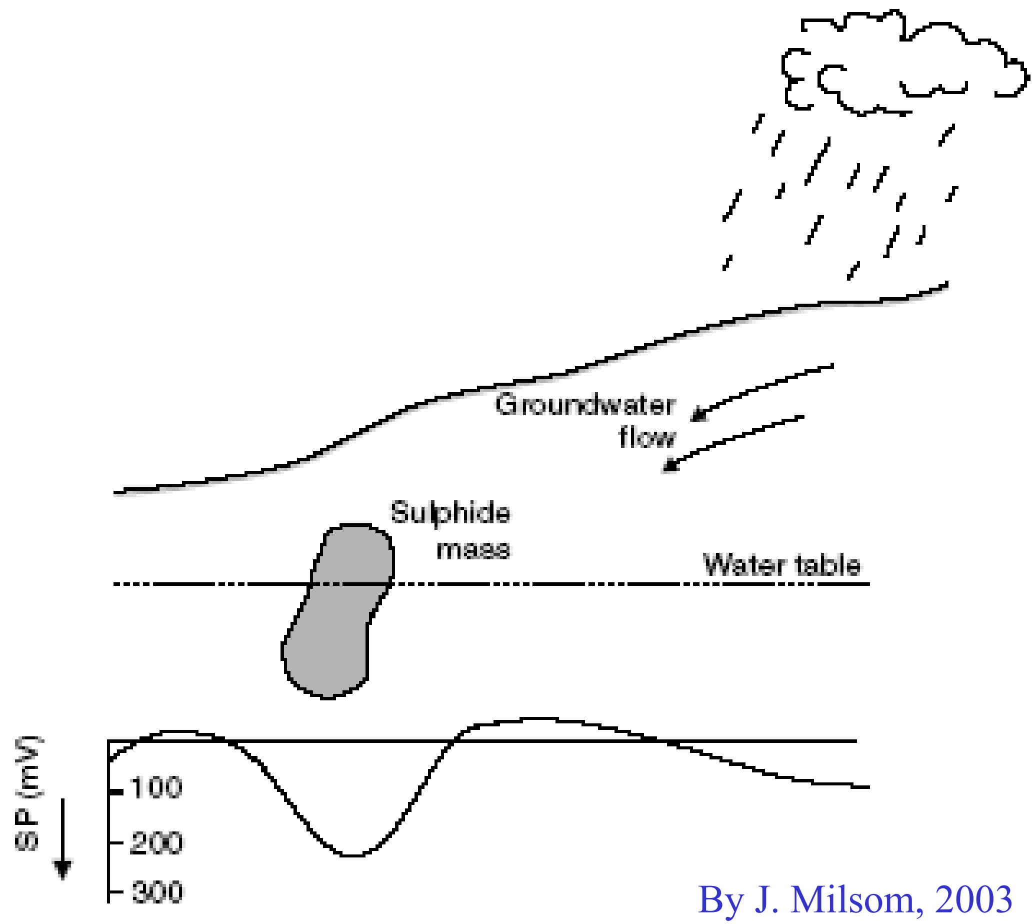
IP Surveys

Electrode polarization

The static *contact potentials are present between* metallic conductors and electrolytes. Additional *over-voltages* are produced whenever currents flow. This *electrode polarization* occurs not merely at artificial electrodes but wherever grains of electronically conducting minerals are in contact with the groundwater. The degree of polarization is determined by the surface area, rather than the volume, of the conductor present, and polarization methods are thus exceptionally well suited to exploration for disseminated *porphyry* ores.

Although, for equivalent areas of active surface, electrode polarization is the stronger mechanism, clays are much more abundant than sulphides and most observed IP effects are due to membrane polarization.

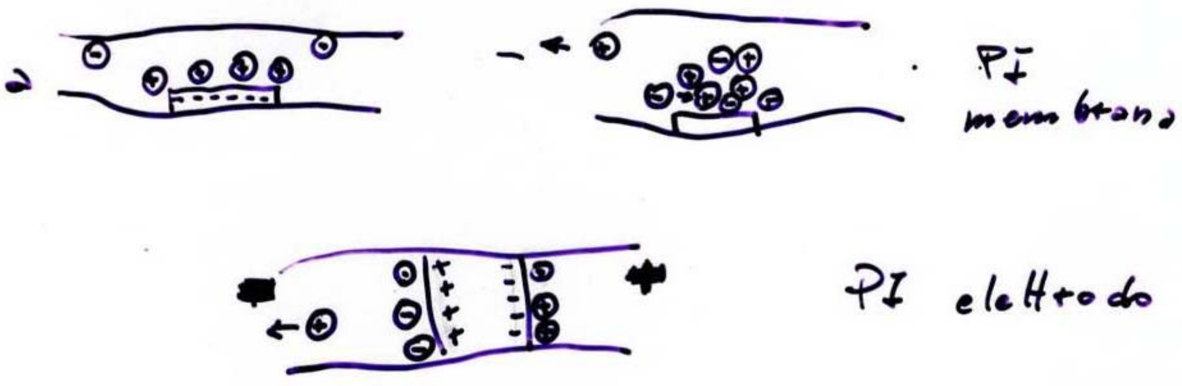
IP Surveys



By J. Milsom, 2003

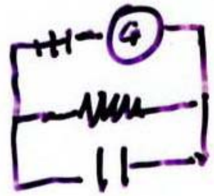
Sources of SP effects. The sulphide mass straddling the water table concentrates the flow of oxidation–reduction currents, producing a negative anomaly at the surface. The downslope flow of groundwater after rain produces a temporary SP, in this case inversely correlated with topography.

Polarizzazione indotta nel dominio del tempo



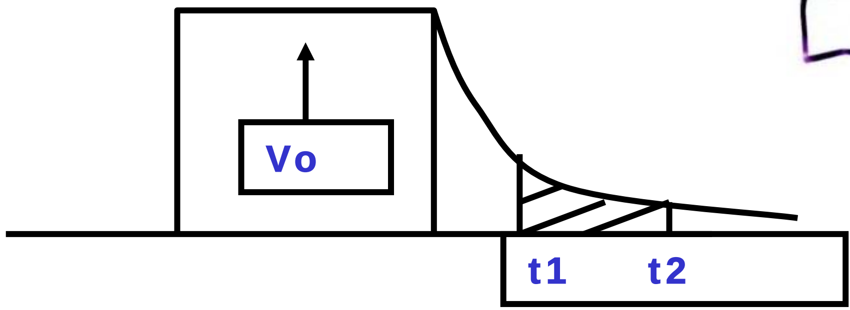
$$\frac{\Delta V_{t0}}{\Delta V_{t1}} = \cos t$$

Condensatore in parallelo



$$\frac{V_t}{V_0} \qquad \frac{\text{mV}}{\text{V}} \%_0$$

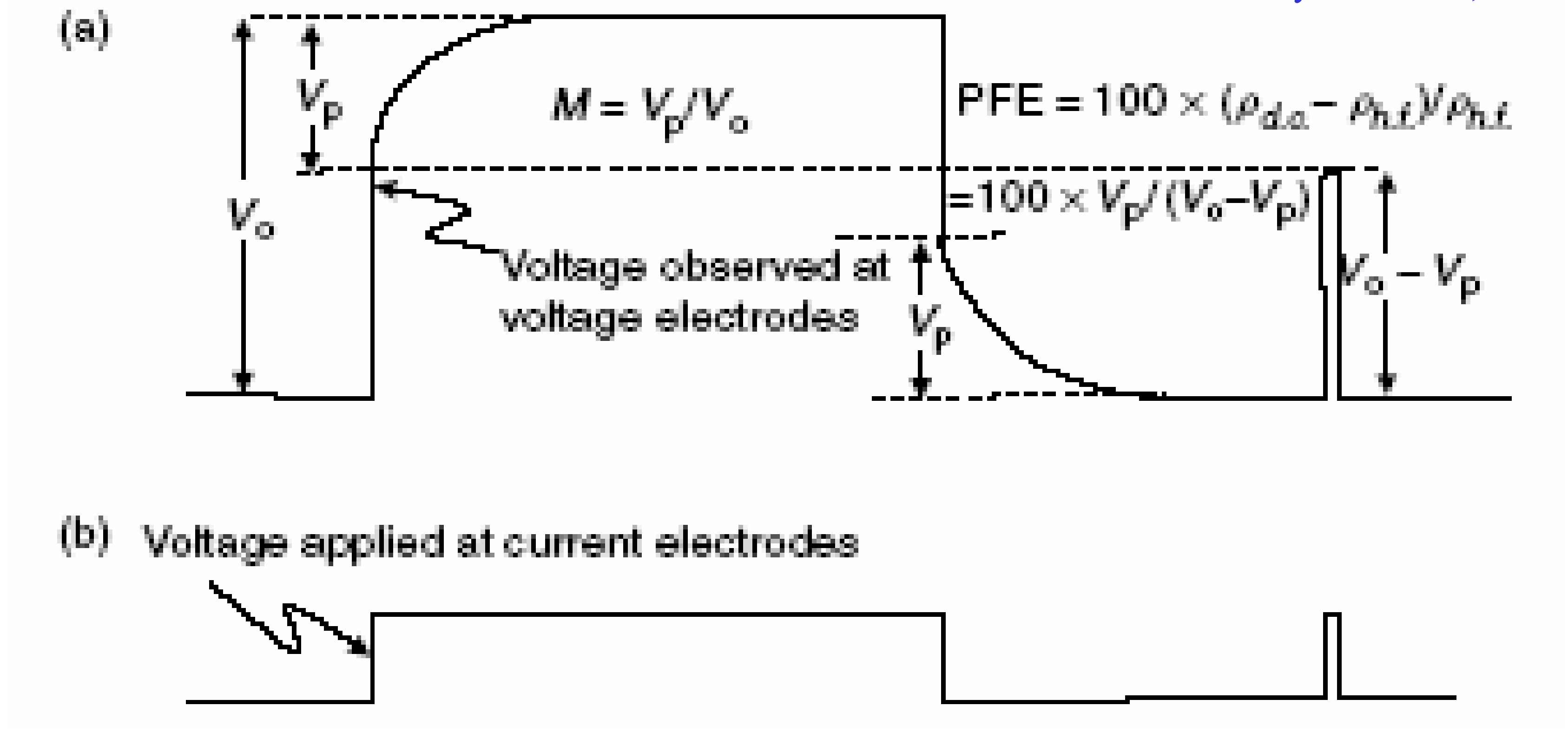
$$M = \frac{1}{V_0} \int_{t_1}^{t_2} V_{(t)} dt$$



IP Surveys (time domain)

When a steady current flowing in the ground is suddenly terminated, the voltage Vo between any two grounded electrodes drops abruptly to a small polarization voltage Vp and then declines asymptotically to zero.

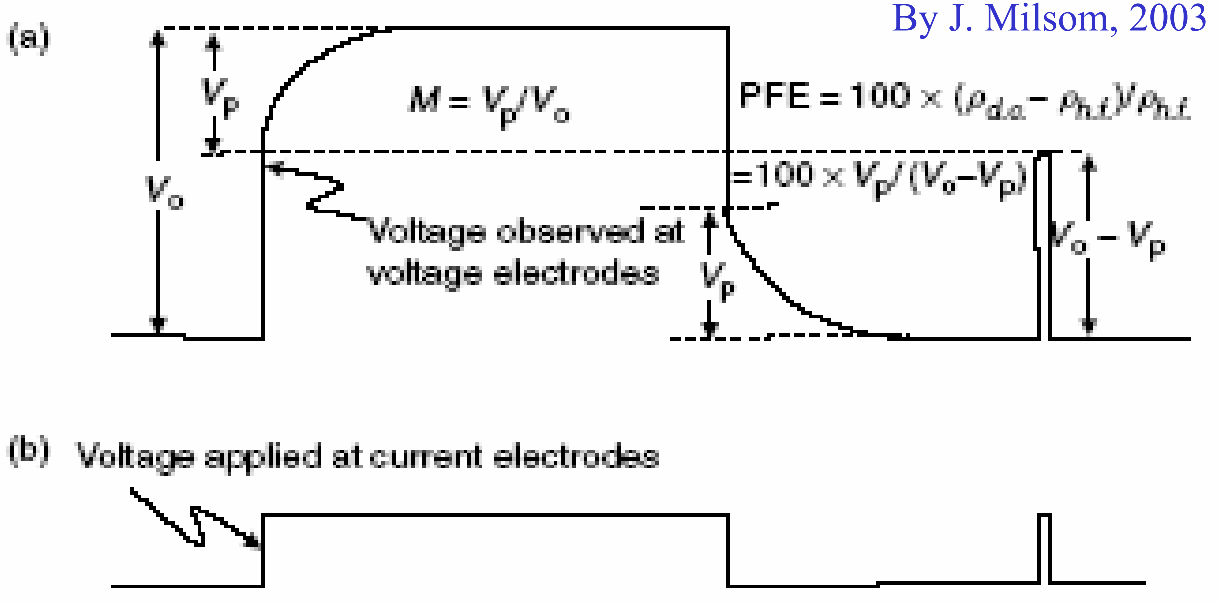
By J. Milsom, 2003



IP Surveys

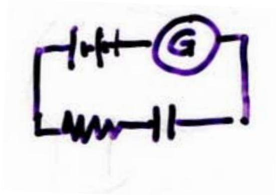
Chargeability is formally defined as the polarization voltage developed across a unit cube energized by a unit current and is thus in some ways analogous to magnetic susceptibility.
The *apparent chargeability* of an entire rock mass is defined, in terms of the square wave, as the ratio of *V*p to *V*o. This is a pure number but in order to avoid very small values it is generally multiplied by a thousand and quoted in millivolts per volt.

By J. Milsom, 2003



Polarizzazione indotta nel dominio delle frequenza

Condensatore in serie



$$f_e = \frac{\rho_c - \rho_a}{\rho_a}$$

$$\text{PFE} = 100\,\frac{\rho_c - \rho_a}{\rho_a}$$

$$\text{MF} = 2\pi \cdot 10^{-5}\,\frac{f_e}{\rho_c}$$

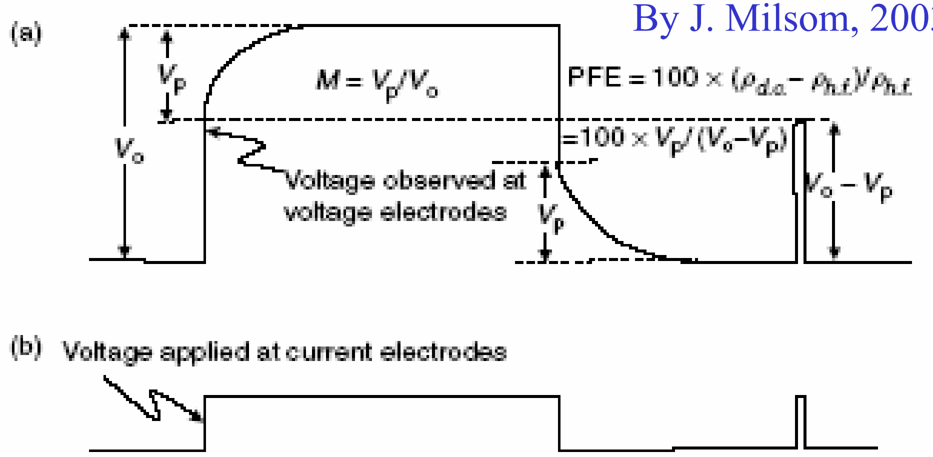
IP Surveys (frequency domain)

If a current were to be terminated almost immediately after being introduced, a lower apparent resistivity, equal to

$(V_o - V_p)/I$

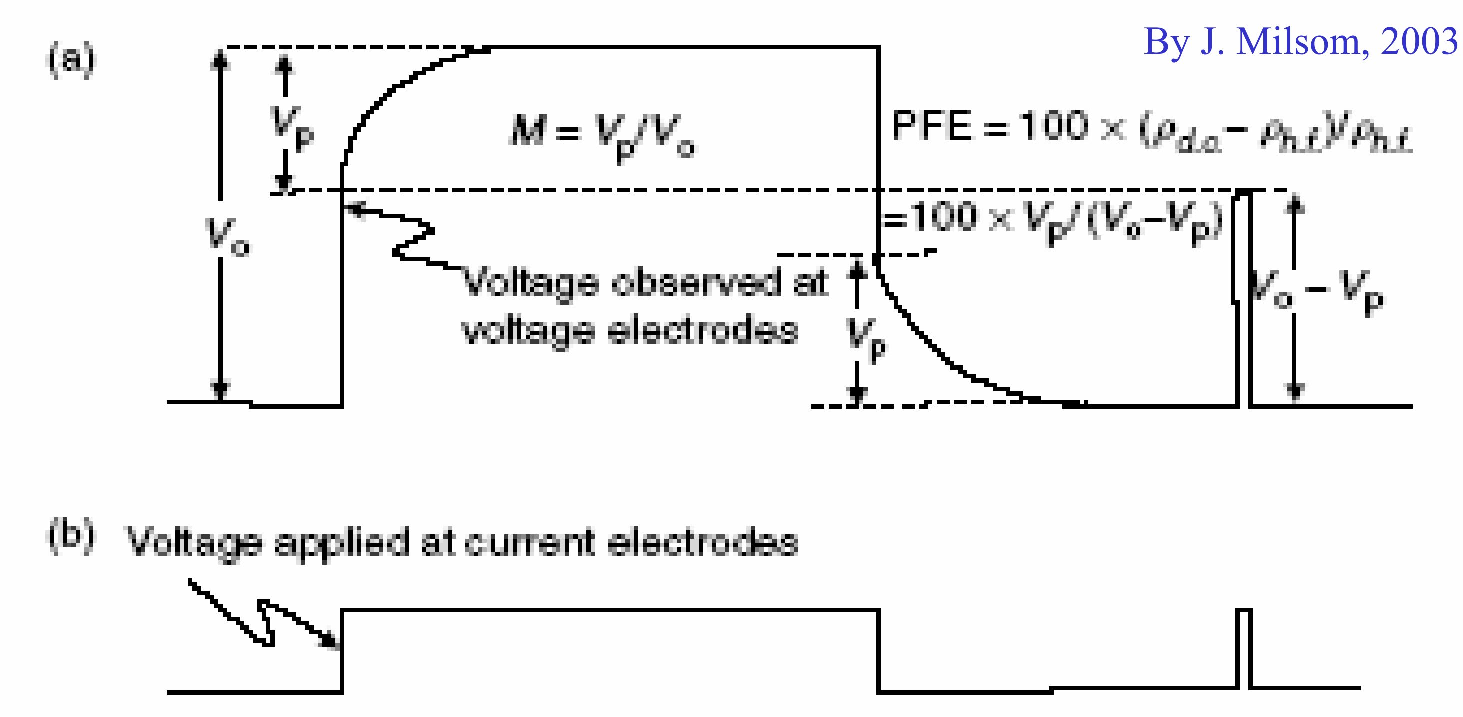
multiplied by the array geometrical factor, would be calculated. The IP *frequency effect* is defined as the difference between the 'DC' and 'high frequency' resistivities, divided by the high-frequency value. This is multiplied by 100 to give an easily handled whole number, the *percent frequency effect* (PFE).

By J. Milsom, 2003



IP Surveys (frequency domain)

A PFE can be divided by the DC resistivity to give a quantity which, multiplied by 1000, 2000 or 2000π, produces a number of convenient size known as the *metal factor*. Metal factors emphasize rock volumes that are both polarizable and conductive and which may therefore be assumed to have a significant sulphide (or graphite) content.



Bibliografia

Carrara, A. Rapolla, N. Robert, “Le indagini geofisiche per lo studio del sottosuolo”, Edizioni Liguori.
J. Milsom, 2003. Field Geophysics. Published by John Wiley & Sons Ltd.