NORAD supported project in MRRD covering Capacity Building and Institutional Cooperation in the field of Hydrogeology for Faryab Province Afghanistan

Geophysics Course
Interpreting DC Resistivity Data

By Andreas de Jong
June 2013

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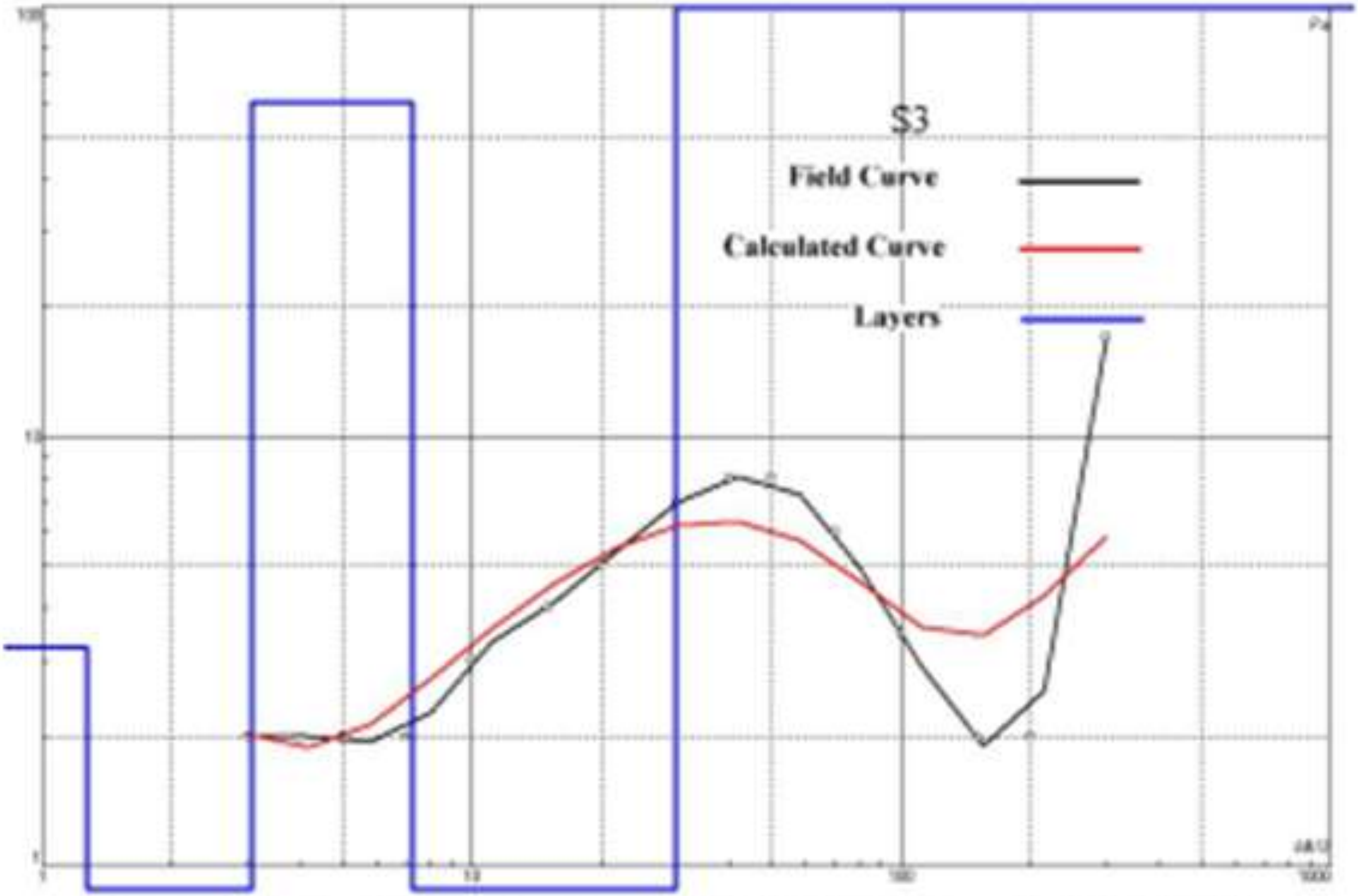
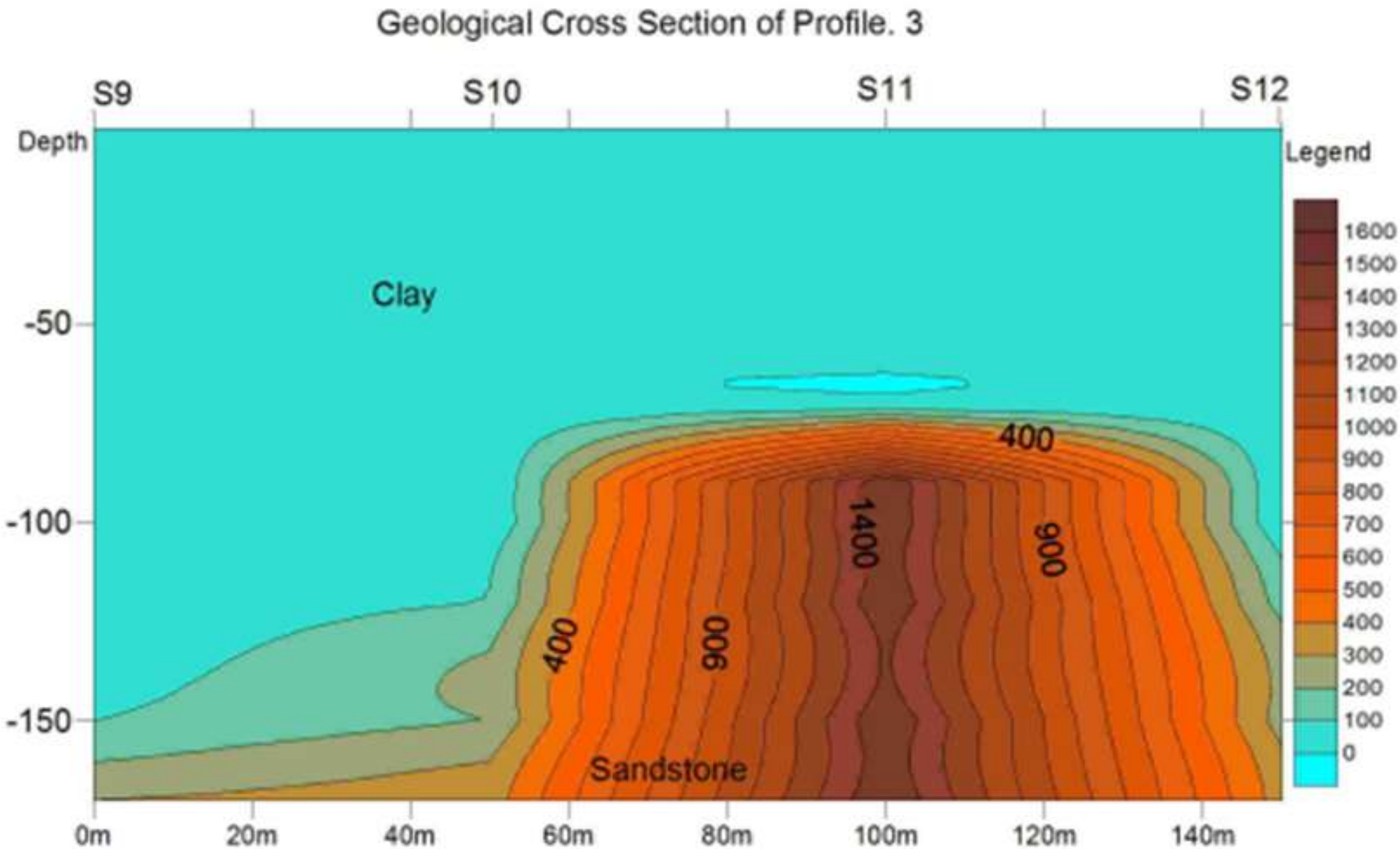


Curve 3.Showing the Apparent Resistivity Curve of Sounding1.



Geological Cross Section of Profile. 3
S9
S10
S11
S12
Depth
-50
-100
-150
Clay
Sandstone
400
1400
900
400
900
0m
20m
40m
60m
80m
100m
120m
140m
Legend
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

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TOPICS TO BE COVERED

1. Introduction
2. Current Flow in the Ground
3. DC Resistivity Surveys
4. VES Interpretation

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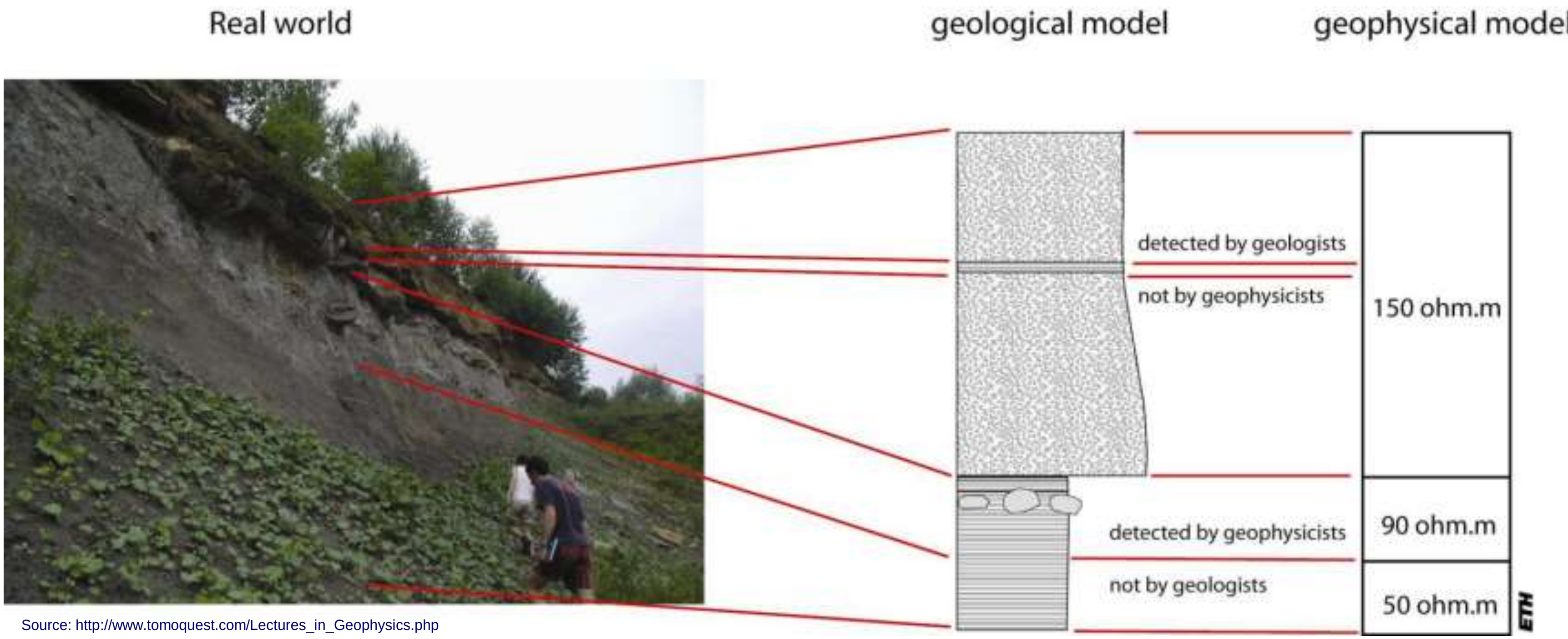
PART 1 – Introduction

1. Definition of a Model
2. Definition of Contrast
3. Definition of Anomaly
4. Sources of Noise
5. DC Resistivity Sounding Principle & Actual Current Distribution

Definition of a Model



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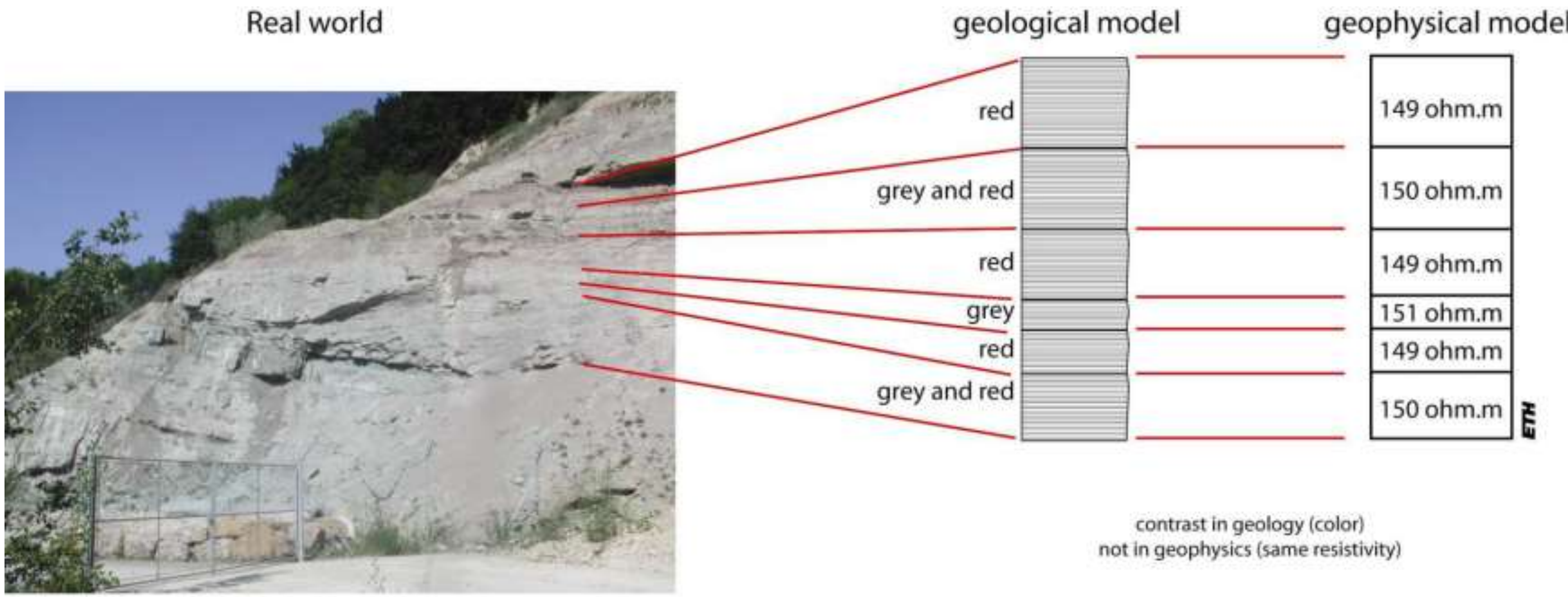
A model is a simple, ideal interpretation of the real world.

Definition of Contrast



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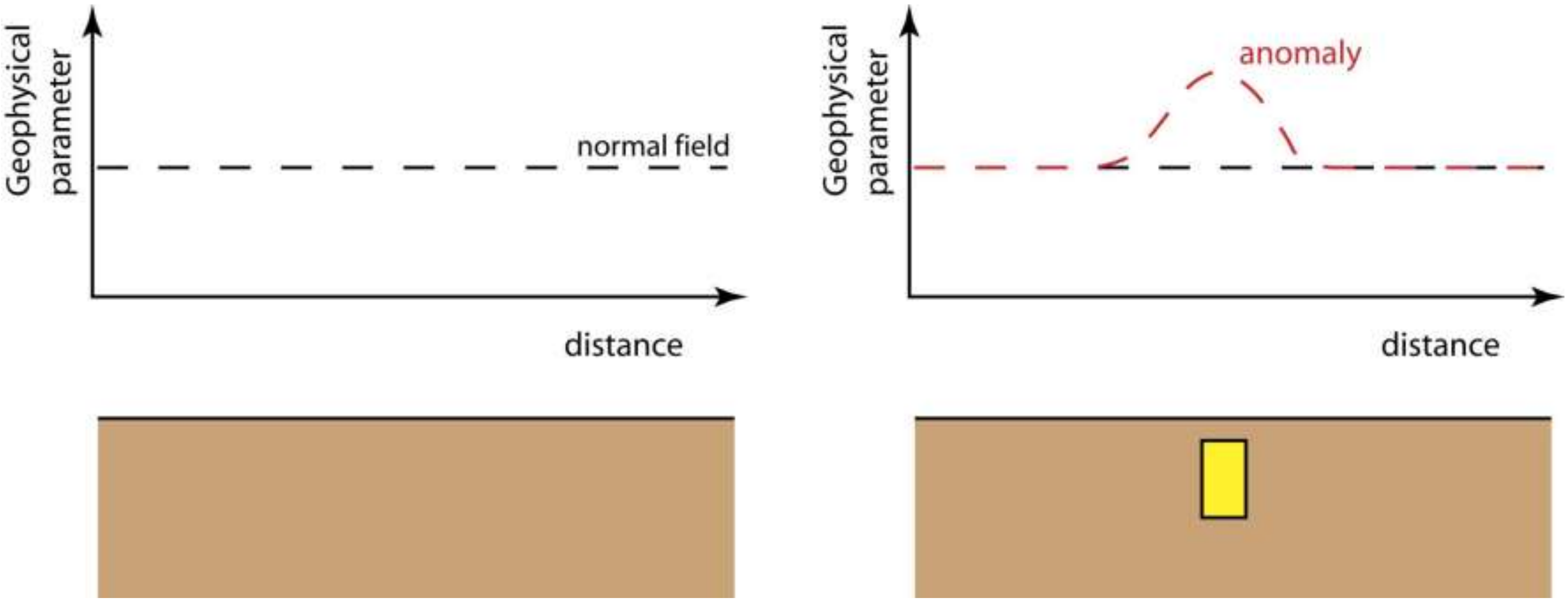
To characterize different material using geophysics, there must be a contrast between the materials (i.e. a difference in the physical properties).

Definition of Anomaly



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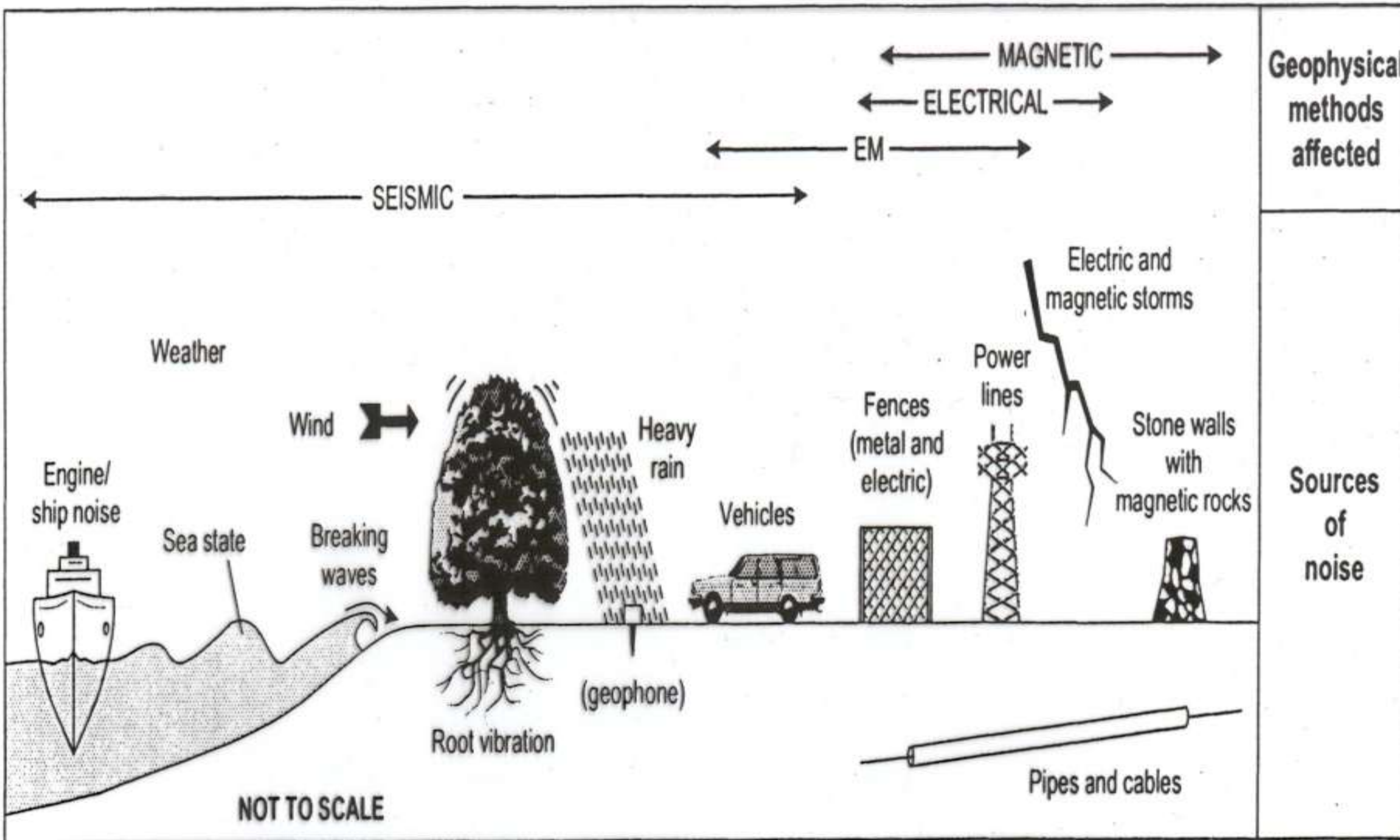
An anomaly is something that deviates from what is standard, normal, or expected.

Sources of Noise



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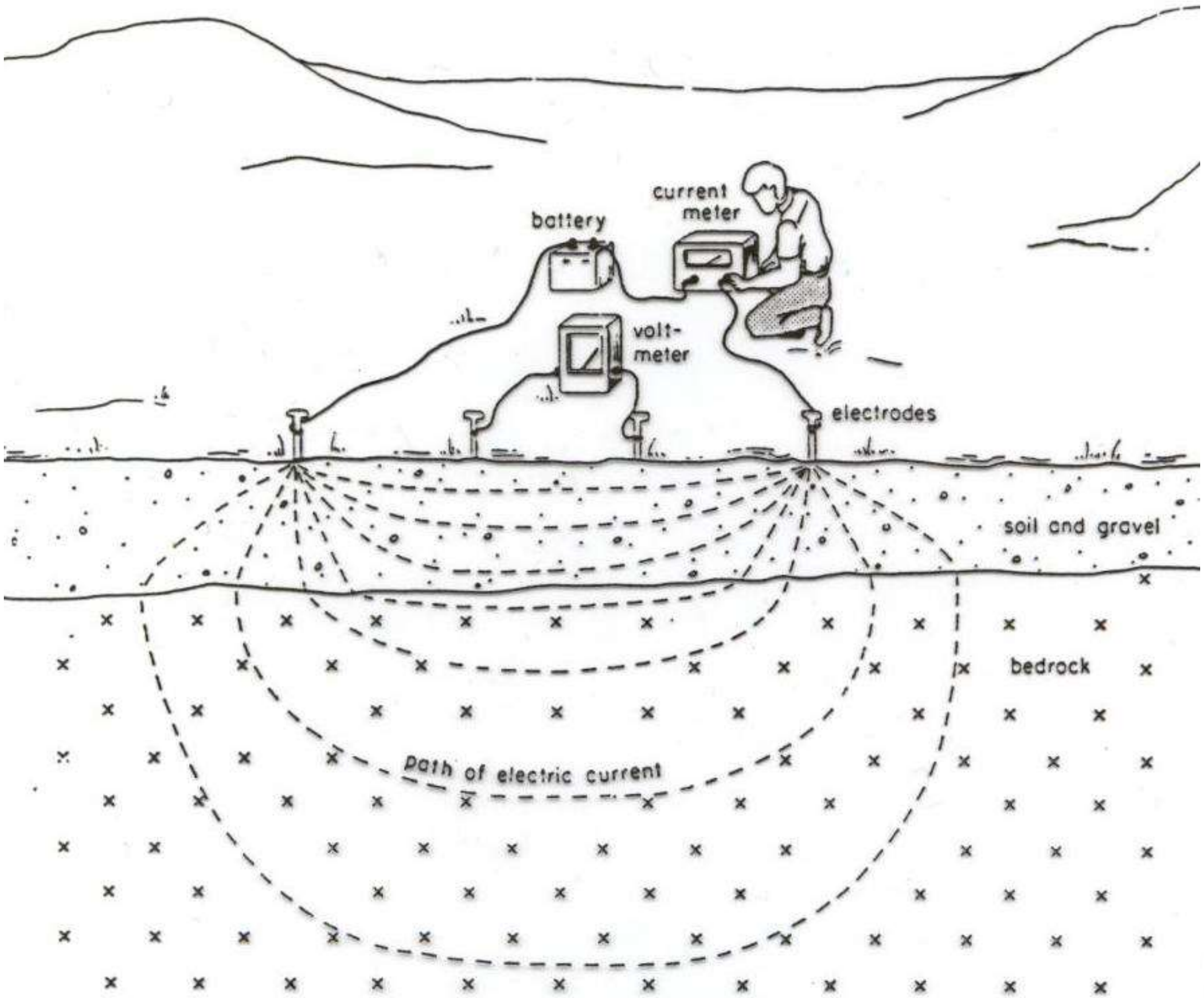
DC Resistivity Sounding Principle



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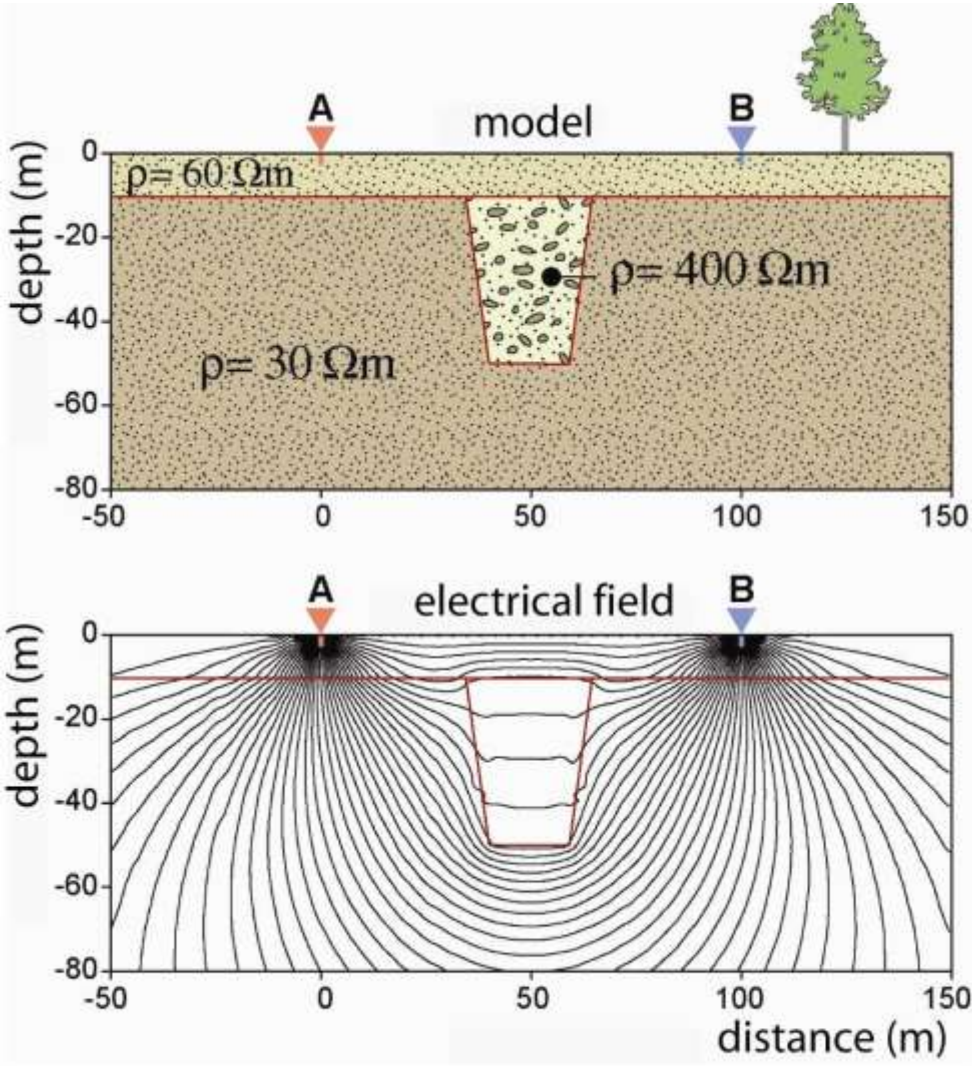
Actual Current Distribution



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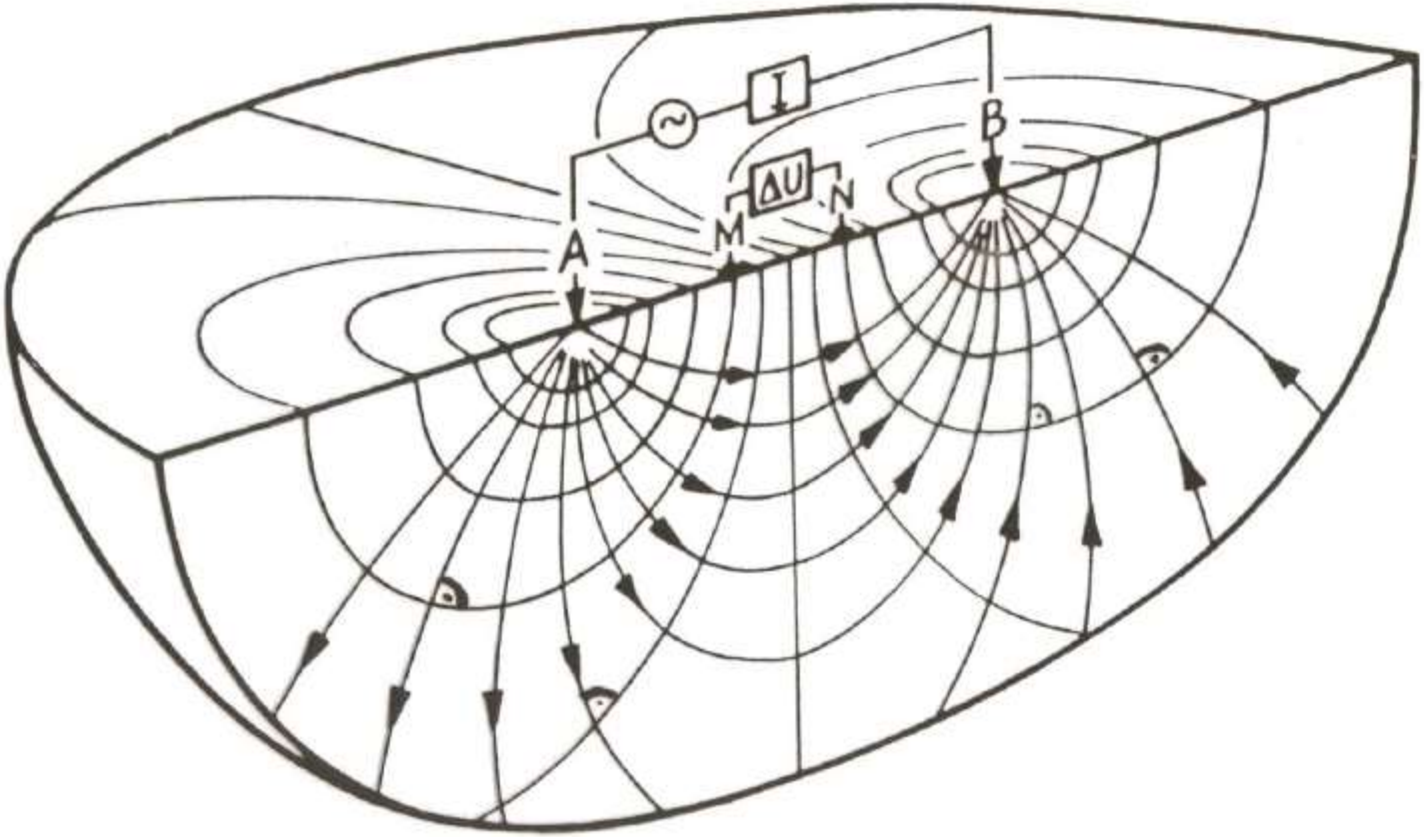
PART 2 – Current Flow in the Ground (I)

1. Calculating Apparent Resistivity
2. Geometric Factors
3. Equations for Various Arrays
4. Current Penetration
5. Depths of Investigation
6. Effect of A-B Distances on Profiling

DC Resistivity Sounding

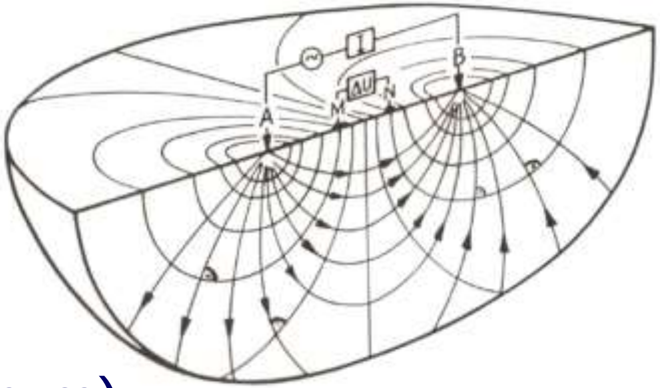


Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Calculating Apparent Resistivity

Measured resistivity is an apparent resistivity.

$$\rho_a = \frac{\Delta V_{MN}}{I} K$$



ρ_a apparent resistivity (ohm-m)

ΔV_{MN} potential (volts) between M and N

I current (amps)

K geometric factor

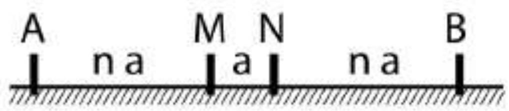
Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Geometric Factors of Various Arrays

Wenner

K=2 π a

Wenner-Schlumberger

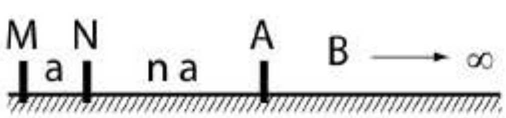


K=π n (n+1) a

dipole-dipole

K=π n (n+1) (n+2) a

pole-dipole



K= 2 π n (n+1) a

pole-pole

K=2 π a

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Equations for Various Arrays

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

Wenner array

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

Schlumberger array

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

dipole-dipole array

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

DC Resistivity Field Sheets - Schlumberger

SCHLUMBERGER ARRAY
FIELD SHEET

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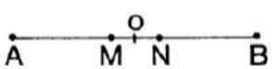
Project: ______________________ Sounding No.: ______________________

Location: ______________________ Coordinates East: ______________________

Equipment: ______________________ Coordinates North: ______________________

Operator: ______________________ Azimuth: ______________________



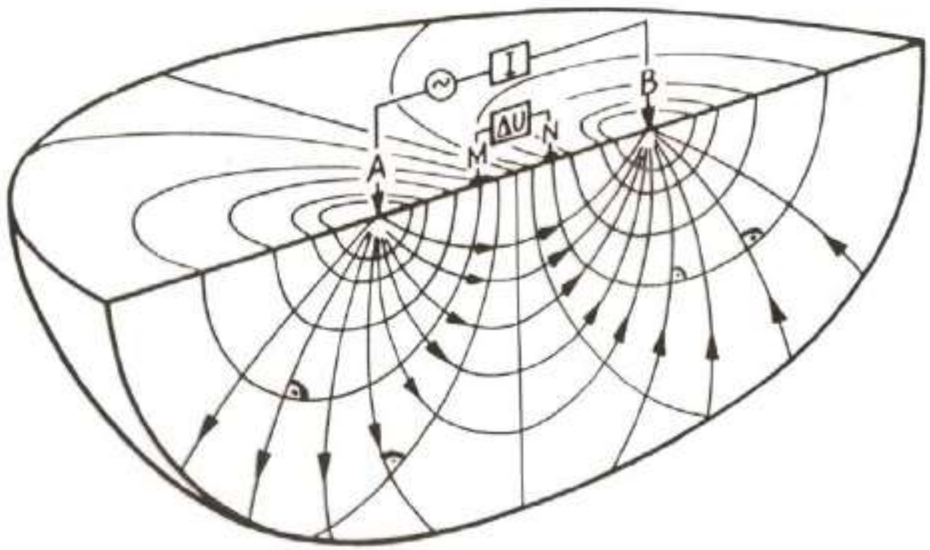
$$K = \frac{AM \cdot AN}{MN}\pi$$

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

Marks	OA in m	K for MN 1m	MN 10m	MN 60m	MN 200m	ΔV in millivolts (mV)	I in milliamperes (mA)	ρ_a in ohm-m (Ωm)
1	1	2.35						
2	2	11.8						
3	3	27.5						
1	4	49.5						
2	5	77.7						

Current Penetration

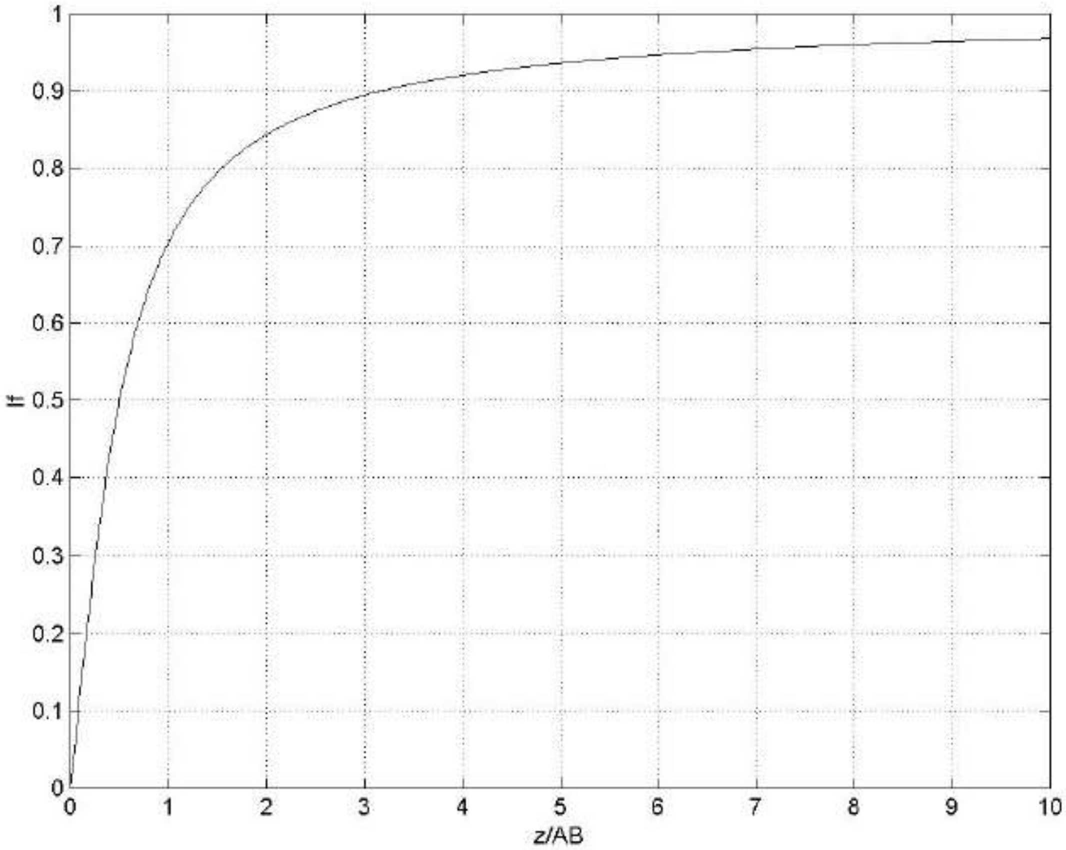
$$I_f = \left(\frac{2}{\pi}\right)\tan^{-1}\left(\frac{2z}{AB}\right)$$



- z depth
- AB distance between current electrodes
- I_f fraction of current penetrating between the surface and z

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Current Penetration



$$I_f = \left(\frac{2}{\pi}\right)\tan^{-1}\left(\frac{2z}{AB}\right)$$

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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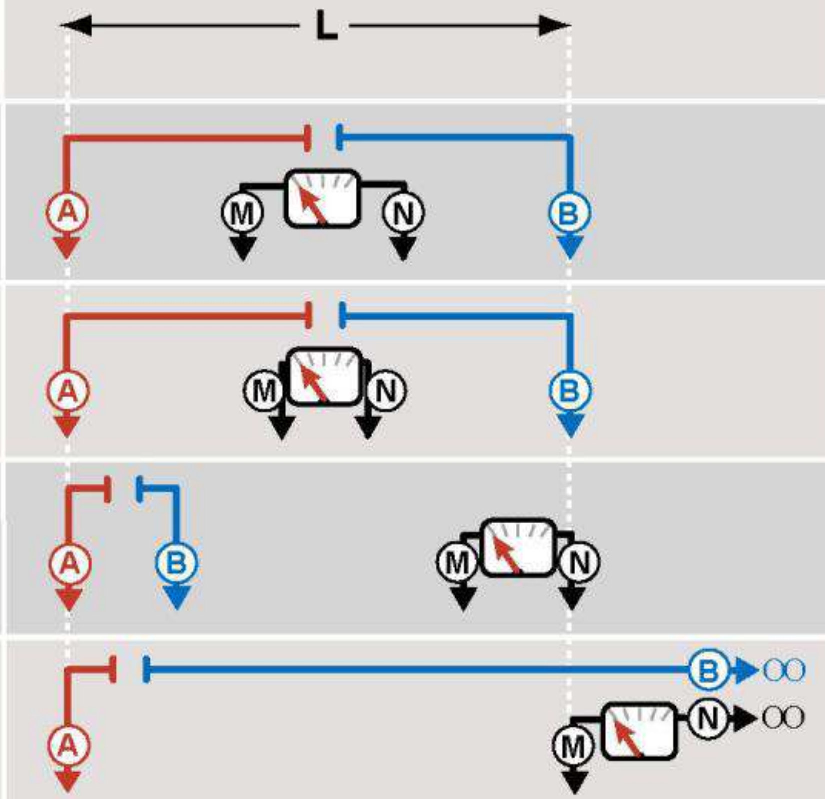
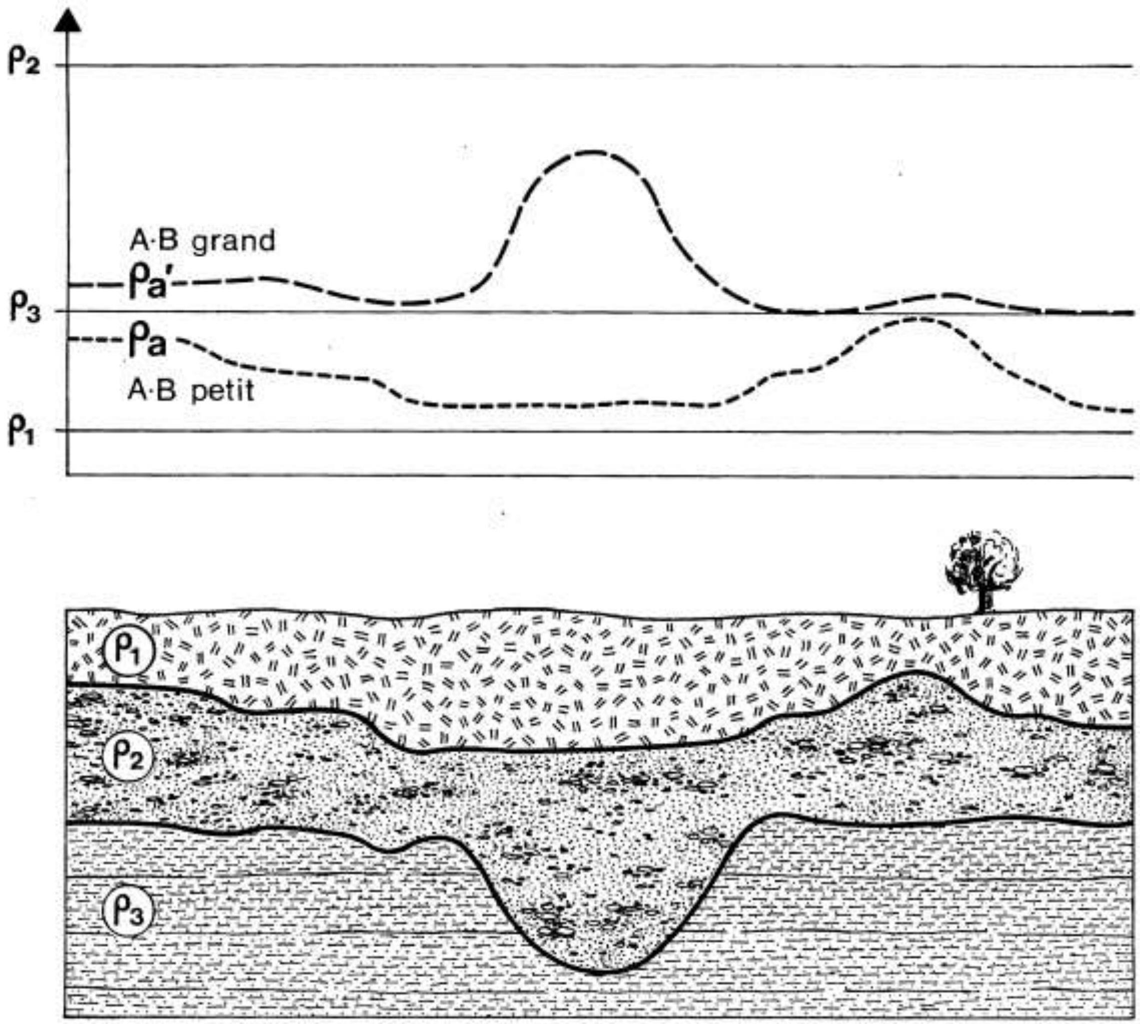
Depths of Investigation



Array	Depth of investigation		Resolving power
	Roy (1971)	Barker (1989)	
Wenner	0.11L	0.17L	1/2.25
Schlumberger	0.125L	0.19L	1/2.45
Dipôle-Dipôle	0.195L	0.25L	1/3.45
Pôle-Pôle	0.35L		1/8.4

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Profiling: Effect of A–B Distances

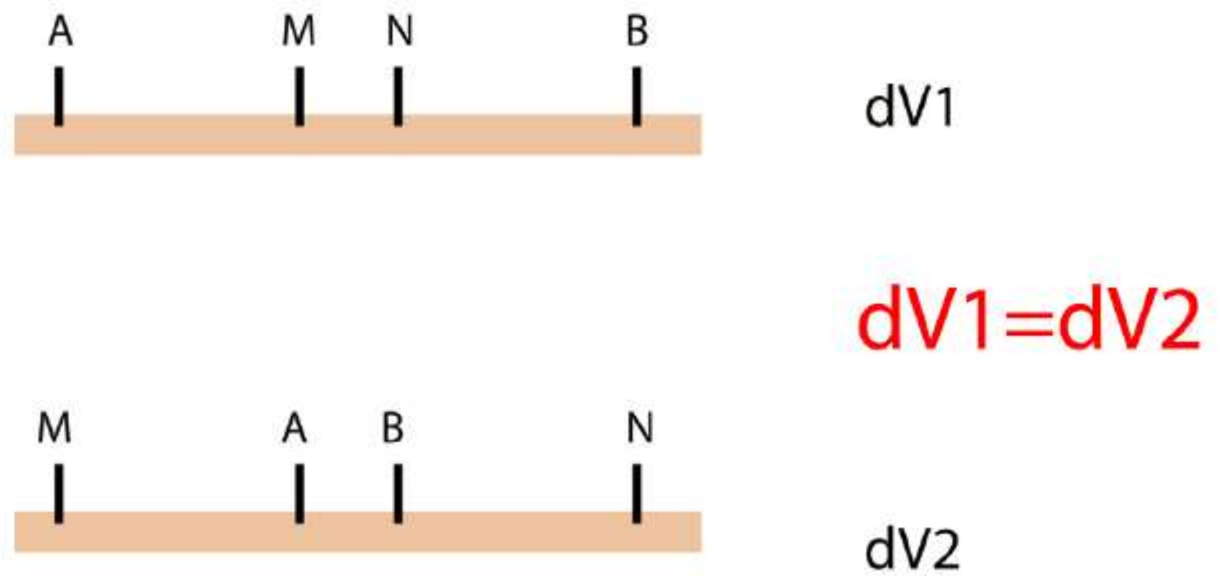


Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

PART 2 – Current Flow in the Ground (II)

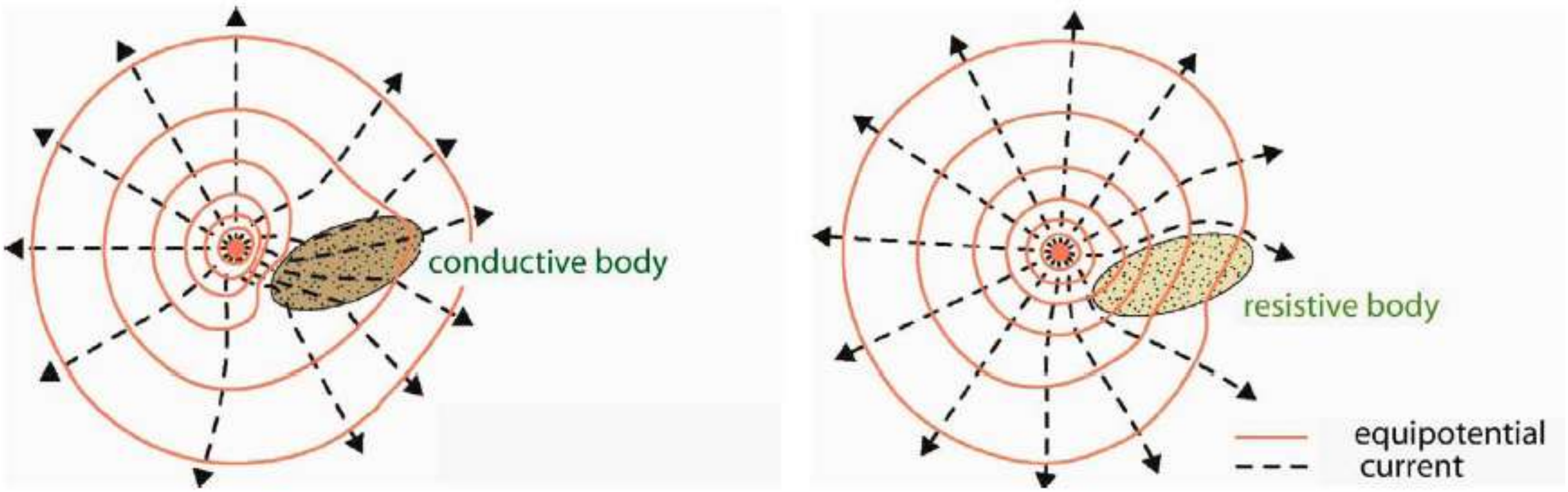
1. Principle of Reciprocity
2. Effects of Heterogeneous Earth
3. Current Flow Lines
4. Effect of Near-Surface Resistivity
5. Effects of Topography
6. Contact Resistance
7. Coping with Noise

Principle of Reciprocity



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Effects of Heterogeneous Earth



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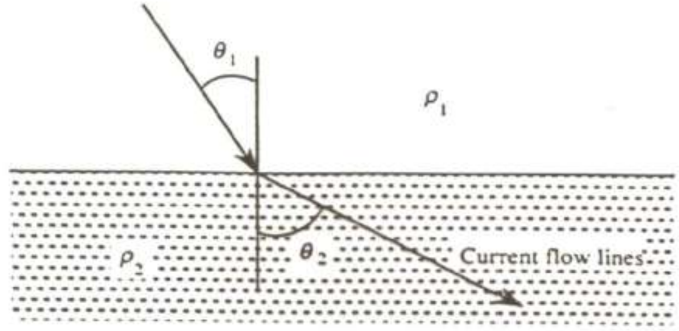
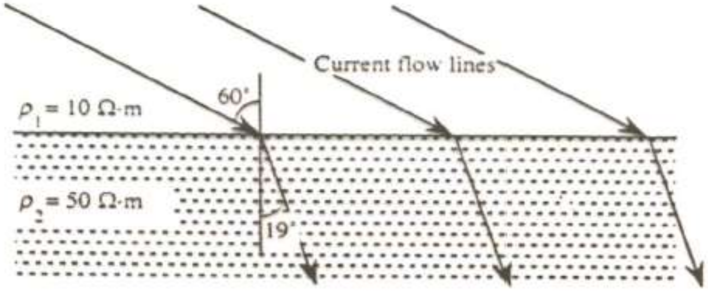
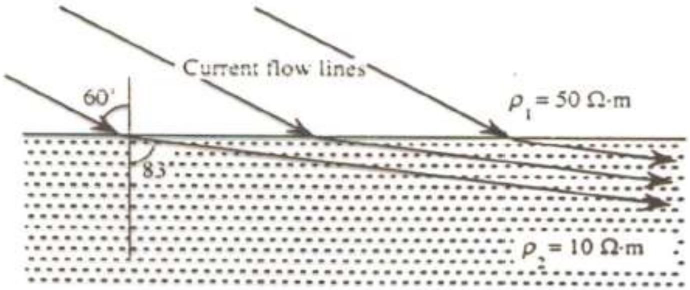
Current Flow Lines



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



$$\rho_1 < \rho_2$$



$$\rho_1 > \rho_2$$

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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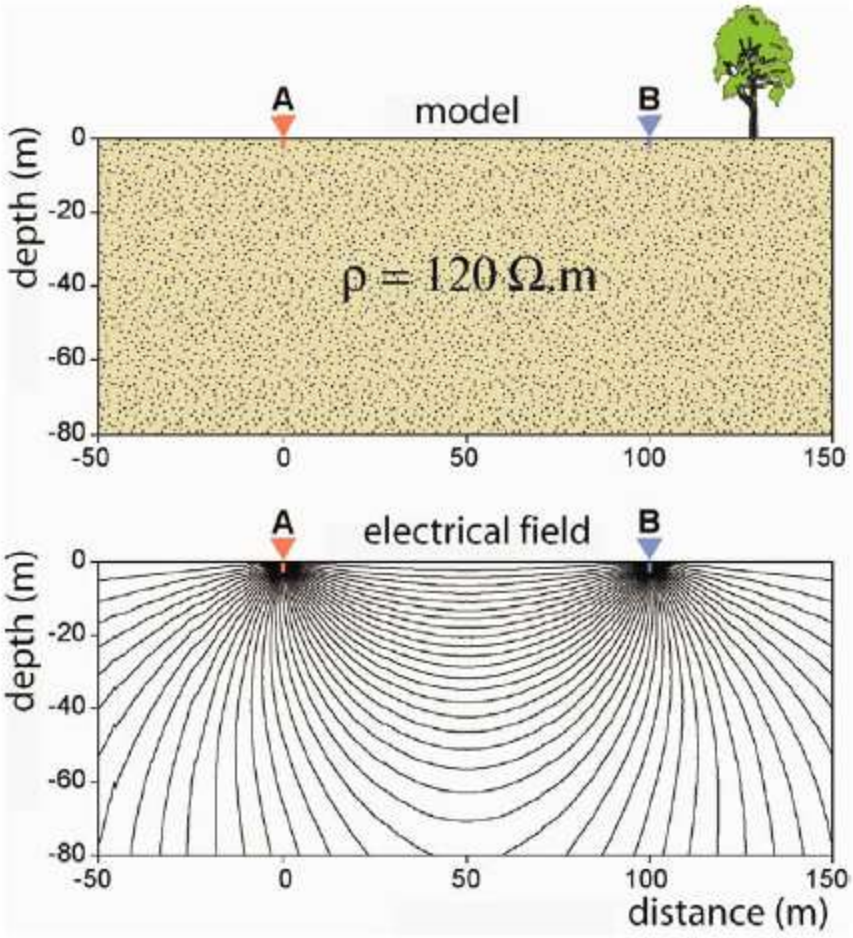
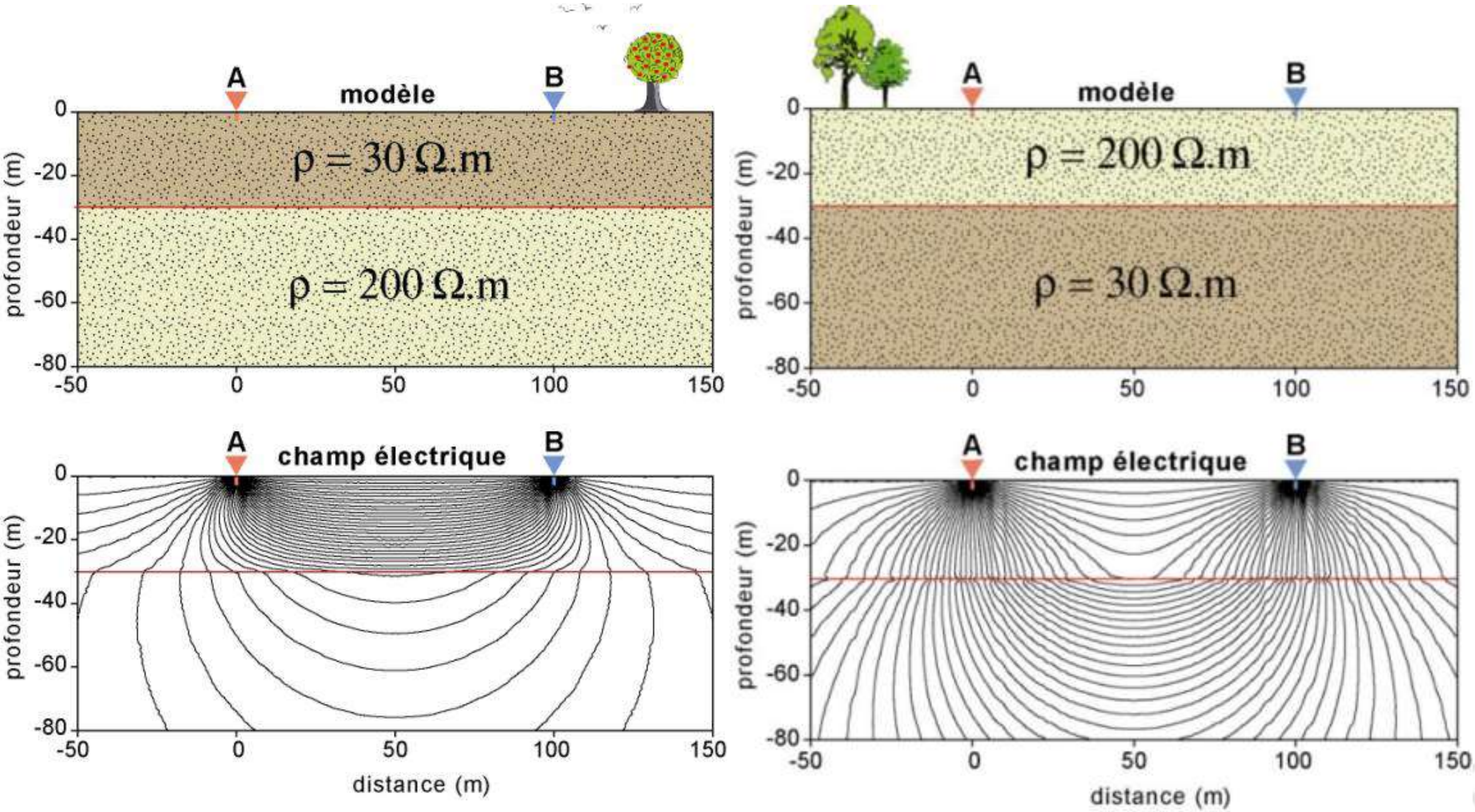
Current Flow Lines



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

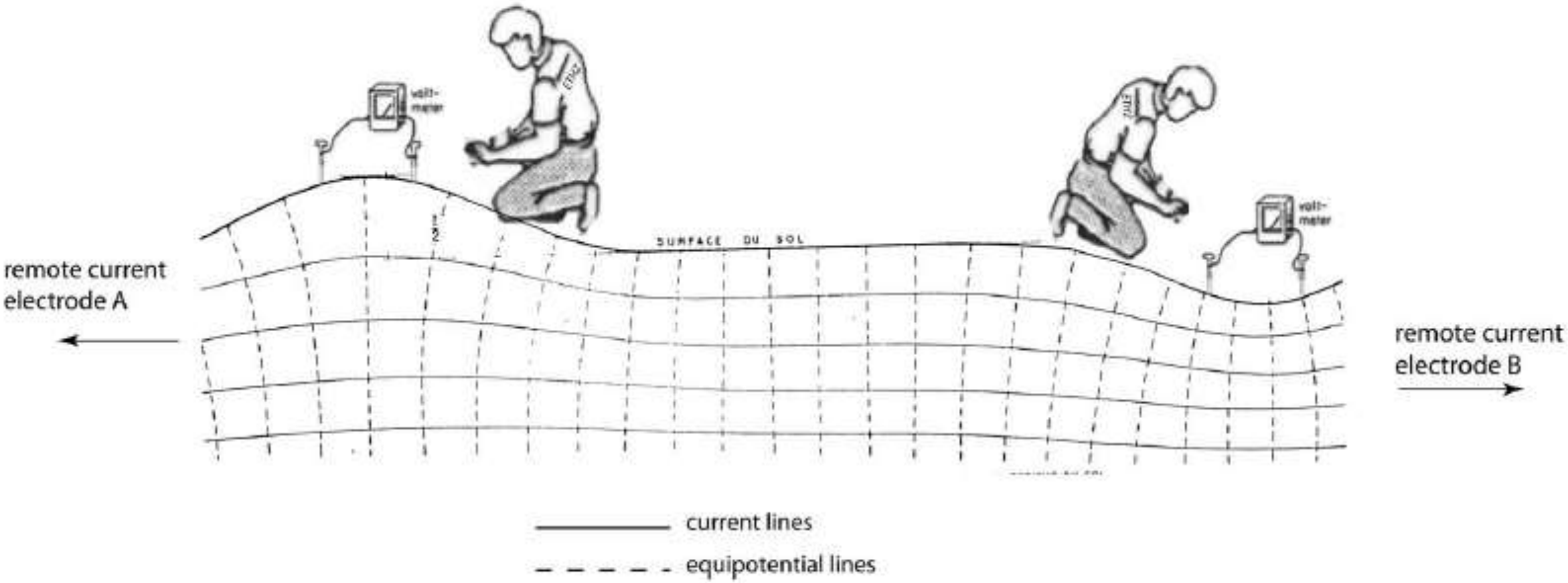
Effect of Near-Surface Resistivity



Resistivity affects depth of investigation

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Effects of Topography



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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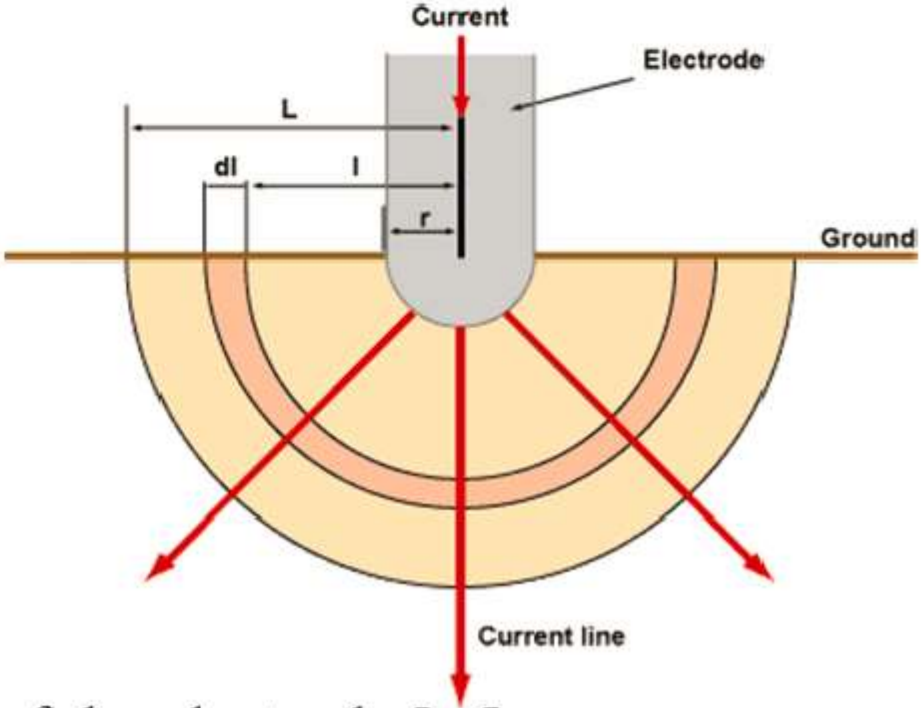
Contact Resistance

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

$$R = \frac{\rho}{2\pi}\left(\frac{1}{r} - \frac{1}{L}\right)$$



L = distance to the centre of the electrode [m]

r = radius of the electrode [m]

R = resistance [ohm]

ρ = resistivity of the surrounding ground [ohm.m]

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Decrease the Contact Resistance

- Add extra electrodes
- Increase current intensity
- Increase diameter of current electrodes
- Hammer electrodes deeper into the ground
- Add water to the ground around the electrodes
- Add salt to water

Approx. 90% of the contact resistance contribution comes from a portion of the ground around the electrode that is equal to 10 times the diameter of the electrode.

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Coping with Noise

- Telluric Currents
- Man-made currents
- Metallic conductors in the ground

Solutions:

- Use Alternating Currents
- Stack the data
- Rejection filters

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

PART 3 – DC Resistivity Surveys

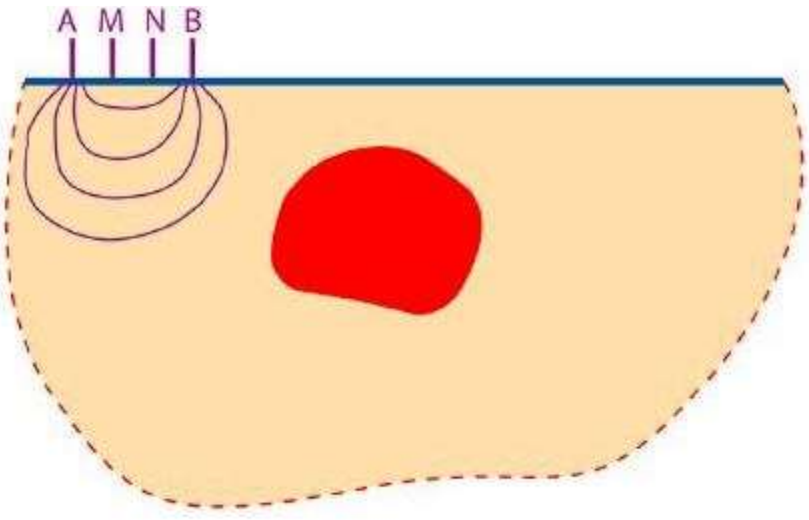
1. Types of Surveys
2. Constant Separation Traversing (CST)
3. Vertical Electrical Sounding (VES)
4. Field Sheets

Types of Surveys

1. **Constant Separation Traversing (CST):** resistivity mapping along profiles to find lateral anomalies in resistivity. Current & Potential electrode separation is fixed, and move along the profile.
2. **Vertical Electrical Sounding (VES):** vertical resistivity mapping. The electrode spread is expanded about a central point.
3. **Electrical Resistivity tomography (ERT)**, also known as Electrical Imaging, is a combination of CST & VES.

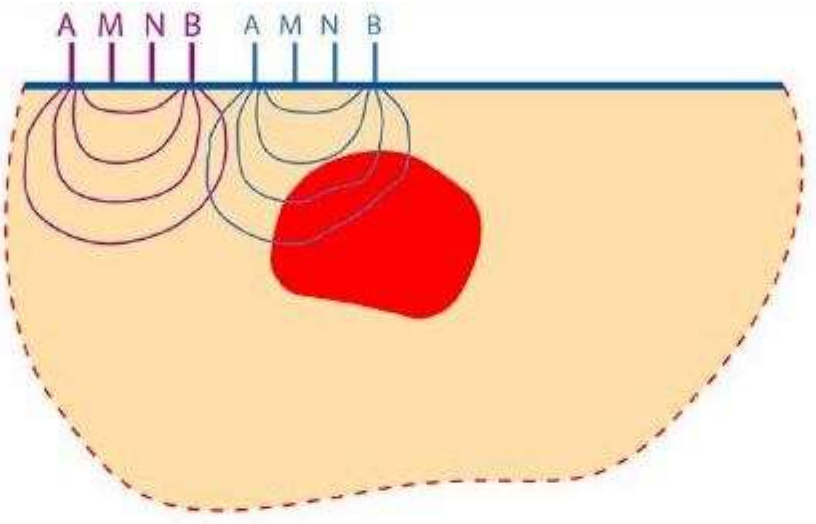
Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

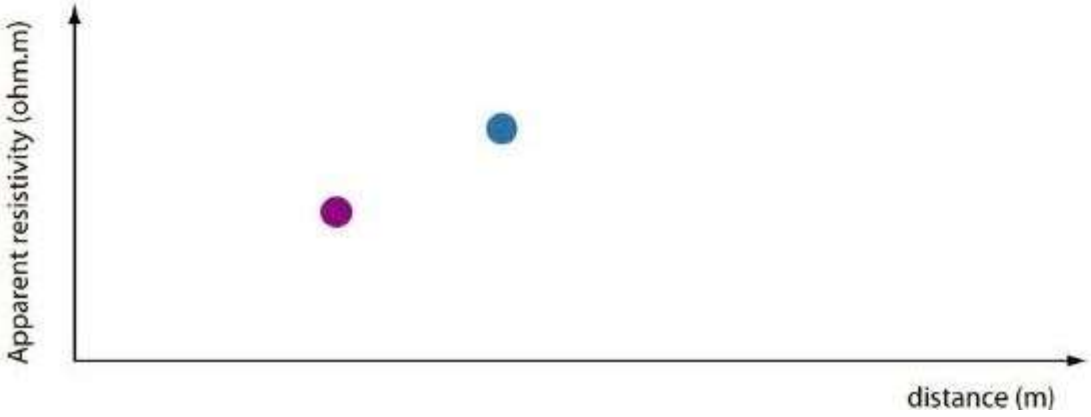
Constant Separation Traversing (CST)



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

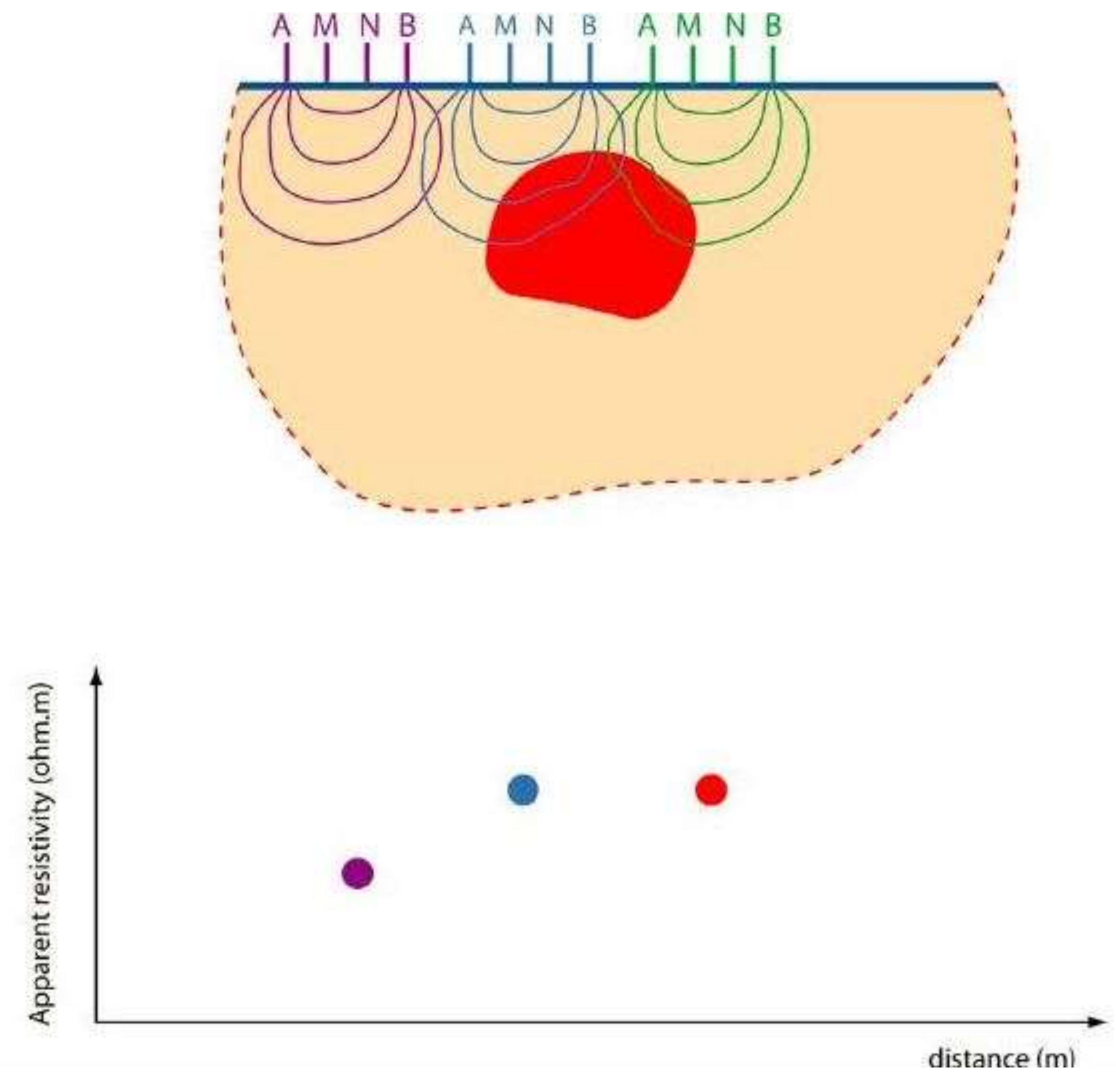
Constant Separation Traversing (CST)





Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Constant Separation Traversing (CST)



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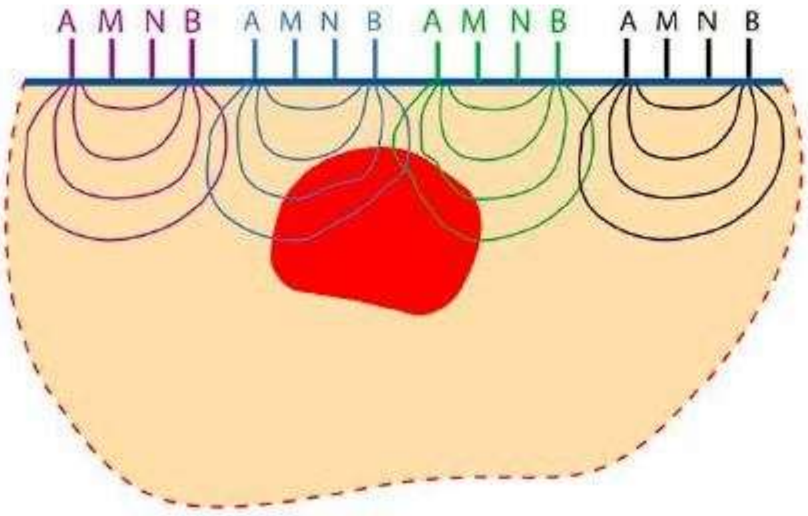
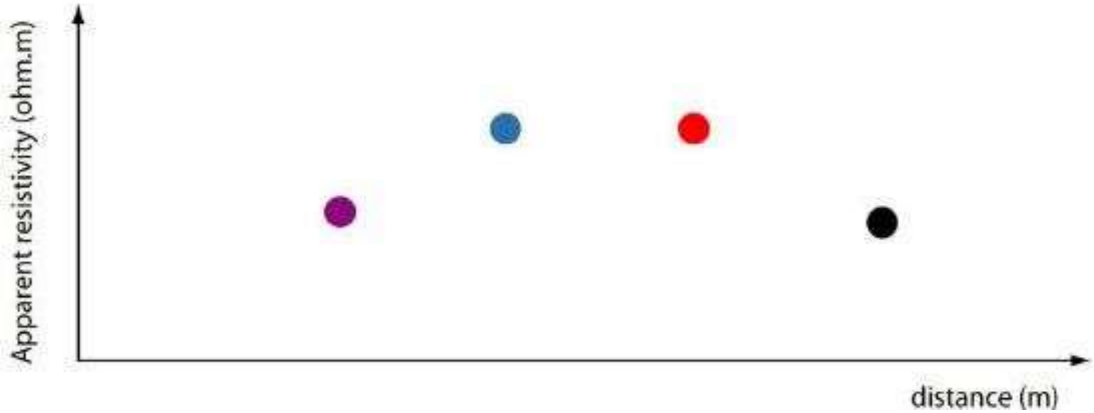
Constant Separation Traversing (CST)





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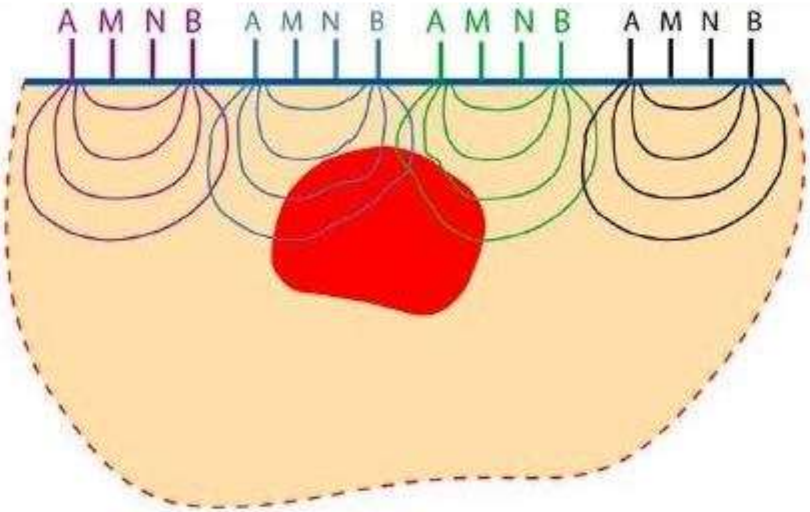
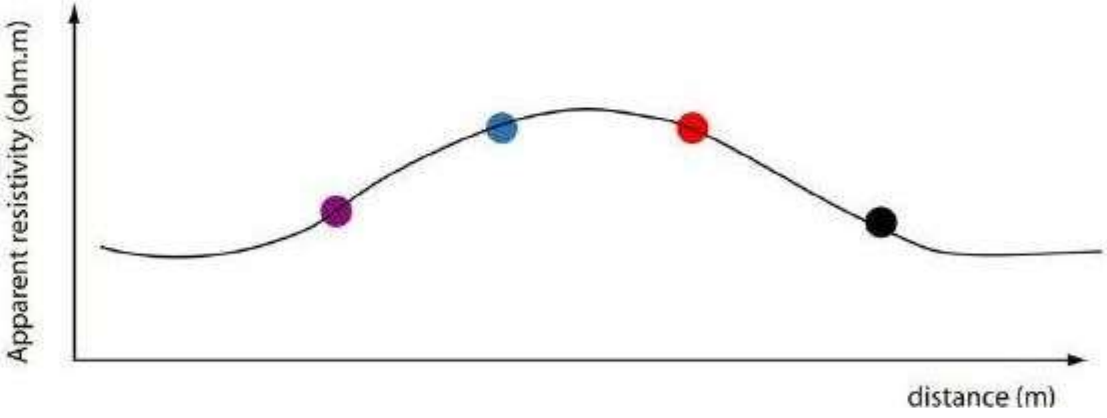
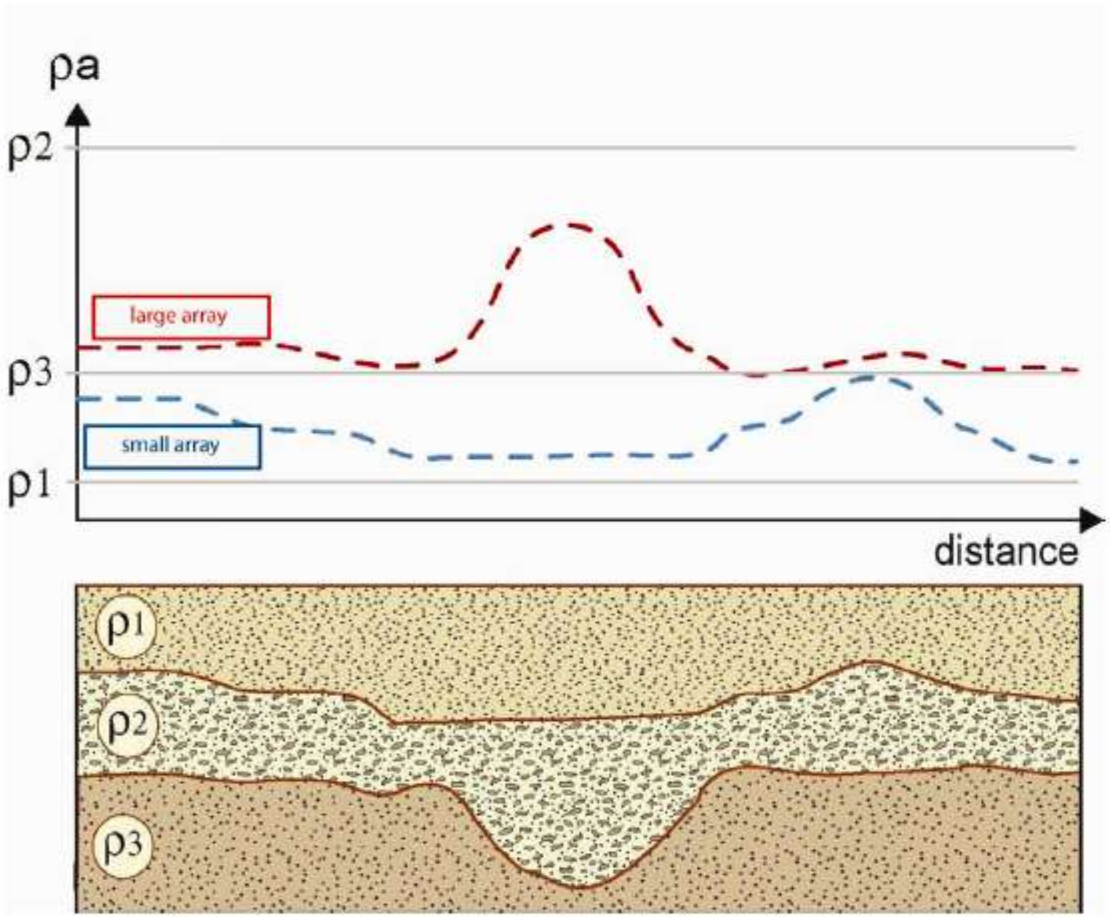
Constant Separation Traversing (CST)





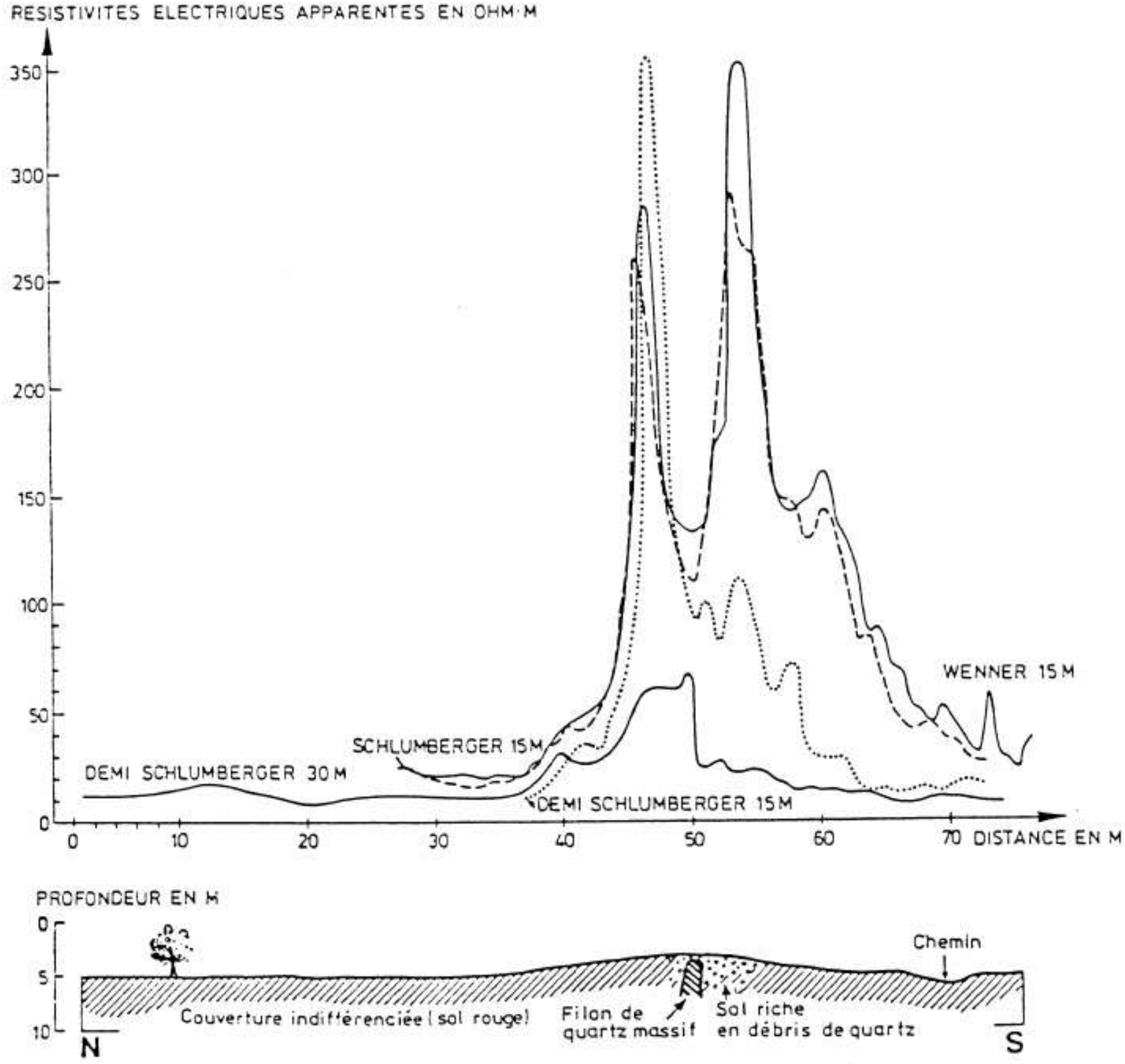
Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Interpretation of CST



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Interpretation of CST



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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Resistivity Traversing

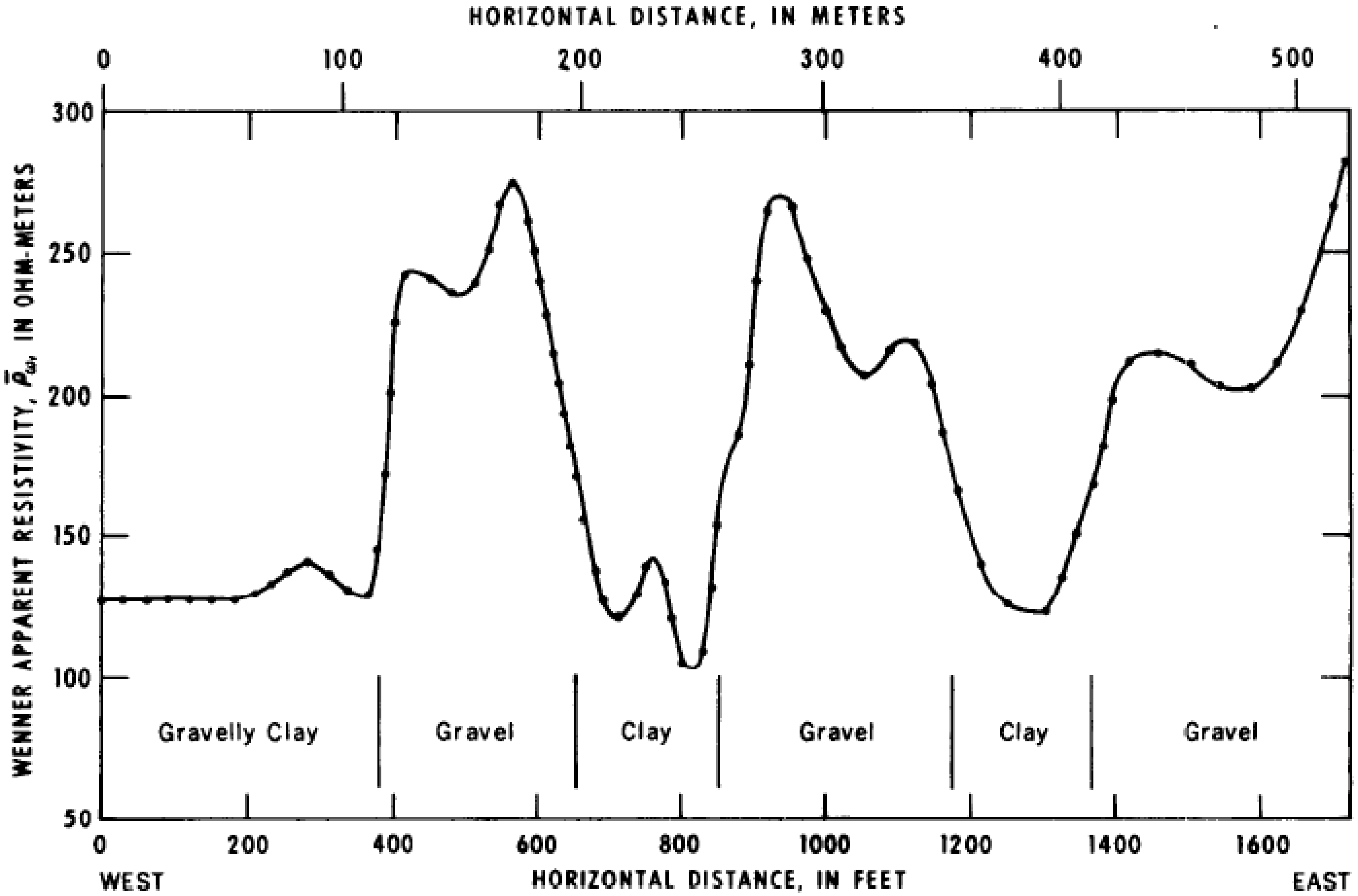

Figure 7.—Horizontal profile and interpretations over a shallow gravel deposit in California (Zohdy, unpub. data, 1964; Zohdy, 1964) using Wenner array at a = 9.15 meters.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Apparent Resistivity Map

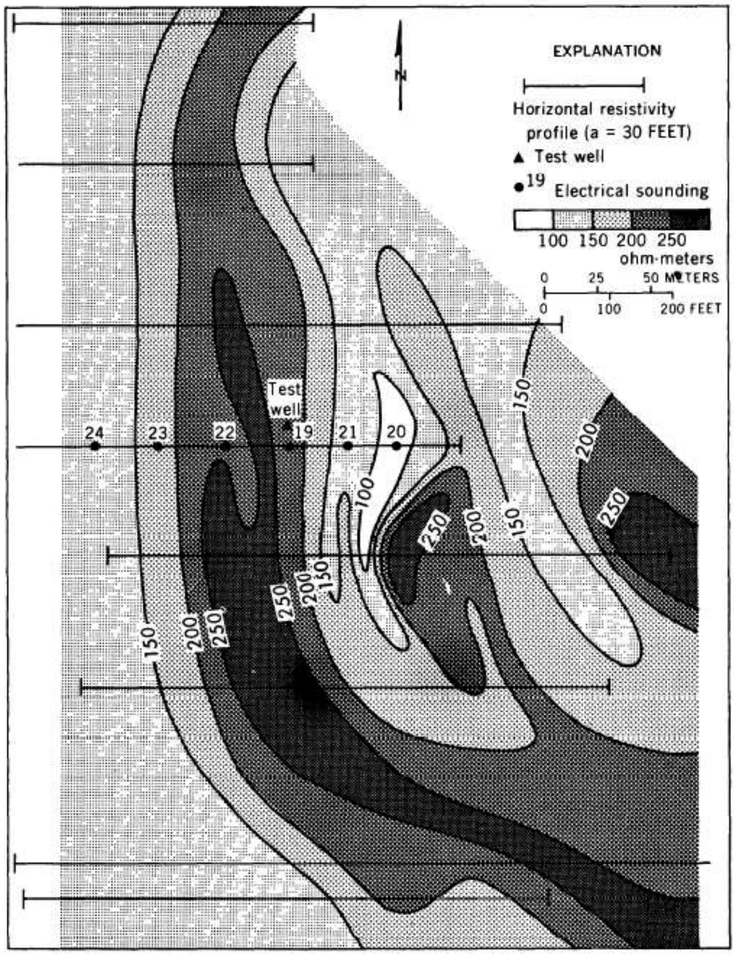

Figure 8.—Apparent-resistivity map near Campbell, Calif. Unpublished data obtained by Zohdy (1964) using Wenner array. Crosshatched areas are buried stream channels containing thick gravel deposits. Stippled areas are gravelly clay deposits.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

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Resistivity Profile over Buried Stream Channel

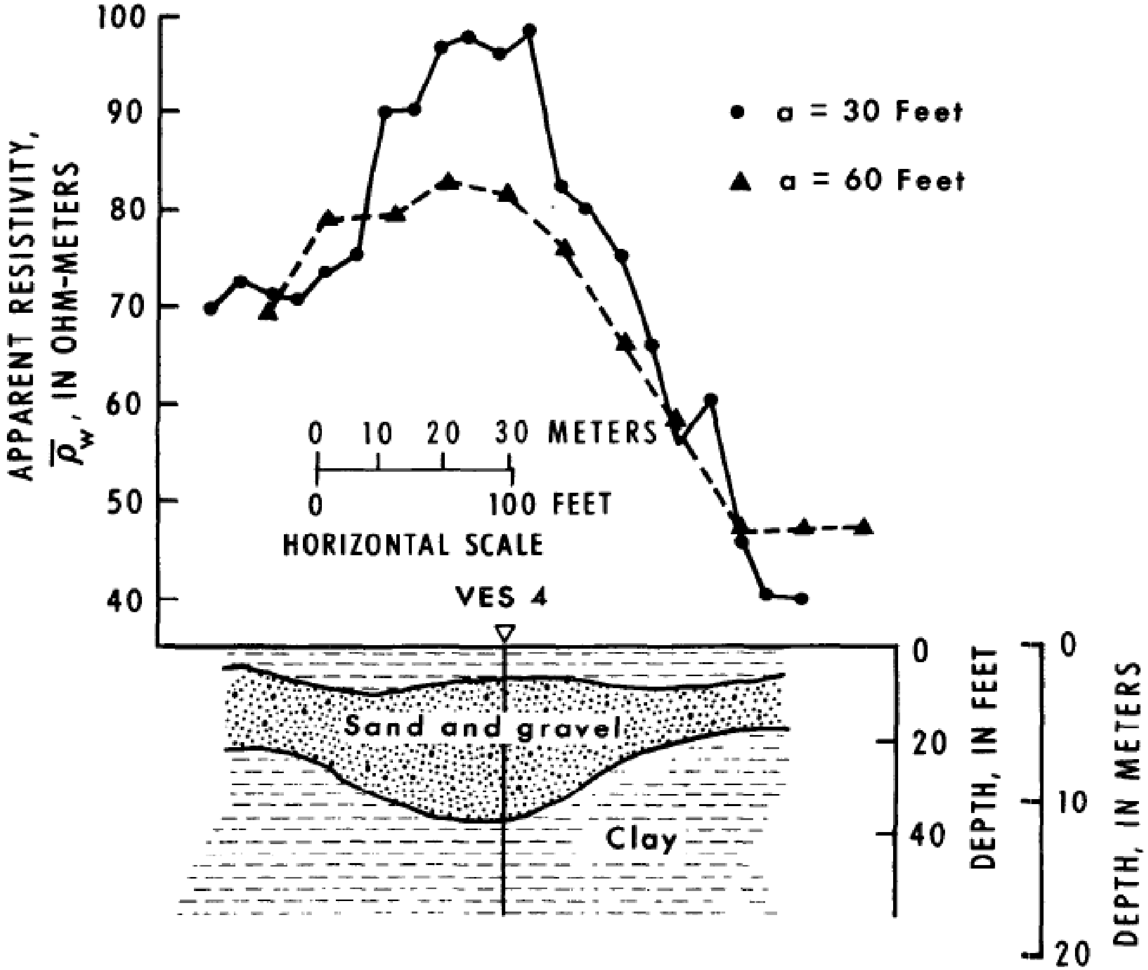

Figure 9.—Horizontal profiles over a buried stream channel using two electrode spacings: a = 9.15 meters (30 feet) and a = 18.3 meters (60 feet) (after Zohdy, 1964). VES 4 marks the location of an electrical sounding used to aid in the interpretation of the profiles.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Mapping Buried Stream Channels

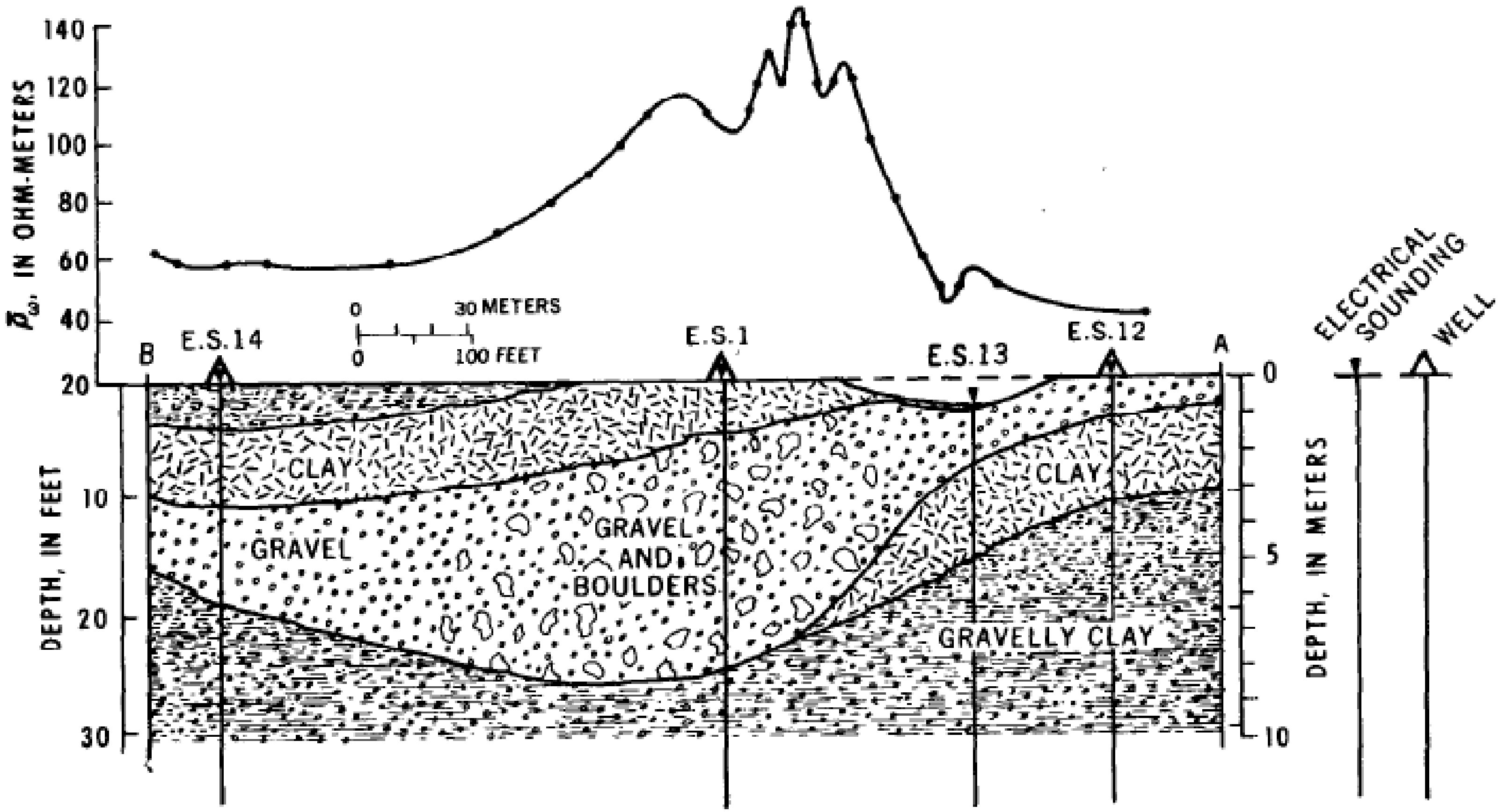

Figure 39.—Resistivity profile and geologic section, Penitencia, Calif. (after Zohdy, 1964, 1965). Horizontal profile obtained using Wenner array with electrode spacing a = 6.1 m (20 feet).

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Mapping Buried Stream Channels

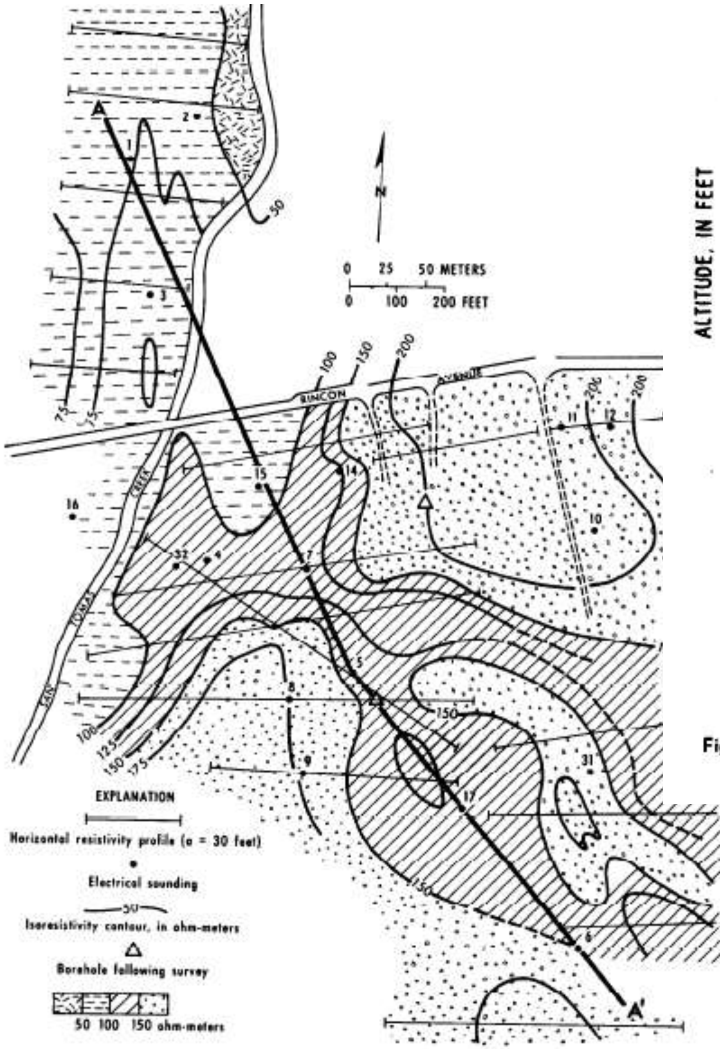

Figure 40.—Map of apparent resistivity near Campbell, Calif., obtained with Wenner array at a = 9.15 m (30 feet) and showing location of section AA'. (Unpub. data obtained by Zohdy, 1964.)

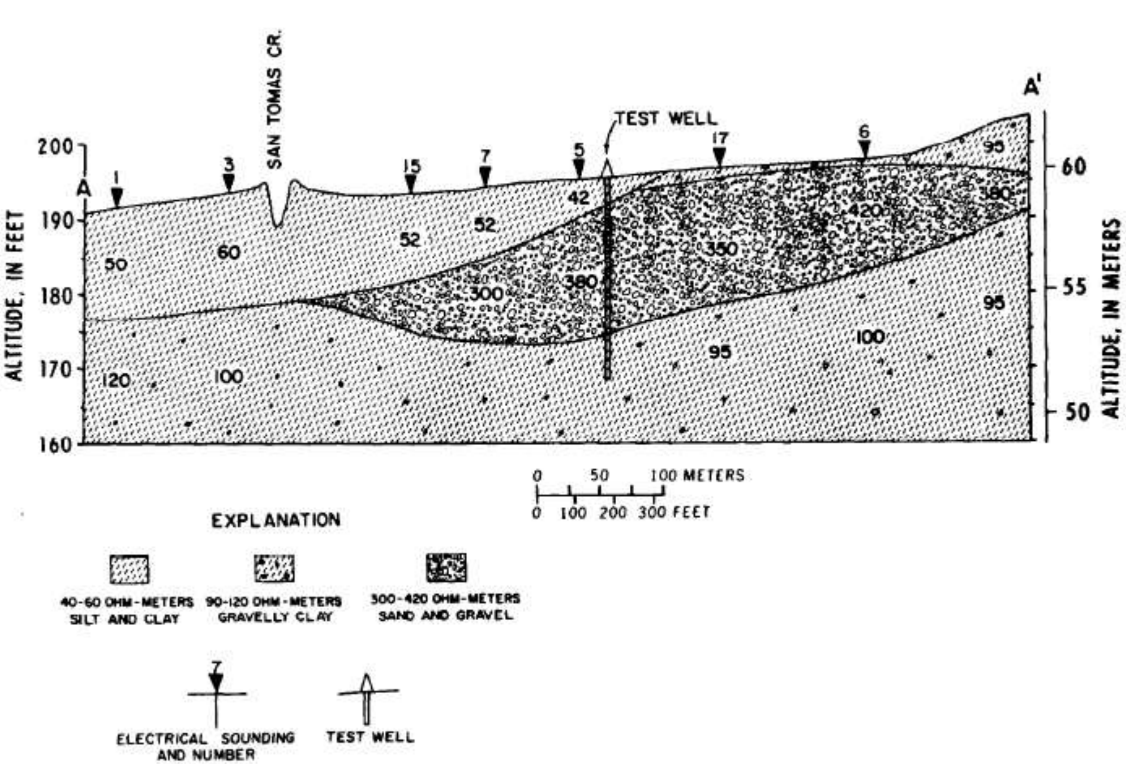

Figure 41.—Geoelectric section and drilling results near Campbell, Calif. Numbers in layers designate interpreted true resistivities. (Unpub. data obtained by Zohdy, 1964.)

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

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Mapping Buried Stream Channels

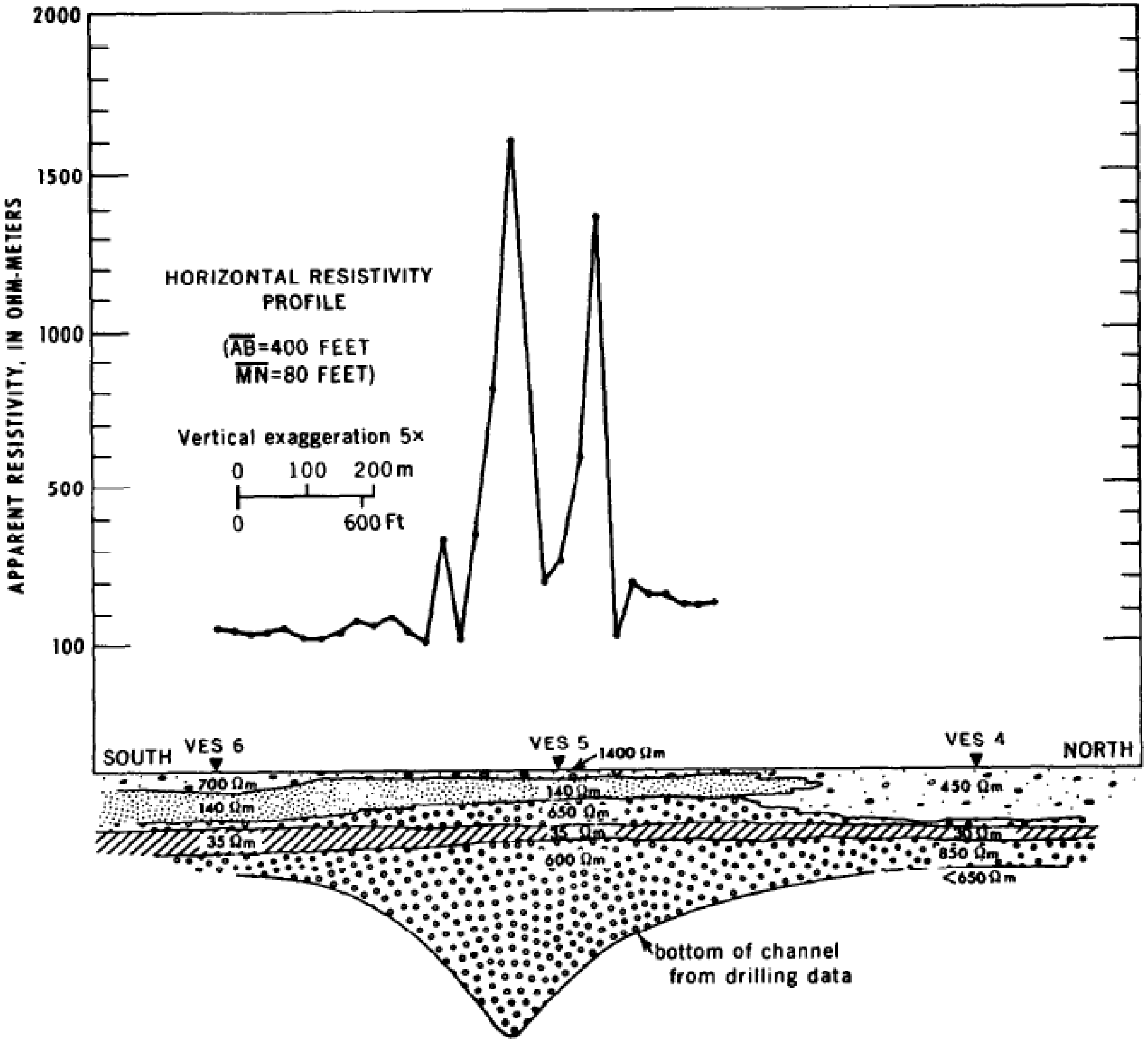

Figure 42.—Apparent-resistivity profile and geologic interpretation over buried channel, near Salisbury, Md. Data obtained by Zohdy and Jackson in 1966.

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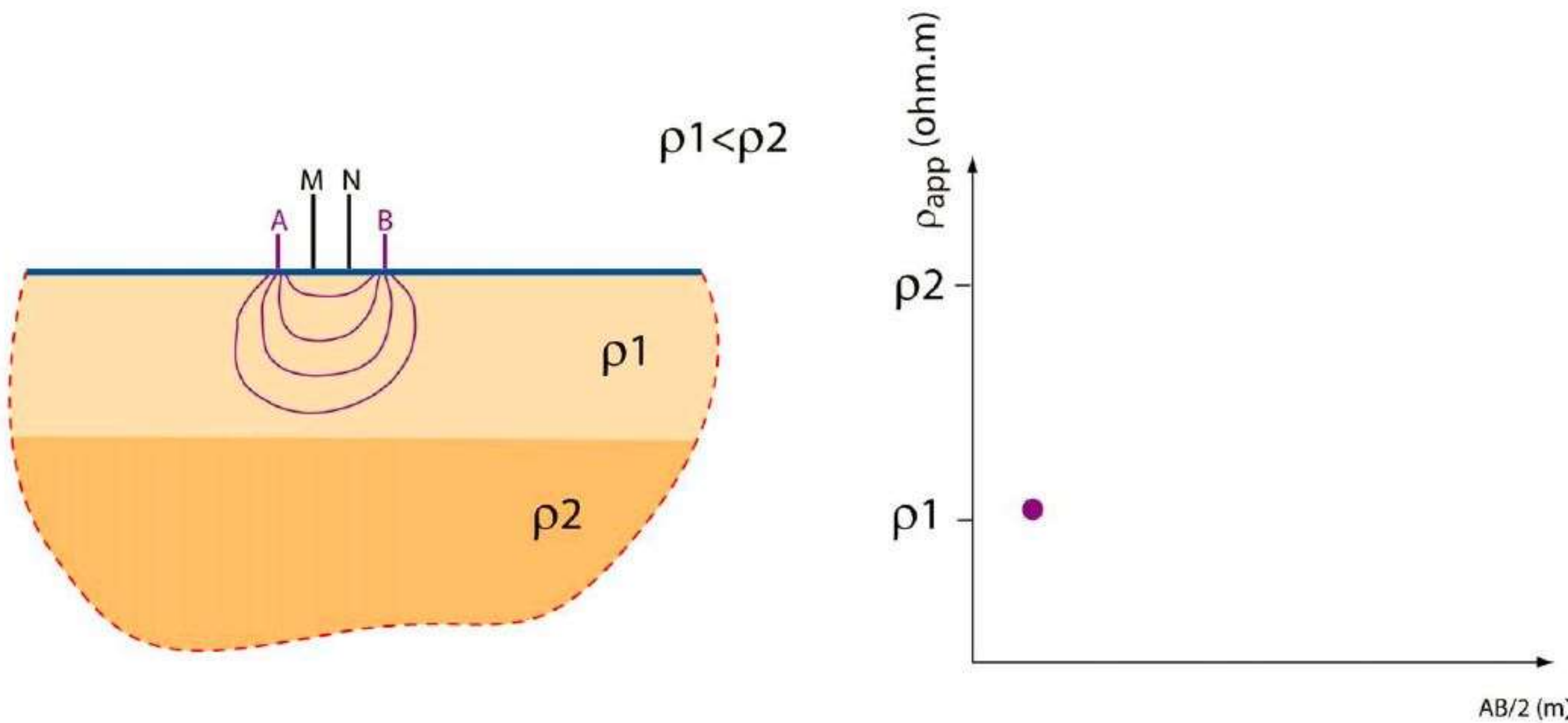
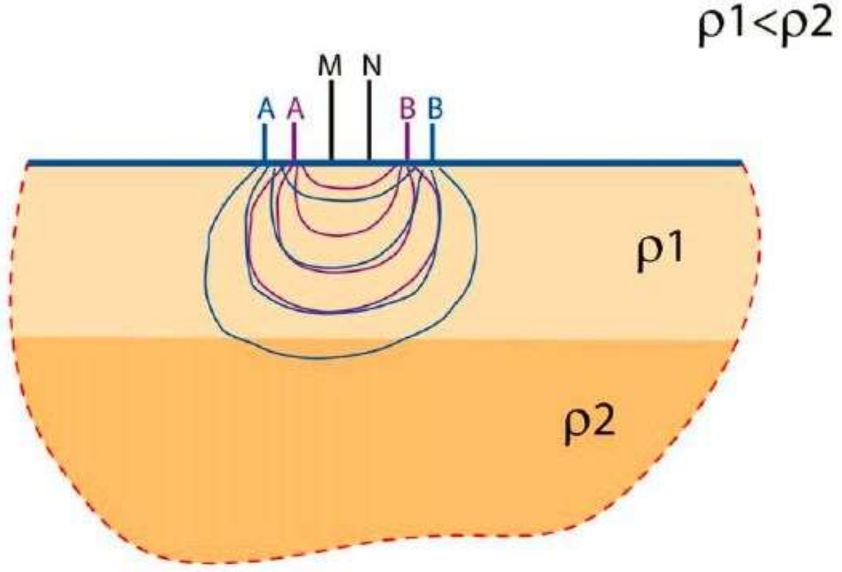
Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

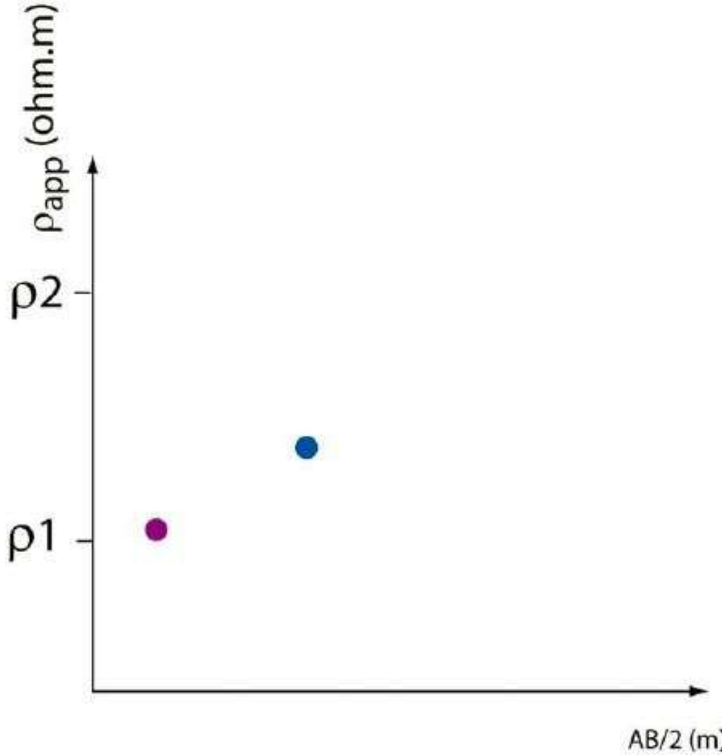
Vertical Electrical Sounding (VES)



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

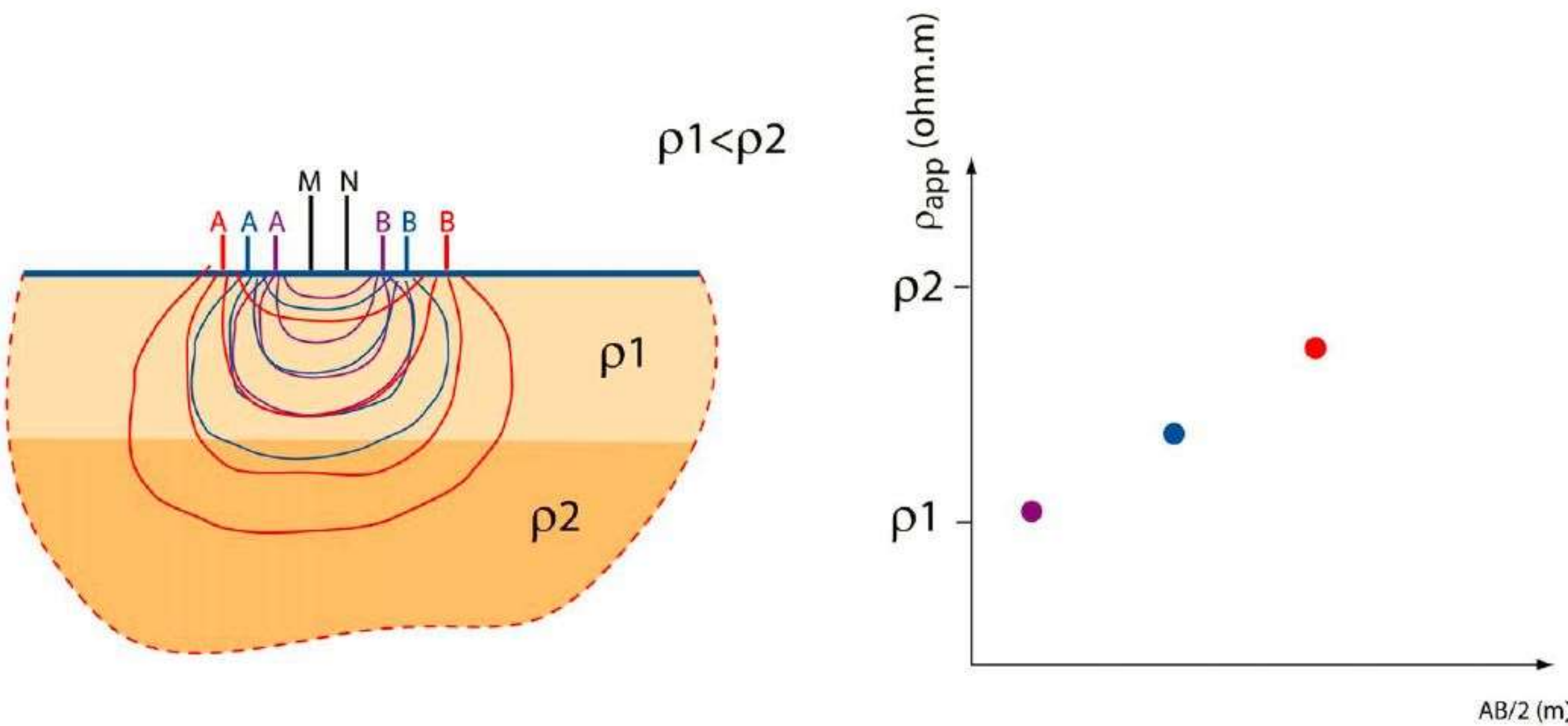
Vertical Electrical Sounding (VES)





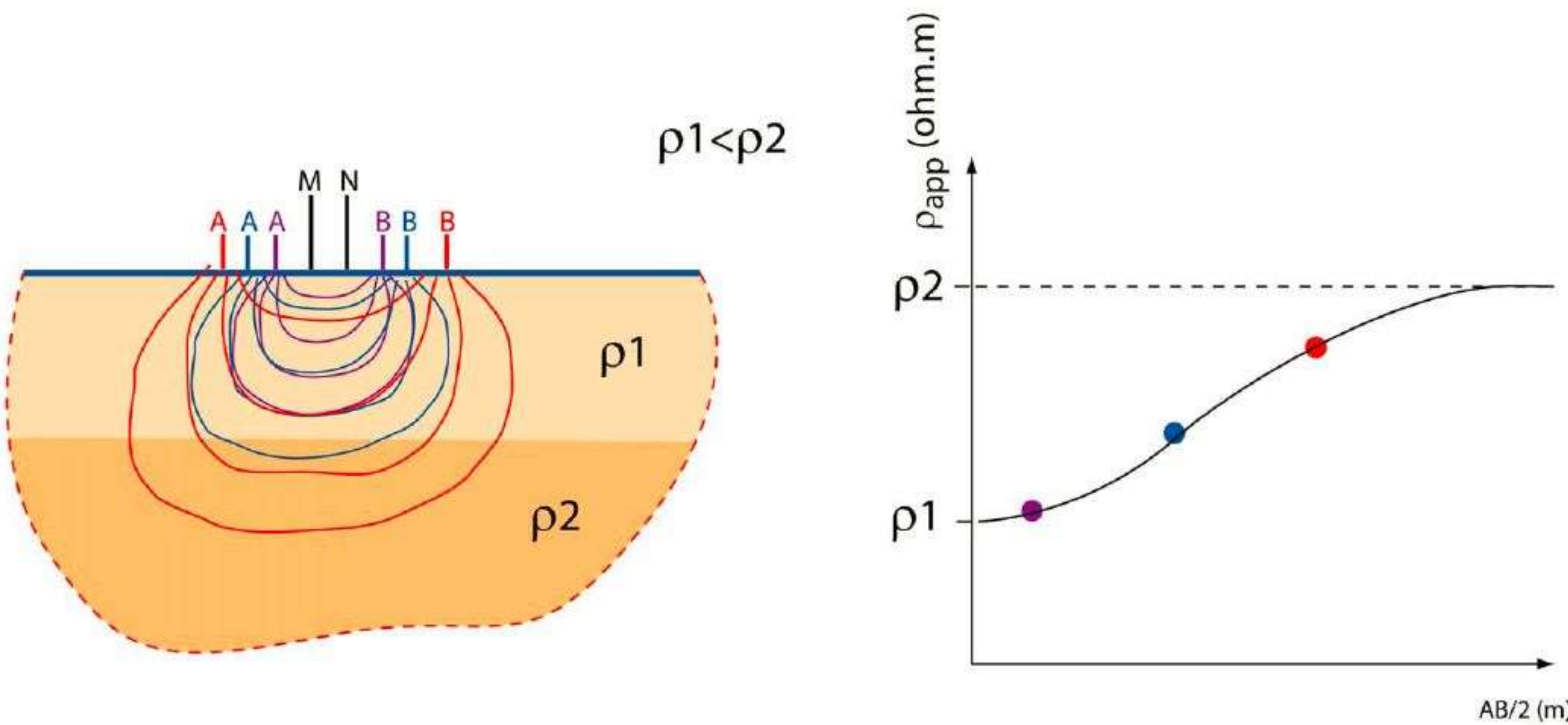
Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Vertical Electrical Sounding (VES)



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Vertical Electrical Sounding (VES)



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

DC Resistivity Field Sheets - Schlumberger

SCHLUMBERGER ARRAY
FIELD SHEET

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Project: ______________________ Sounding No.: ______________________

Location: ______________________ Coordinates East: ______________________

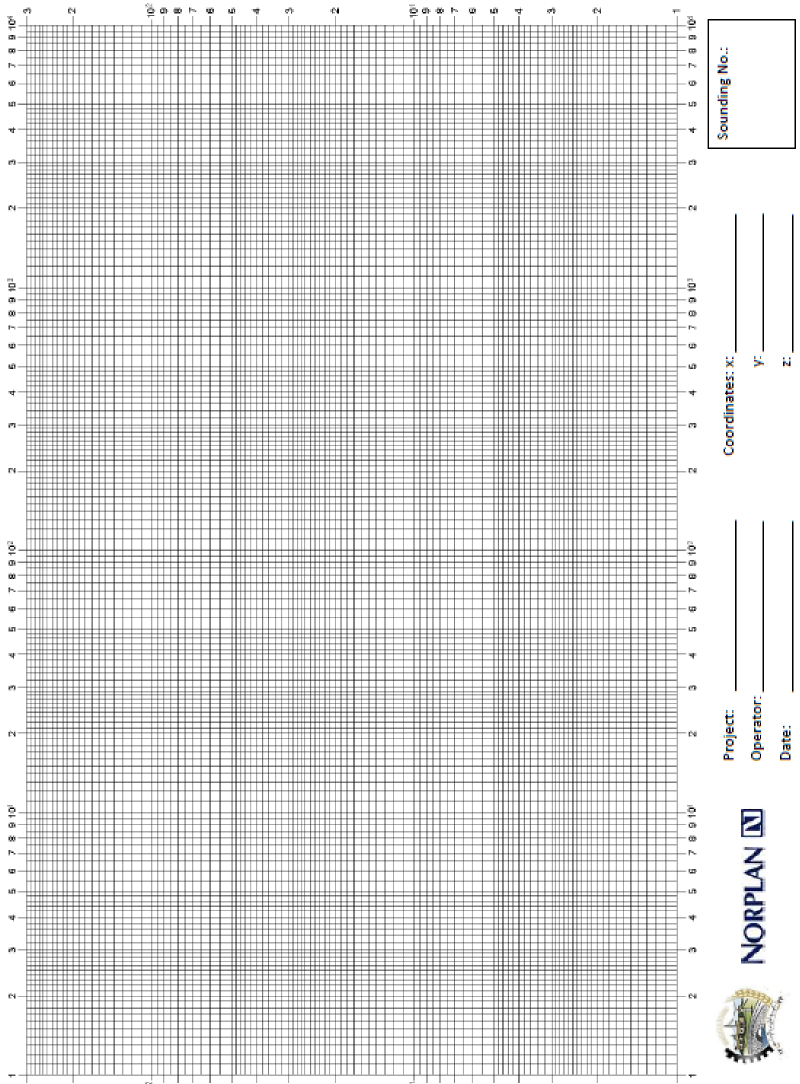
Equipment: ______________________ Coordinates North: ______________________

Operator: ______________________ Azimuth: ______________________

A M O N B

$$K = \frac{AM \cdot AN}{MN}\pi \qquad \rho_a = K\frac{\Delta V}{I}$$

Marks	OA in m	K for M—N 1m	M—N 10m	M—N 60m	M—N 200m	ΔV in millivolts (mV)	I in milliamperes (mA)	ρ_a in ohm-m (Ωm)
1	1	2.35						
2	2	11.8						
3	3	27.5						
1	4	49.5						
2	5	77.7						
3	6	112						
1	8	200						
2	10	313						
3	15	705	62.8					
1	20	1250	118					
2	25	1960	188					
3	30	2820	275					
1	35	3850	377					
2	40	5020	495					
3	50	7850	780					
1	60	11300	1120					
2	70	15400	1530					
3	80	20100	2000	288				
1	100	31400	3130	475				
2	125		4900	770				
3	150		7050	1130				
1	175		9600	1560				
2	200		12500	2040				
3	250		19600	3230				
1	300		28200	4660				
2	350			6360	1766			
3	400			8300	2360			
1	450			10500	3000			
2	500			13000	3760			



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PART 4 – VES Interpretation

1. Schlumberger – Wenner comparison
2. One & Two Layer Models
3. Three Layer Models
4. Effects of Inhomogeneity
5. Correcting Sounding Curves
6. Principle of Equivalence
7. Principle of Suppression

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Comparison: Wenner & schlumberger Arrays

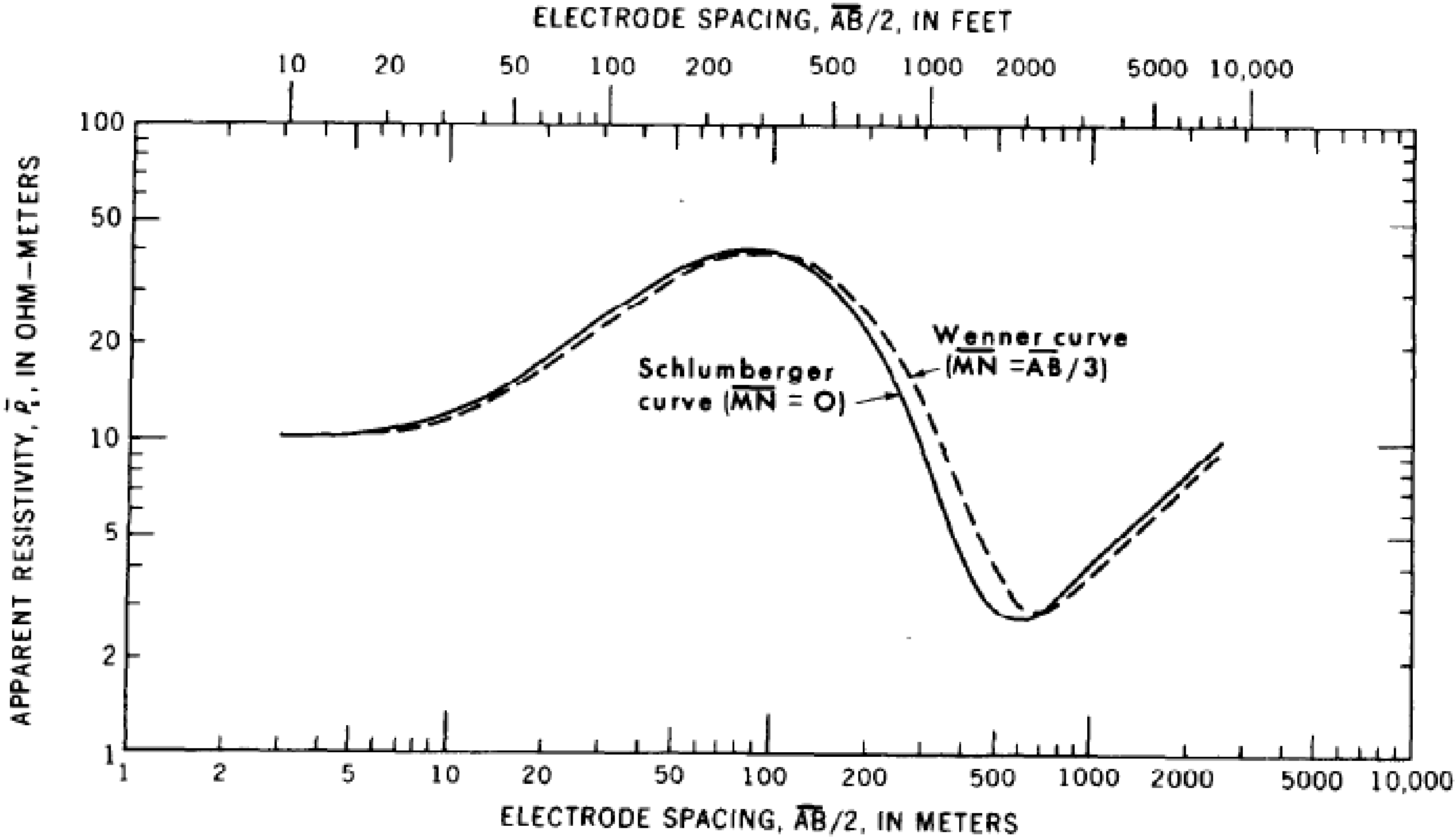
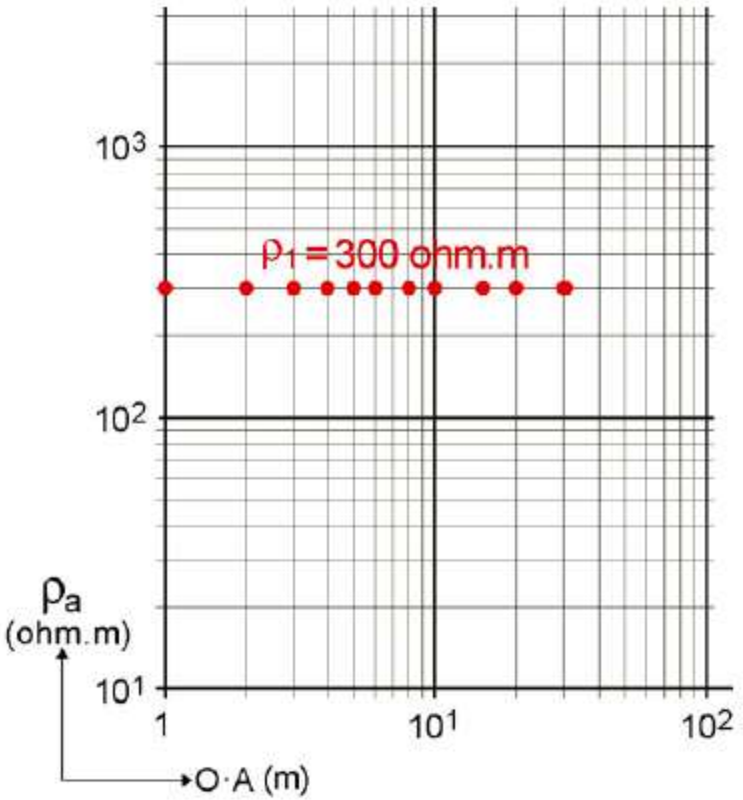
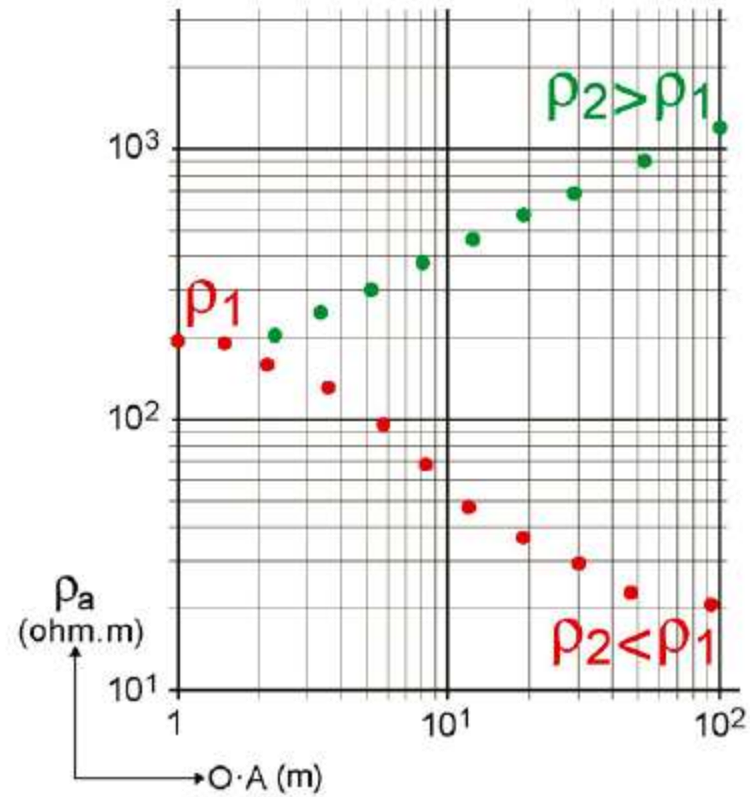


Figure 11.—Comparison between four-layer Schlumberger and Wenner sounding curves. Electrode spacing is $\overline{AB}/2$ for both curves.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

VES: 1 & 2 Layers





Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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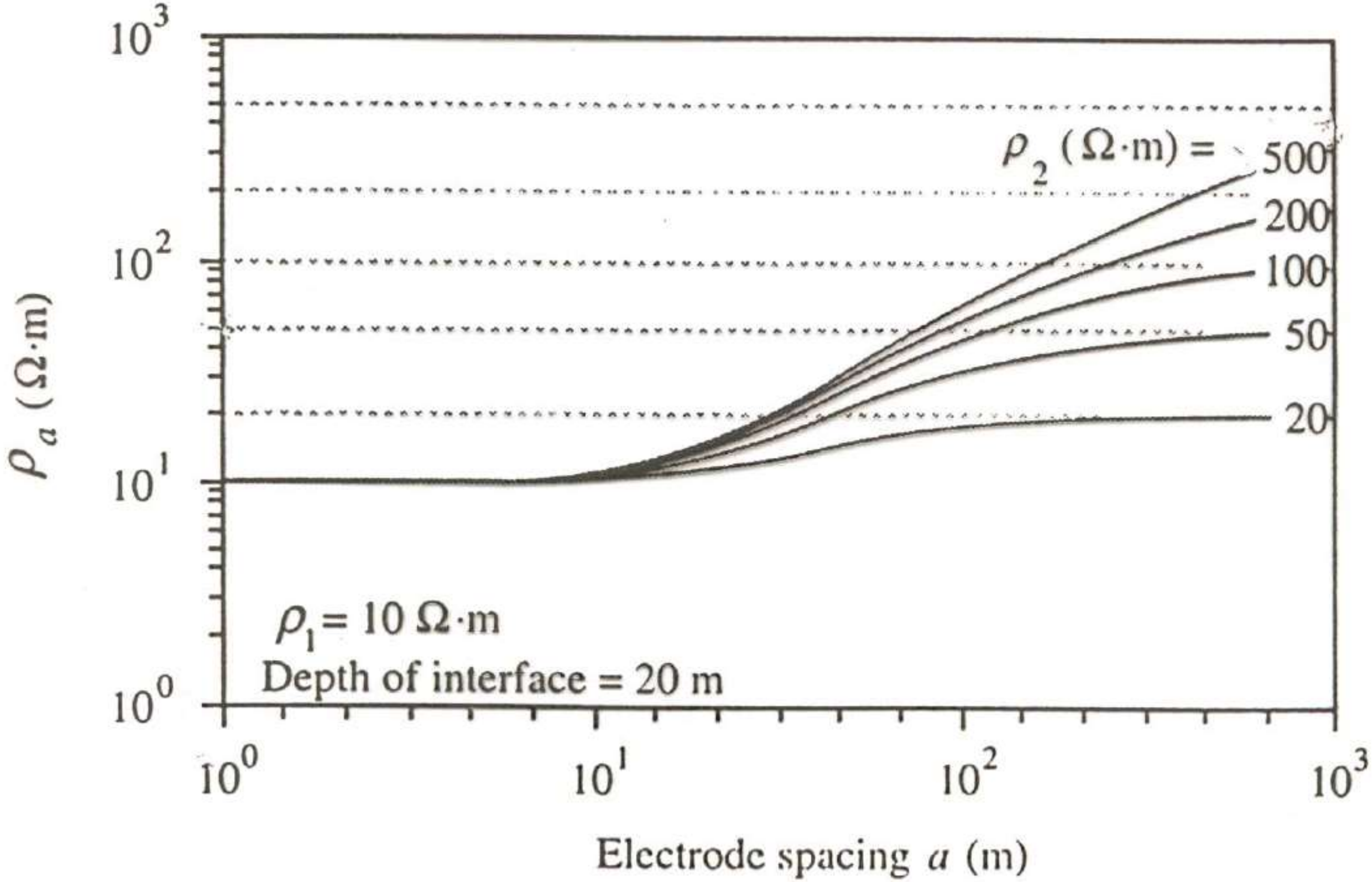
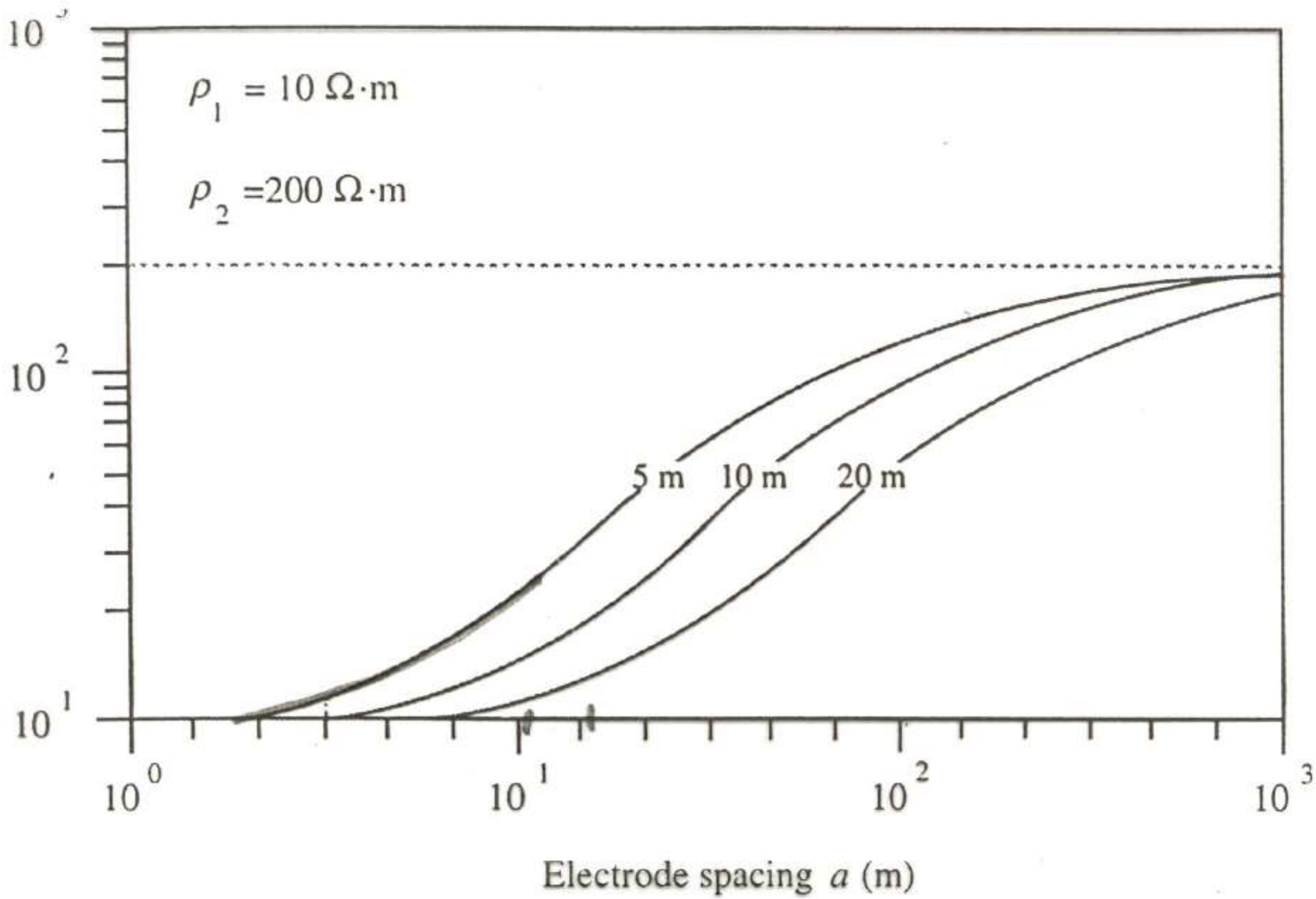
VES: 2 Layers



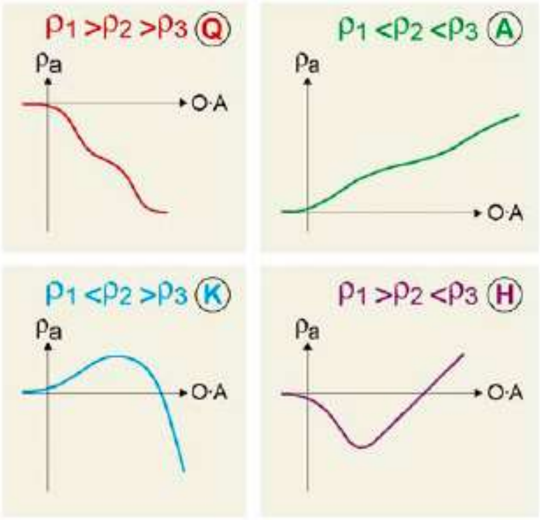
Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

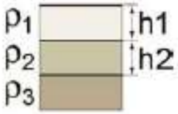
VES: 2 Layers

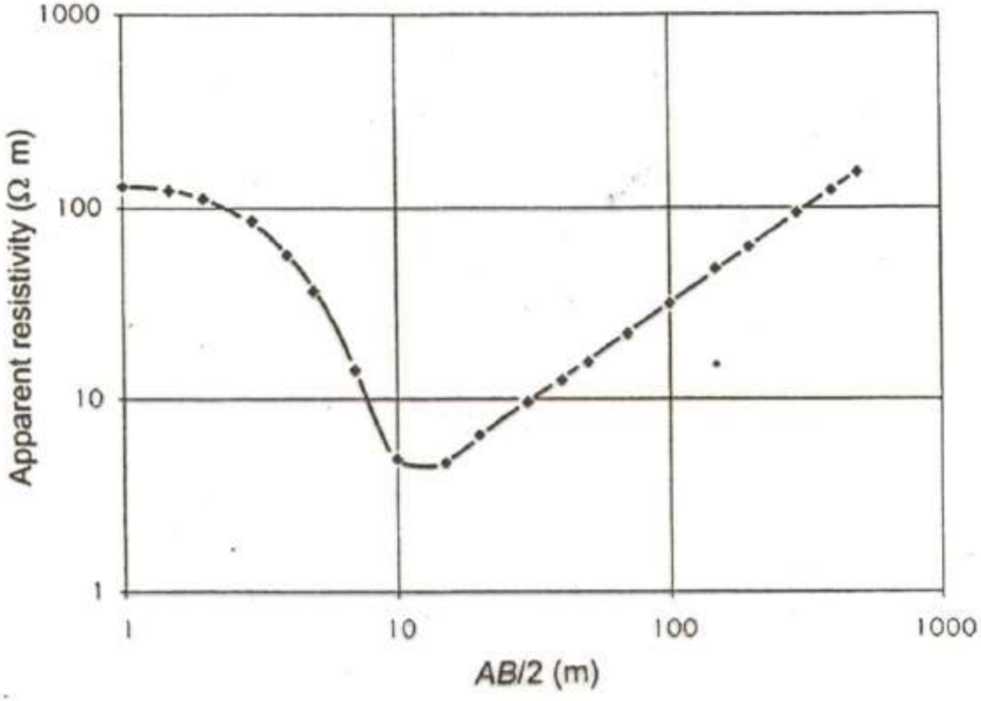


Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

VES: 3 Layers







Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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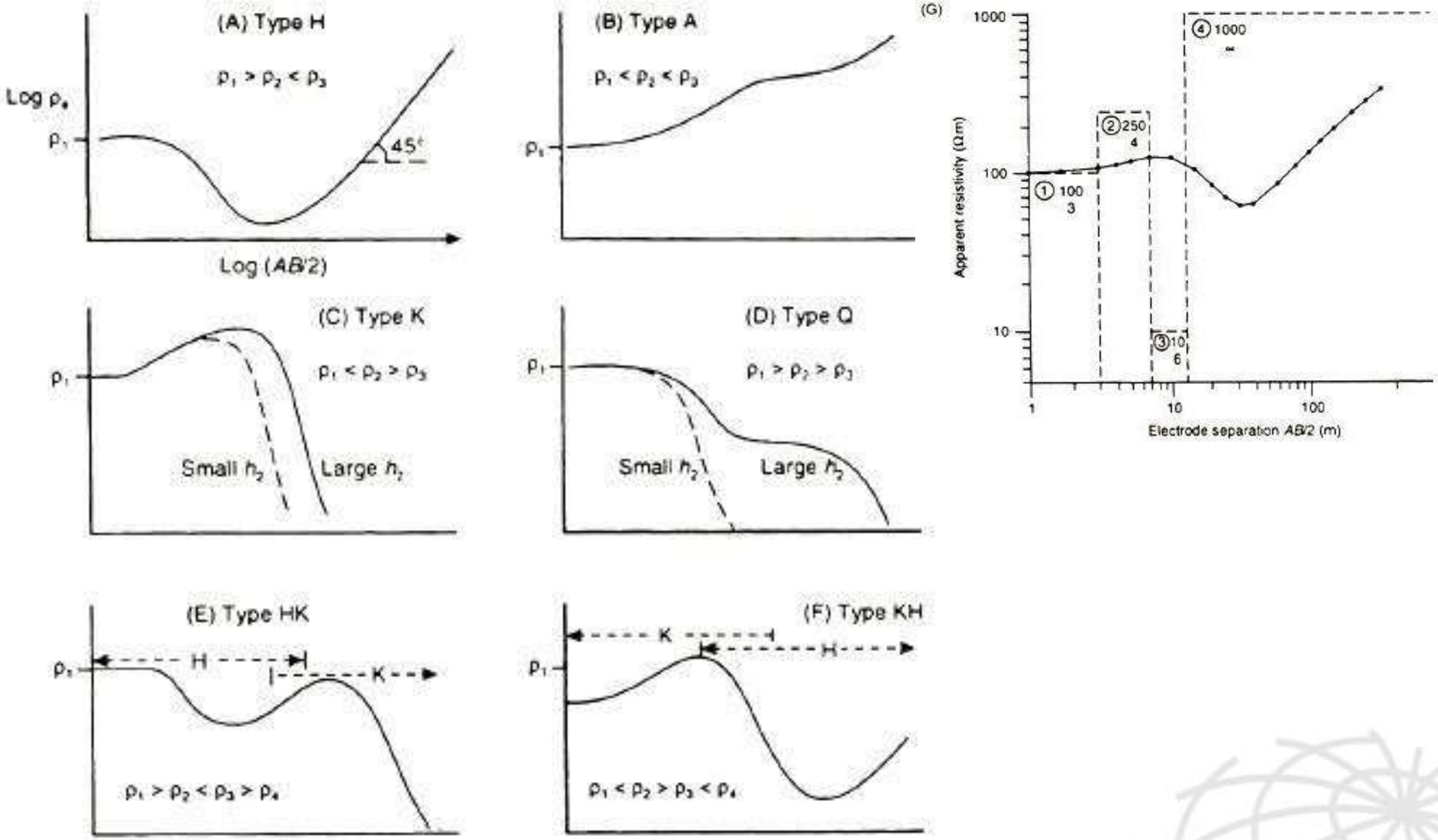
VES: 3 Layers



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

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Sounding Curves Remain the Same on Log-Log

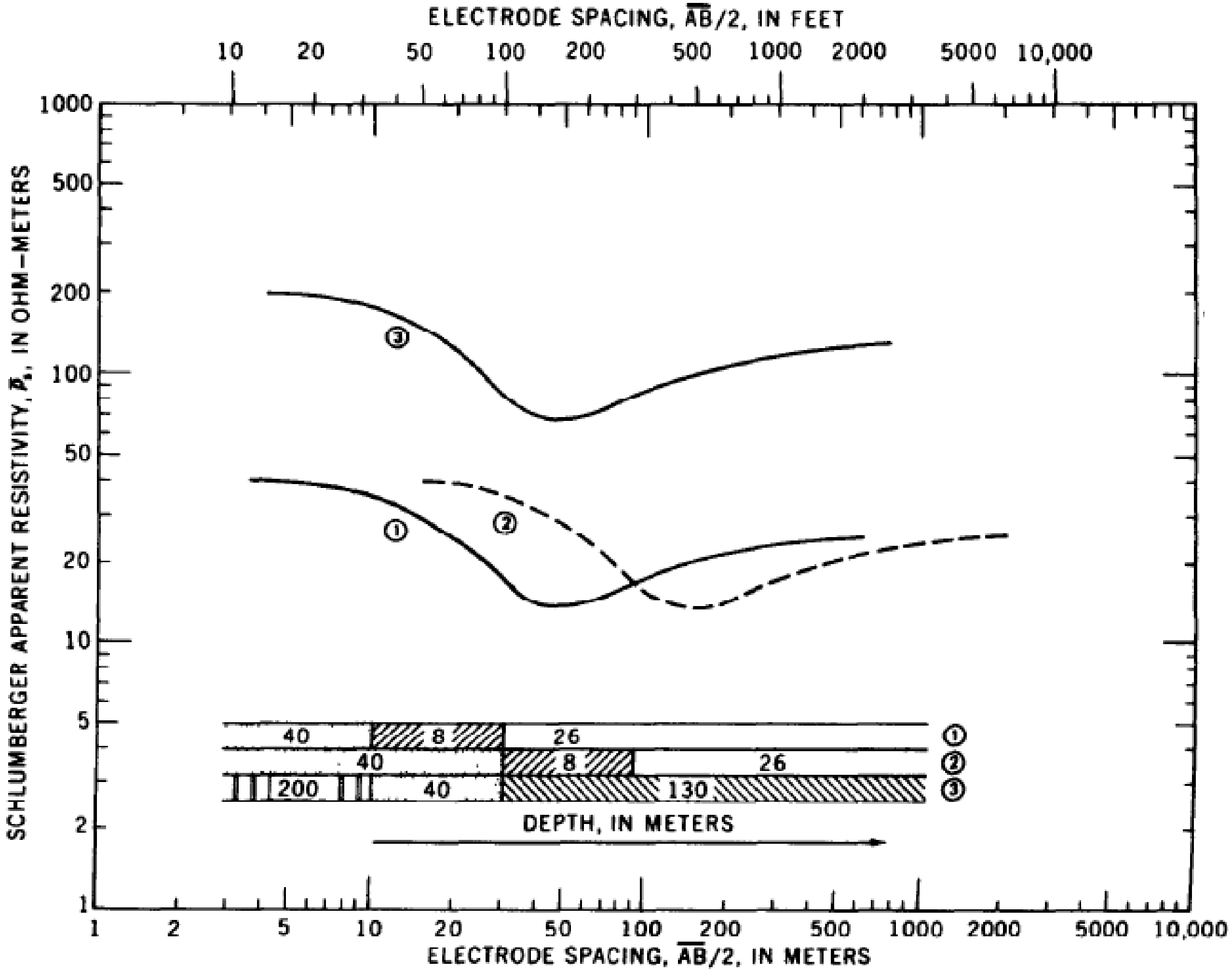

Figure 13.—Logarithmic plot of sounding curves. The layers in model 2 are three times as thick as model 1; the layer resistivities in model 3 are five times as large as model 1; however, the shapes of all three curves are identical.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Sounding Curves Are Different on Normal Plots!

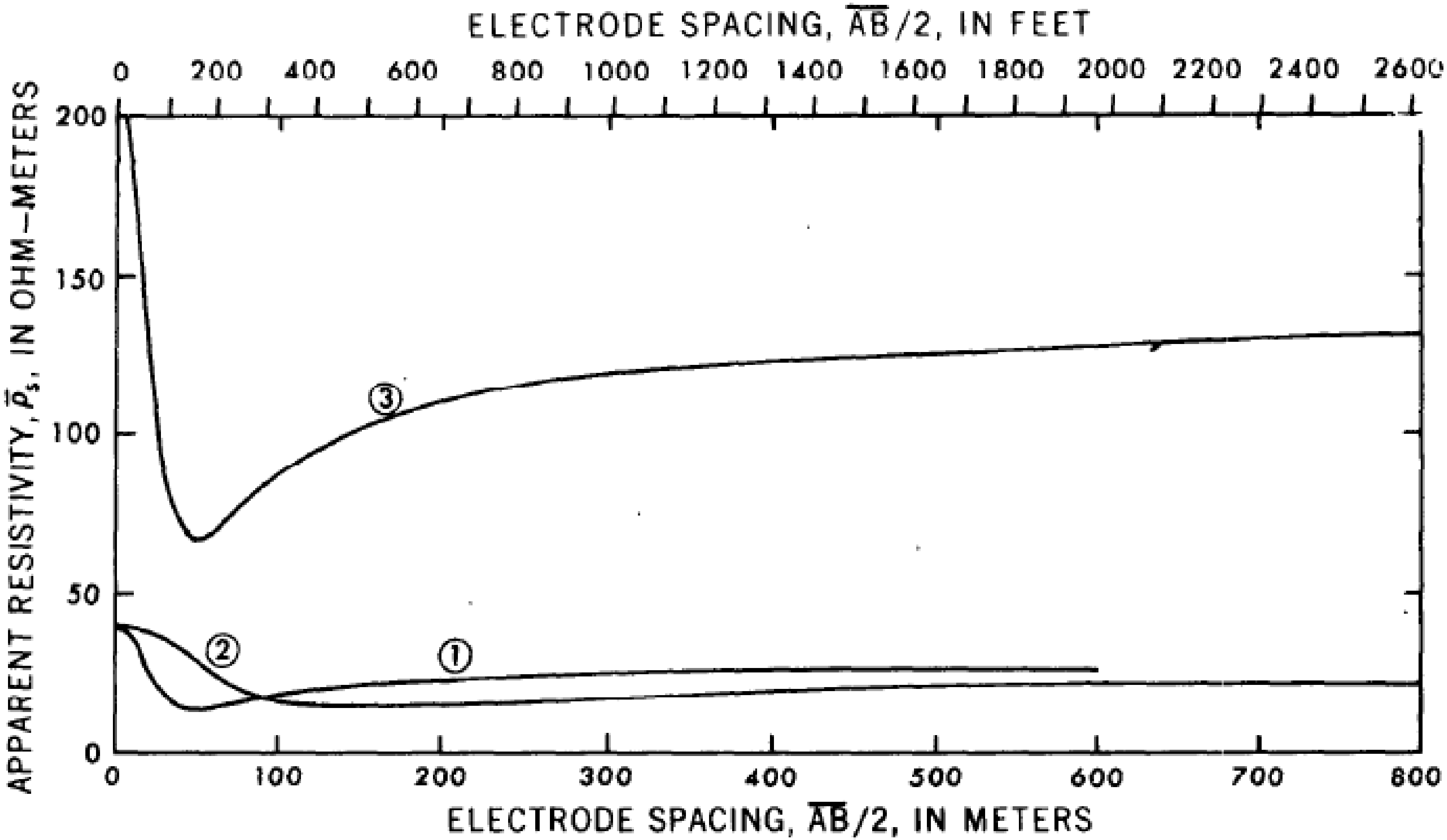

Figure 14.—Linear plot of sounding curves. Earth models are the same as in figure 13. Curve form is not preserved.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Schlumberger Sounding Curves – 3 Layer Earth

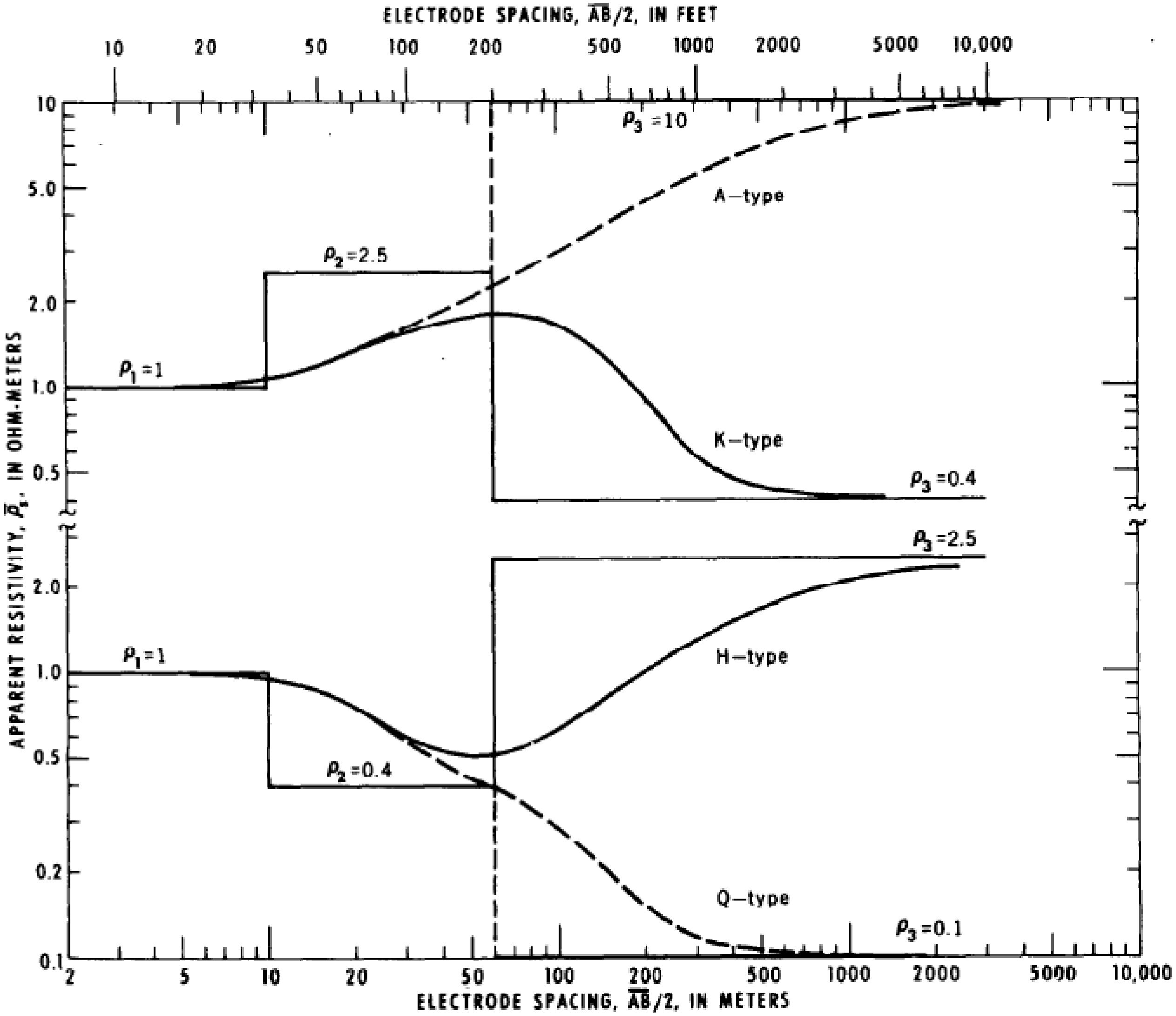

Figure 18.—Examples of the four types of three-layer Schlumberger sounding curves for three-layer Earth models.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Schlumberger Sounding Curves – 4 Layer Earth

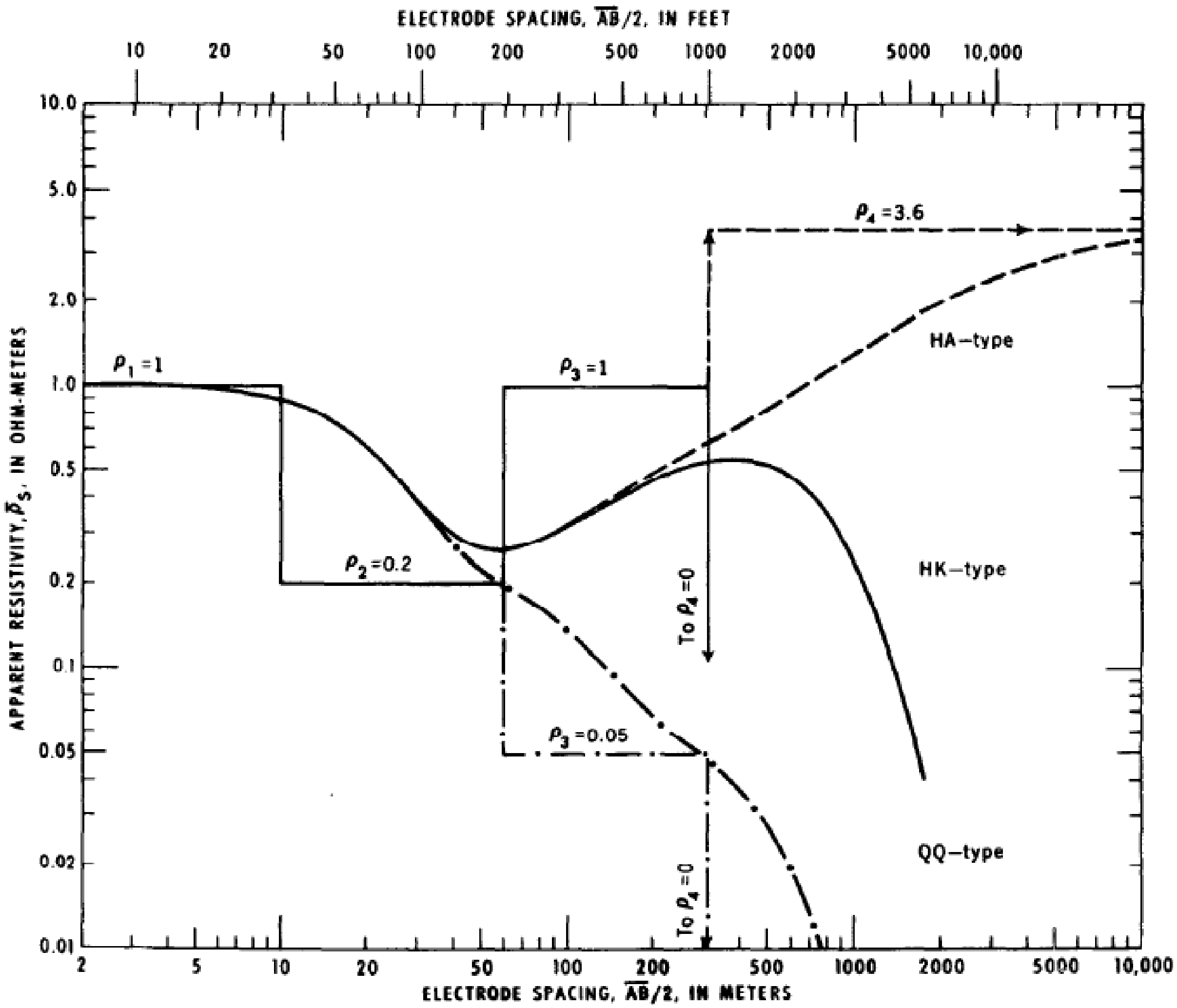

Figure 19.—Examples of three of the eight possible types of Schlumberger sounding curves for four-layer Earth models.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

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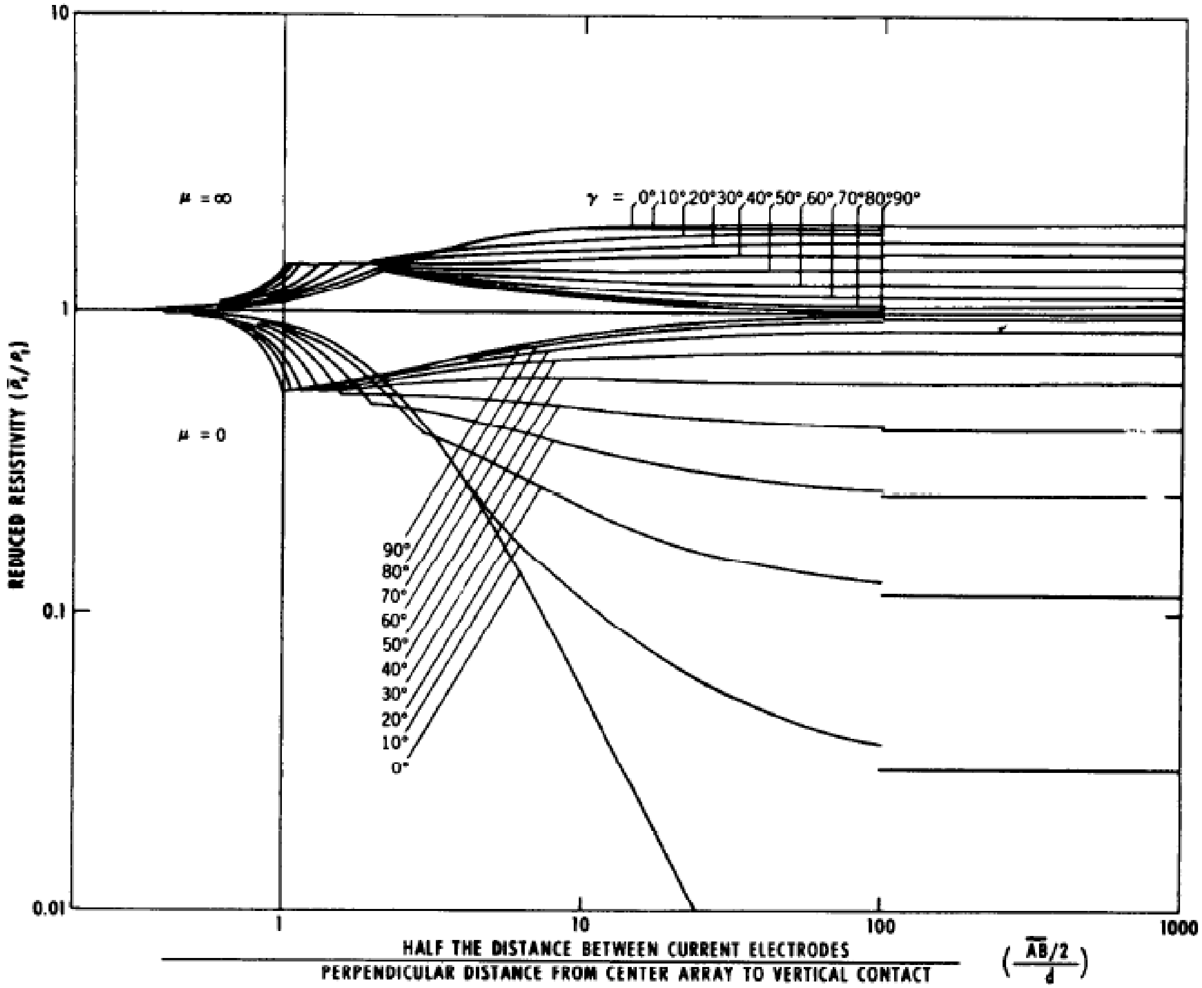
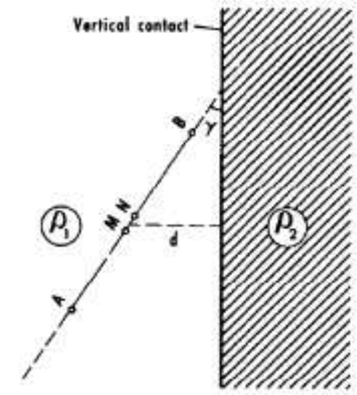
Schlumberger Sounding Curves – Vertical Contact





Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Cusp in Sounding Curves

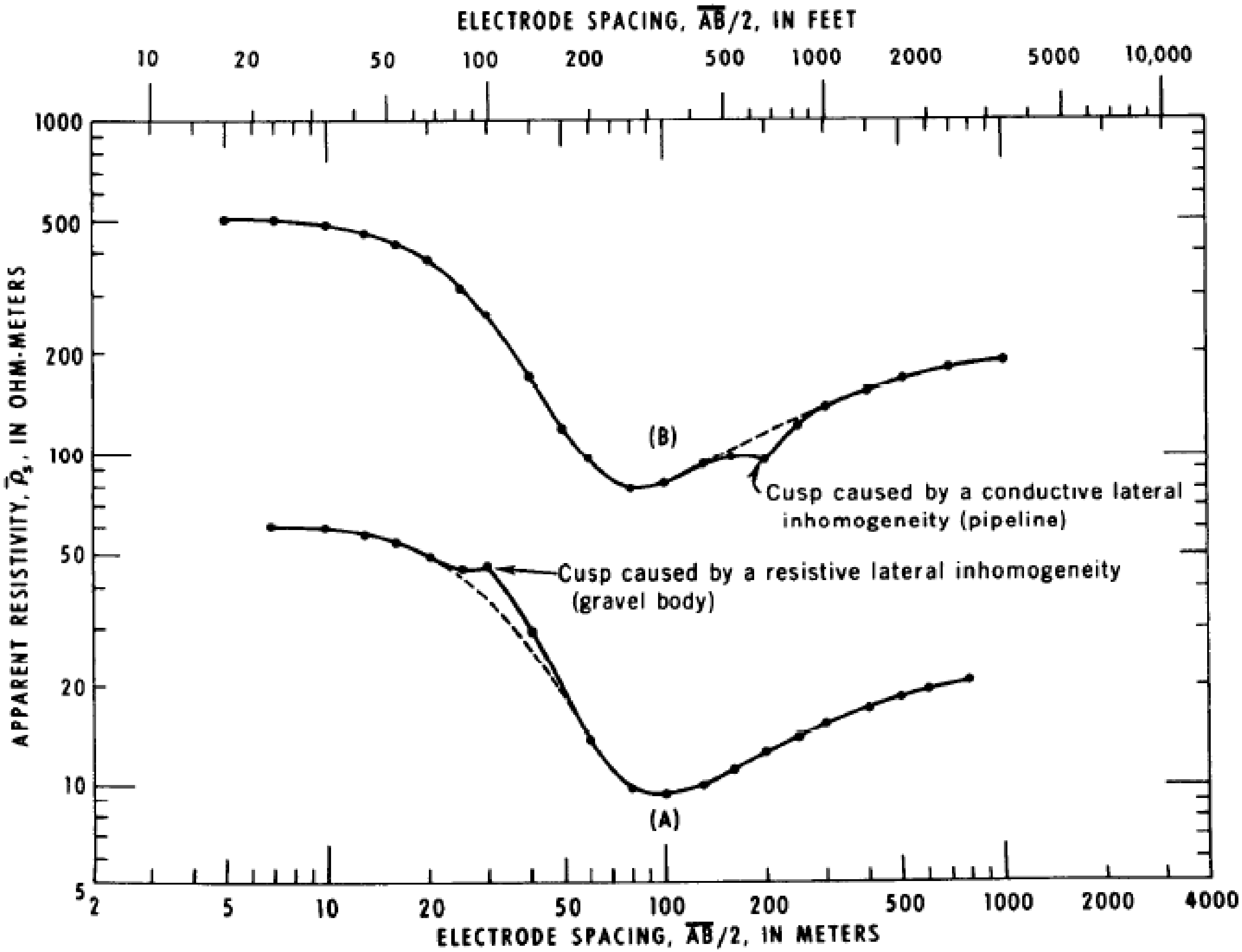


Figure 29.—Distortion of sounding curves by cusps caused by lateral inhomogeneites.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Sounding Curves Distortion

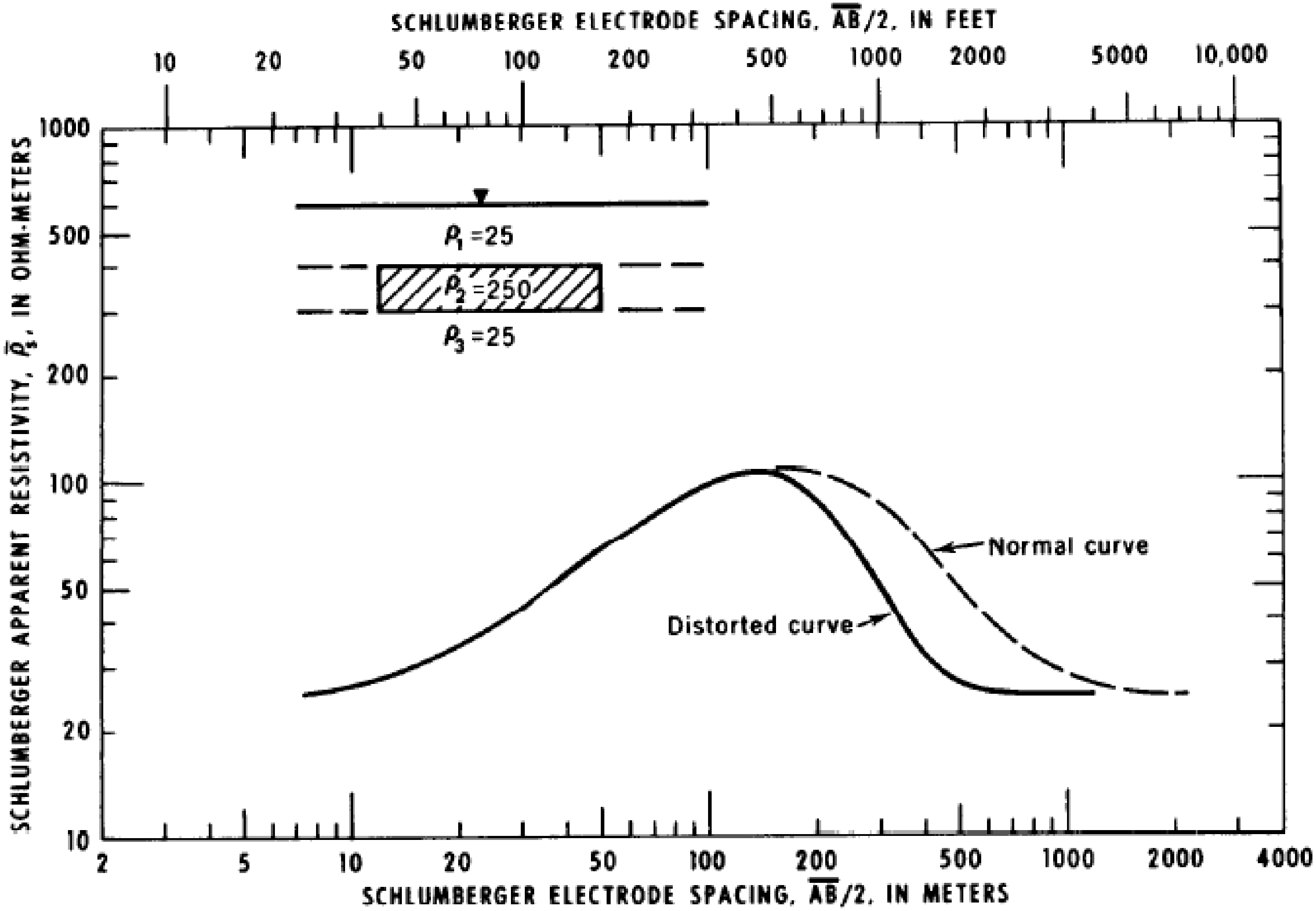


Figure 30.—Example of a narrow peak on a K-type curve, caused by the limited lateral extent of a resistive middle layer (after Alfano, 1959). Reproduced with permission of "Geophysical Prospecting."

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

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Correcting Distorted Sounding Curves

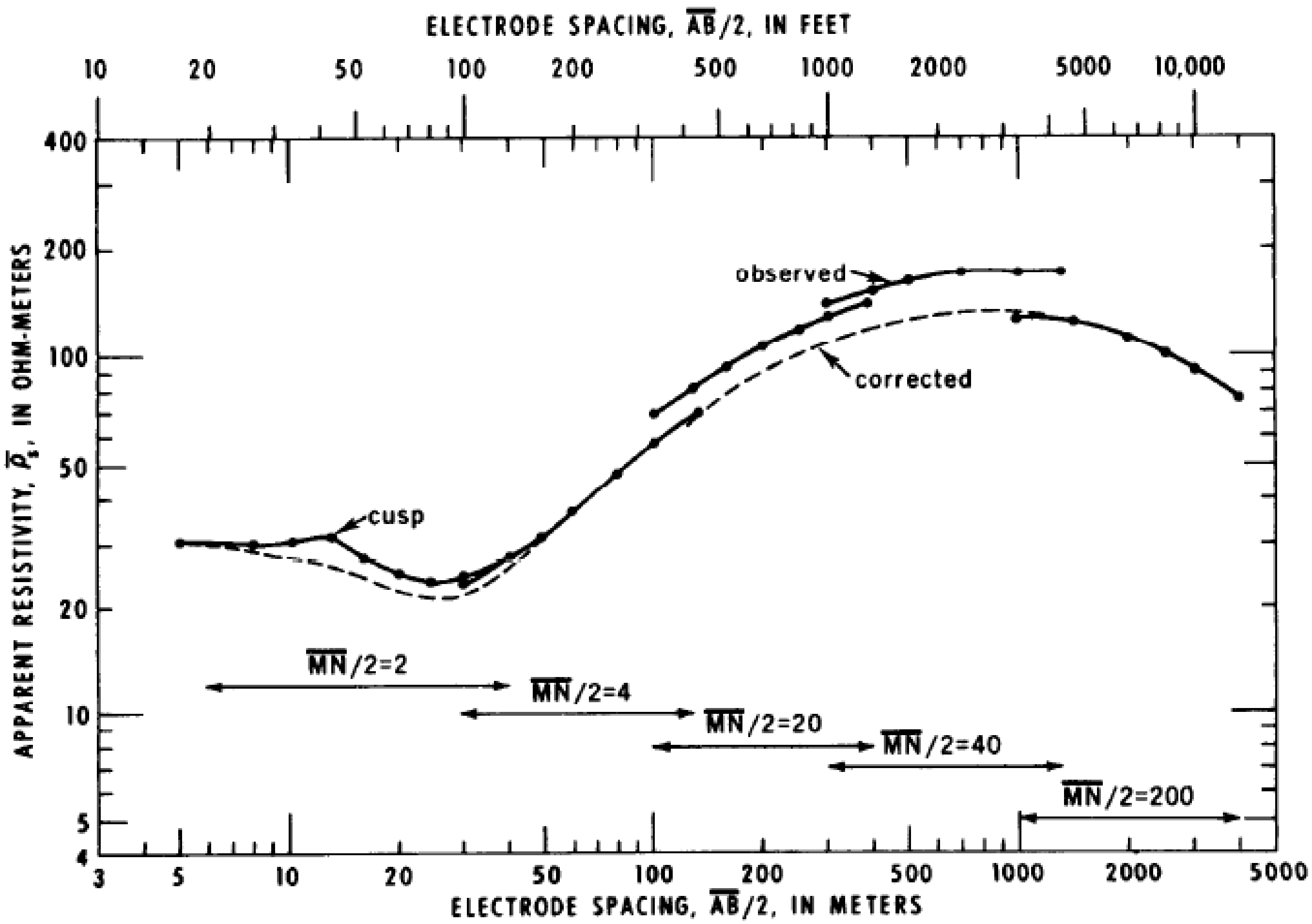

Figure 31.—Example of a distorted HK-Schlumberger curve and the method of correction.

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

Sounding Curves Distortion

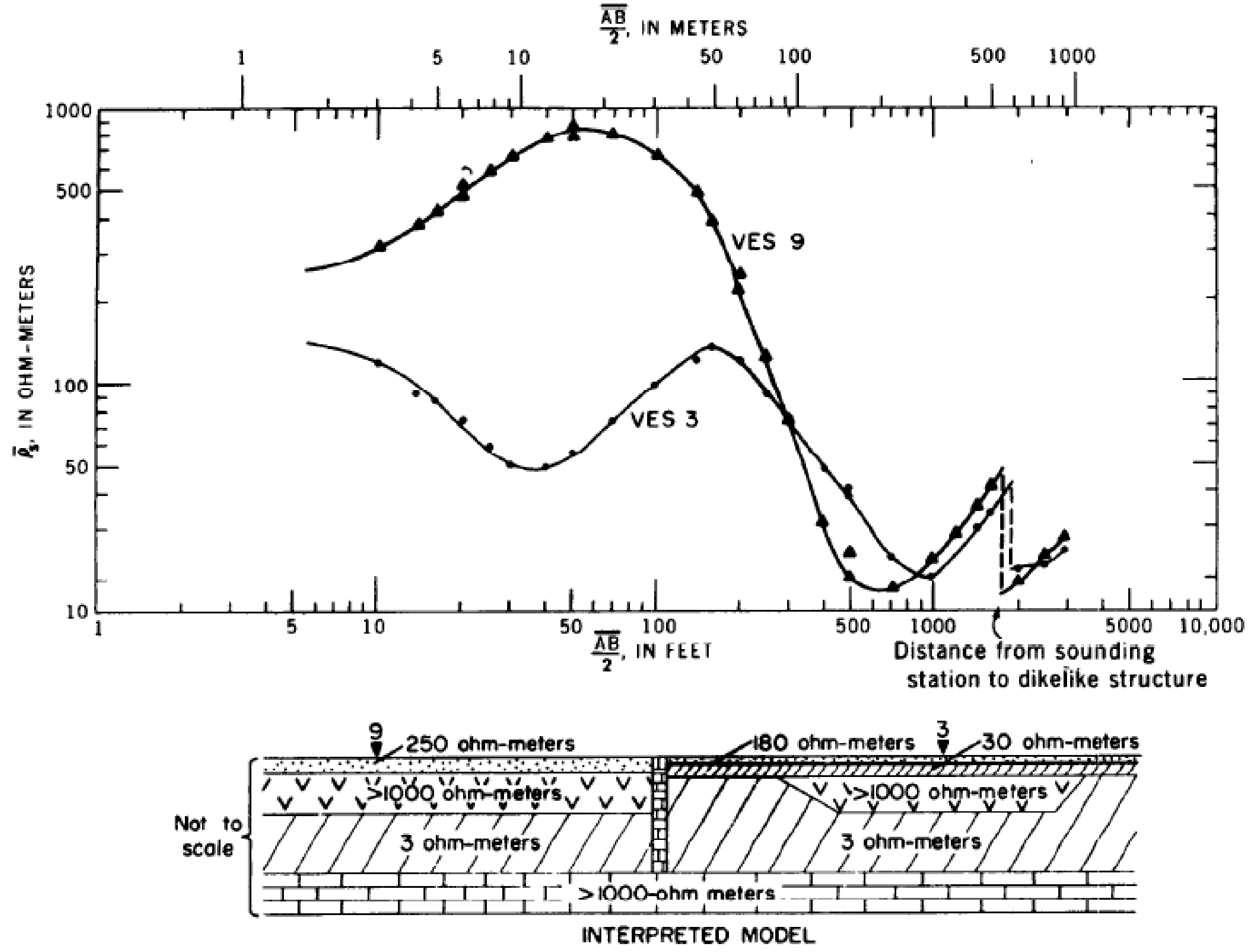

Figure 32.—Examples of tares (discontinuities) on Schlumberger curves caused by a near vertical dikelike structure. (after Zohdy, 1969a). Reproduced with permission of "Geophysics."

Source: USGS Techniques of Water Resources Investigations – D1 Application of Surface Geophysics to Ground-water Investigations

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Principle of Equivalence

Transverse Resistance

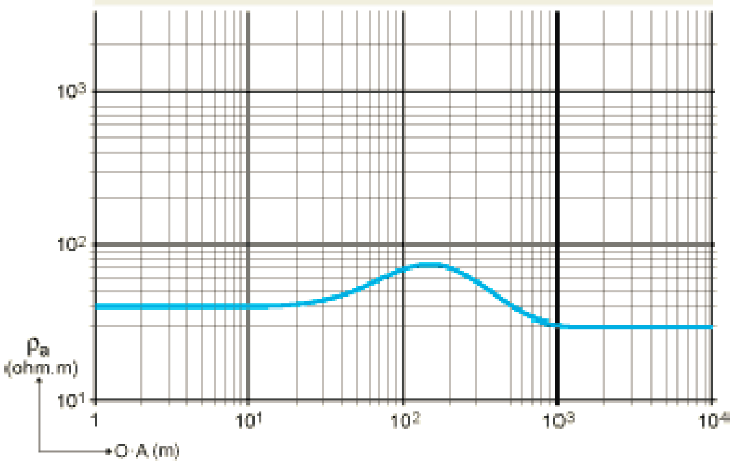
EQUIVALENCE TYPE K ($\rho_1 < \rho_2 > \rho_3$)

INTERPRETATION (A)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
40	36	0
800	10	36
30		46

INTERPRETATION (B)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
40	36	0
400	20	36
30		56



$$R = h\rho$$

Longitudinal Conductance

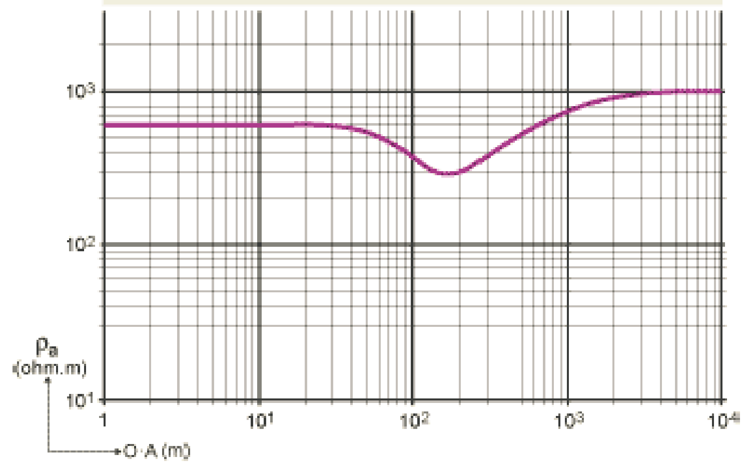
EQUIVALENCE TYPE H ($\rho_1 > \rho_2 < \rho_3$)

INTERPRETATION (A)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
600	50	0
20	10	50
1000		60

INTERPRETATION (B)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
600	50	0
40	20	50
1000		70



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

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Principle of Suppression

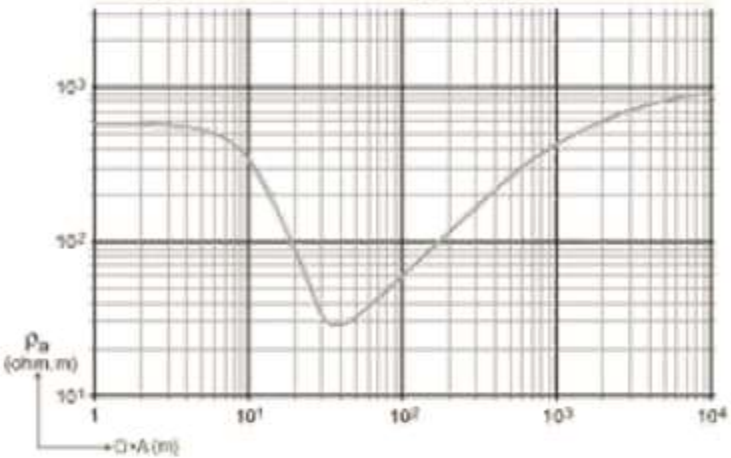
SUPPRESSION TYPE H and A

INTERPRETATION (A)

Resistivity (ohm.m)	Thickness (m)	Depth (m)	
600	6	0	**Sandy alterite**
20	30	6	**Argillous alterite**
1000		36	**Bedrock**

INTERPRETATION (B)

Resistivity (ohm.m)	Thickness (m)	Depth (m)	
600	6	0	**Sandy alerite**
20	26	6	**Argillous alterite**
200	3	32	**altered bedrock**
1000		35	**Bedrock**



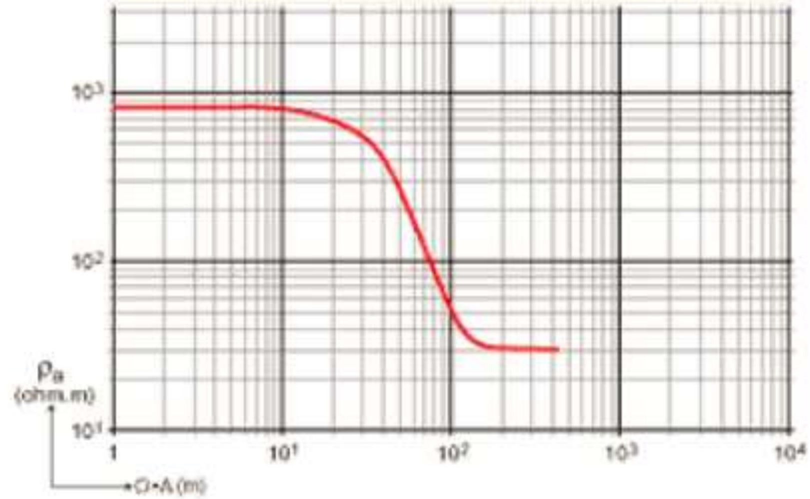
SUPPRESSION TYPE Q $(\rho_3 < \rho_2 < \rho_1)$

INTERPRETATION (A)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
800	21	0
30		21

INTERPRETATION (B)

Resistivity (ohm.m)	Thickness (m)	Depth (m)
800	20	0
200	5	20
30		25



Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Calibration Sounding

Calibration soundings are carried out to determine the precise resistivity of a formation.

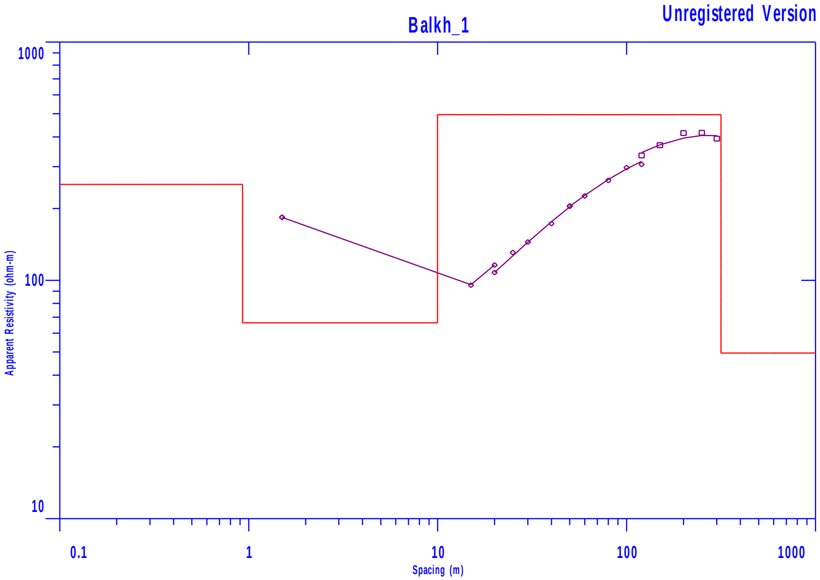
This reduces the problem of equivalence.

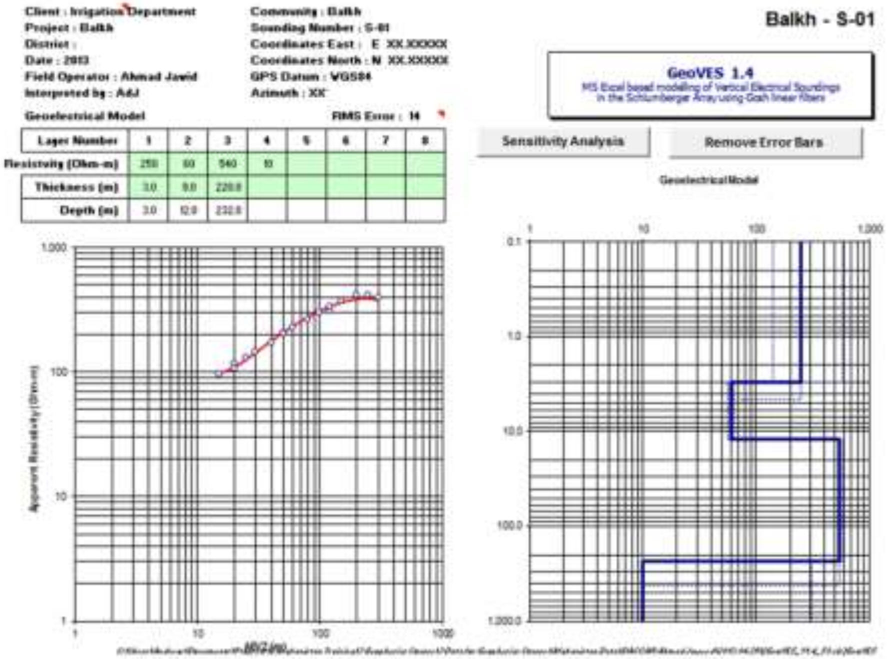
VES near a borehole with downhole geophysical logs or on an outcrop.

ALWAYS DO AT LEAST ONE CALIBRATION SOUNDING!

Source: http://www.tomoquest.com/Lectures_in_Geophysics.php

Practical – 1D Inversion Software





Layer Number	1	2	3	4	5	6	7	8
Resistivity (Ohm-m)	250	60	540	10				
Thickness (m)	3.0	9.0	220.8					
Depth (m)	3.0	12.0	232.8					