ELECTRICAL RESISTIVITY TOMOGRAPHY

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INTRODUCTION TO RESISTIVITY SURVEYS

- The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface.

- From these measurements, the true resistivity of the subsurface can be estimated.

- The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock.

- Used for hydrogeological, mining, geotechnical and environmental investigations.

- The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2).

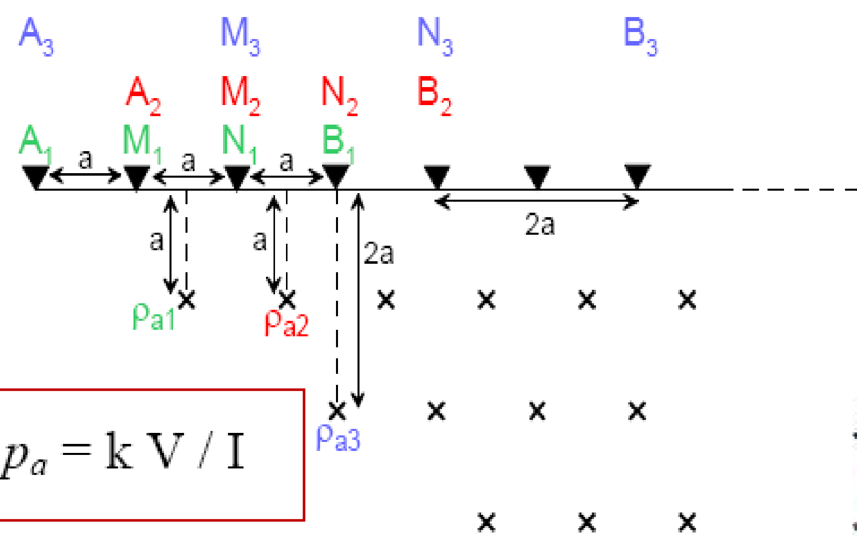
- From the current (I) and voltage (V) values, an apparent resistivity *(pa) value is calculated.*

- Resistivity meters give resistance value R=V/I and the apparent resistivity values is calculated as:

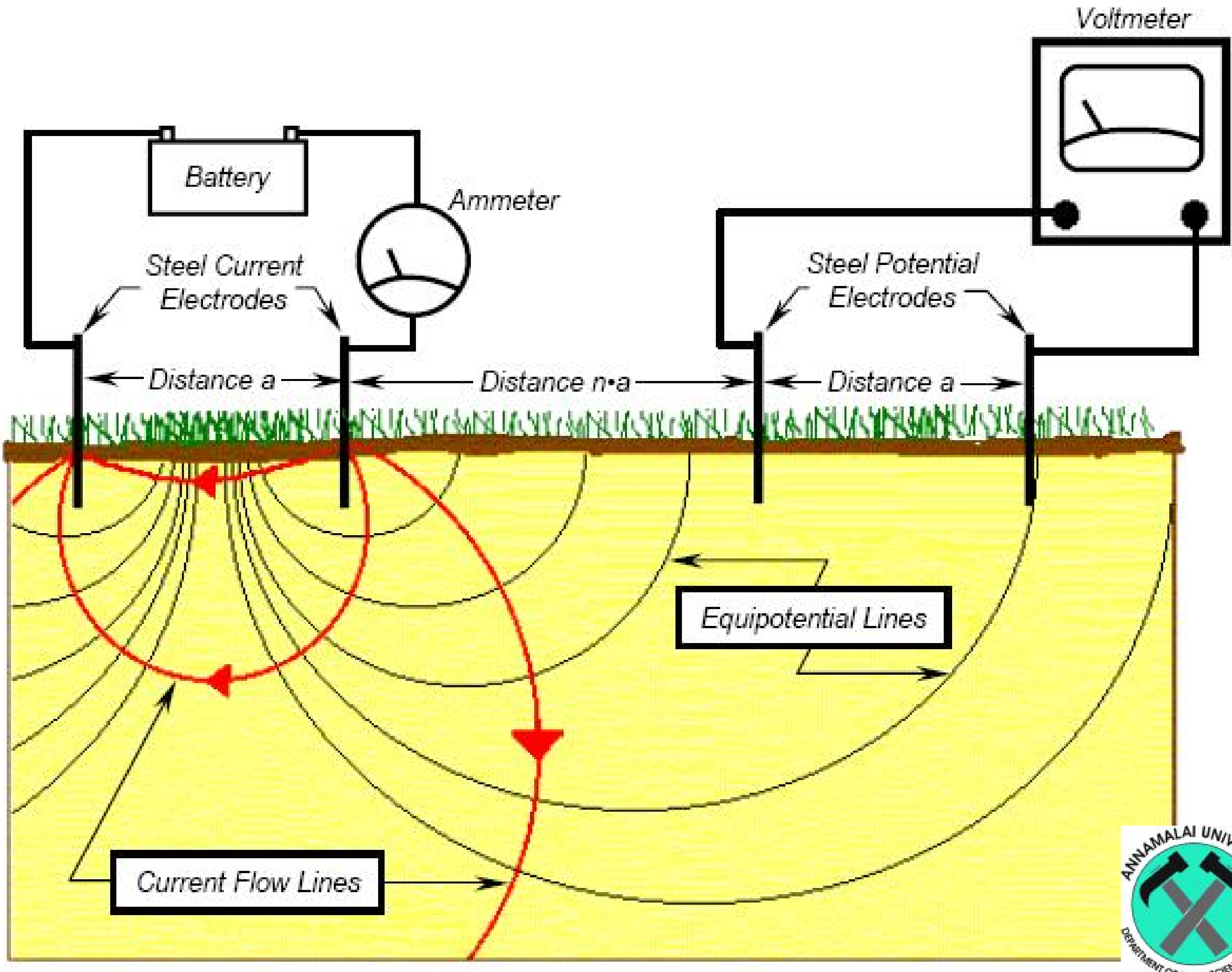
$$P_a = KR$$

- The calculated resistivity value is not the true resistivity but the apparent resistivity (resistivity of homogenous ground) which will give the same resistance value for the same electrode arrangement.

- To determine the true resistivity an inversion of the measured apparent resistivity using a computer program is generally carried out.

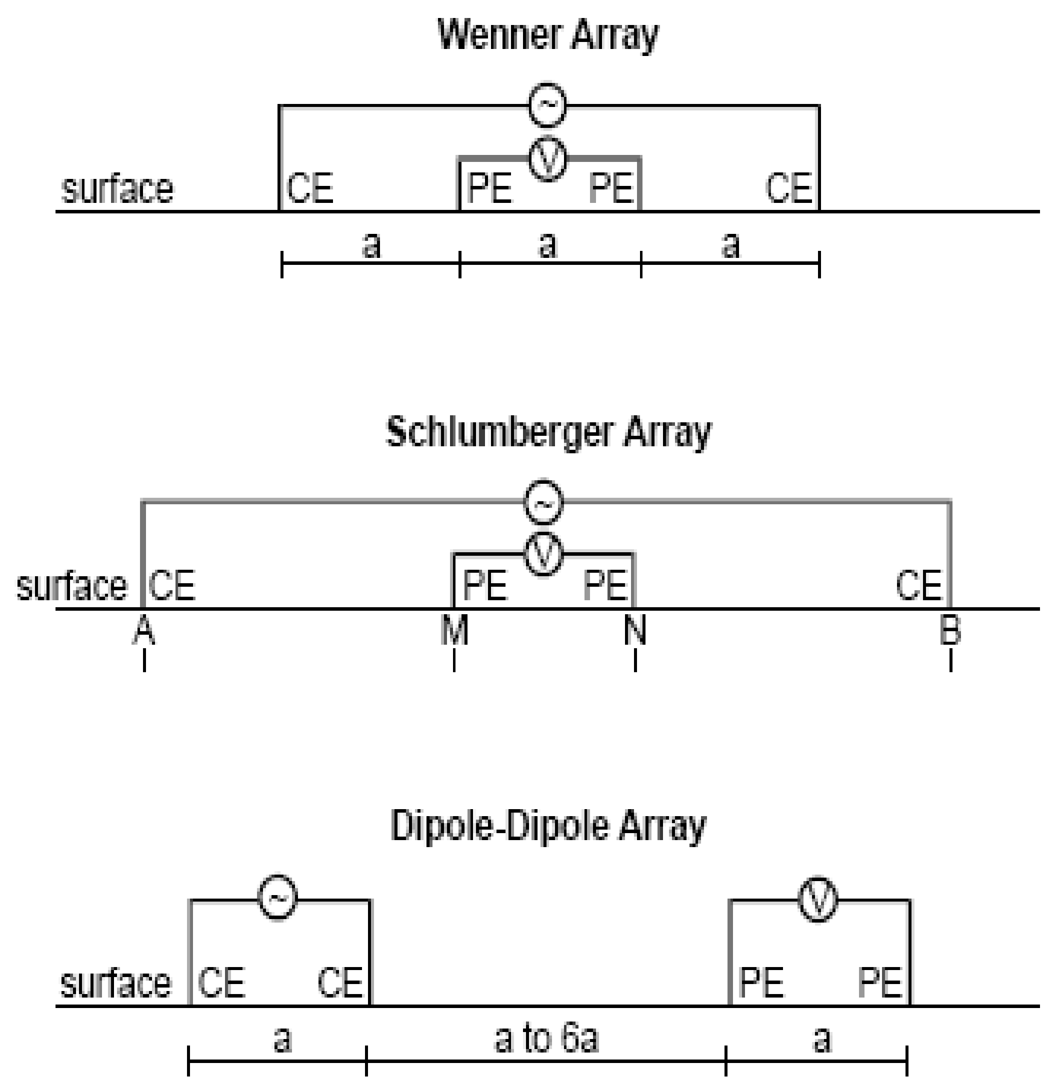


$$\rho_a = k\,V / I$$

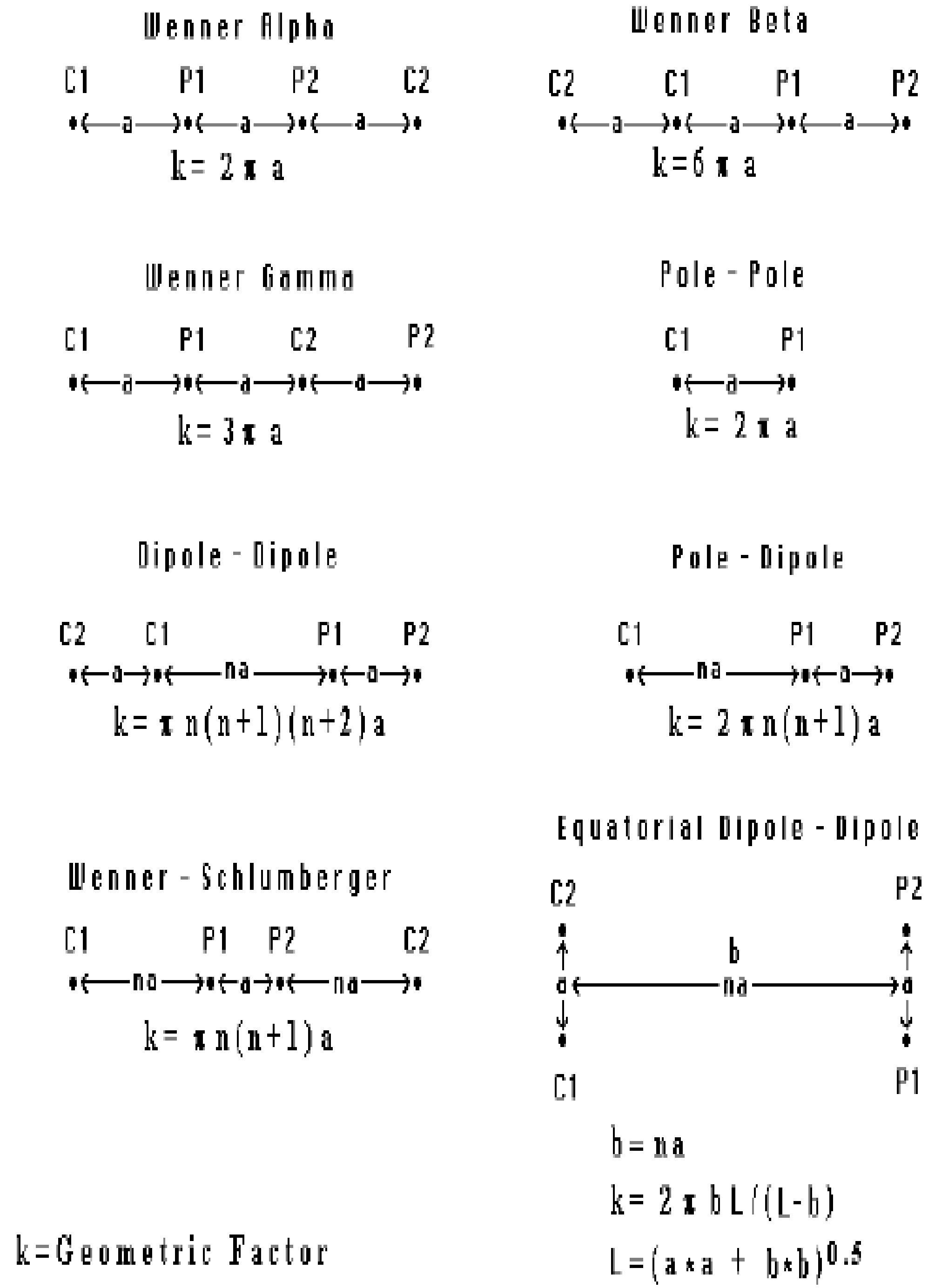


Voltmeter
Battery
Ammeter
Steel Current Electrodes
Steel Potential Electrodes
Distance a
Distance n•a
Distance a
Equipotential Lines
Current Flow Lines

General arrays and Models



Explanation
PE potential electrode
CE current electrode
V voltmeter
~ current source



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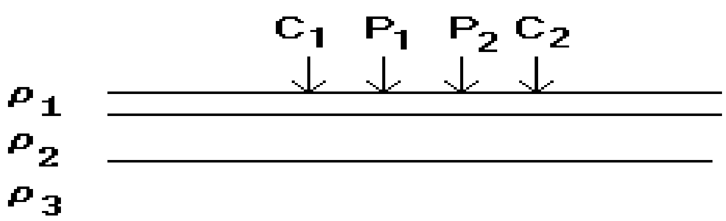
RESISTIVITY VALUES FOR ROCK MATERIALS

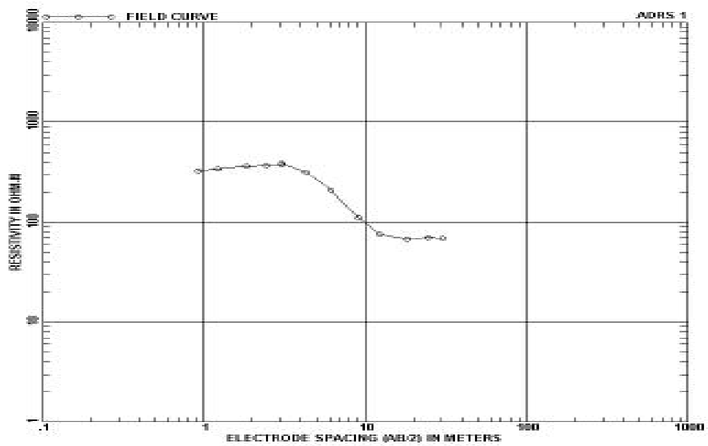
Material	Resistivity (Ω•m)	Conductivity (Siemen/m)
Igneous and Metamorphic Rocks		
Granite	$5x10^{3}$ - 10^{6}	10^{-6} - $2x10^{-4}$
Basalt	10^{3} - 10^{6}	10^{-6} - 10^{-3}
Slate	$6x10^{2}$ - $4x10^{7}$	$2.5x10^{-8}$ - $1.7x10^{-3}$
Marble	10^{2} - $2.5x10^{8}$	$4x10^{-9}$ - 10^{-2}
Quartzite	10^{2} - $2x10^{8}$	$5x10^{-9}$ - 10^{-2}
Sedimentary Rocks		
Sandstone	8 - $4x10^{3}$	$2.5x10^{-4}$ - 0.125
Shale	20 - $2x10^{3}$	$5x10^{-4}$ - 0.05
Limestone	50 - $4x10^{2}$	$2.5x10^{-3}$ - 0.02
Soils and waters		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	$1.25 x10^{-3}$ - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1
Sea water	0.2	5
Chemicals		
Iron	$9.074x10^{-8}$	$1.102x10^{7}$
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	$6.998x10^{16}$	$1.429x10^{-17}$

- Igneous and metamorphic rocks show high resistivity due to degree of fractures and liquid in the fractures.
- Sedimentary rocks with high porosity and water content contain lower resistivity values.
- Resistivity of rocks/soil depend on porosity, degree of water saturation and concentration of water saturation.
- Wet soils and fresh ground water have even lower resistivity values.
- Clayey soil normally has a lower resistivity value than sandy soil.
- The resistivity of ground water varies from 10 to 100 Ωm, depending on the concentration of dissolved salts.
- Note the low resistivity (about 0.2 Ωm) of sea water due to the relatively high salt content. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas.
- Chemicals and effluents record lower resistivity values useful in prediction of contamination inventory.

RESISTIVITY MODELS

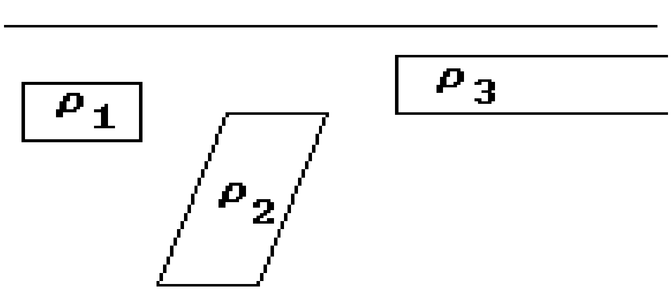
a). 1D Model





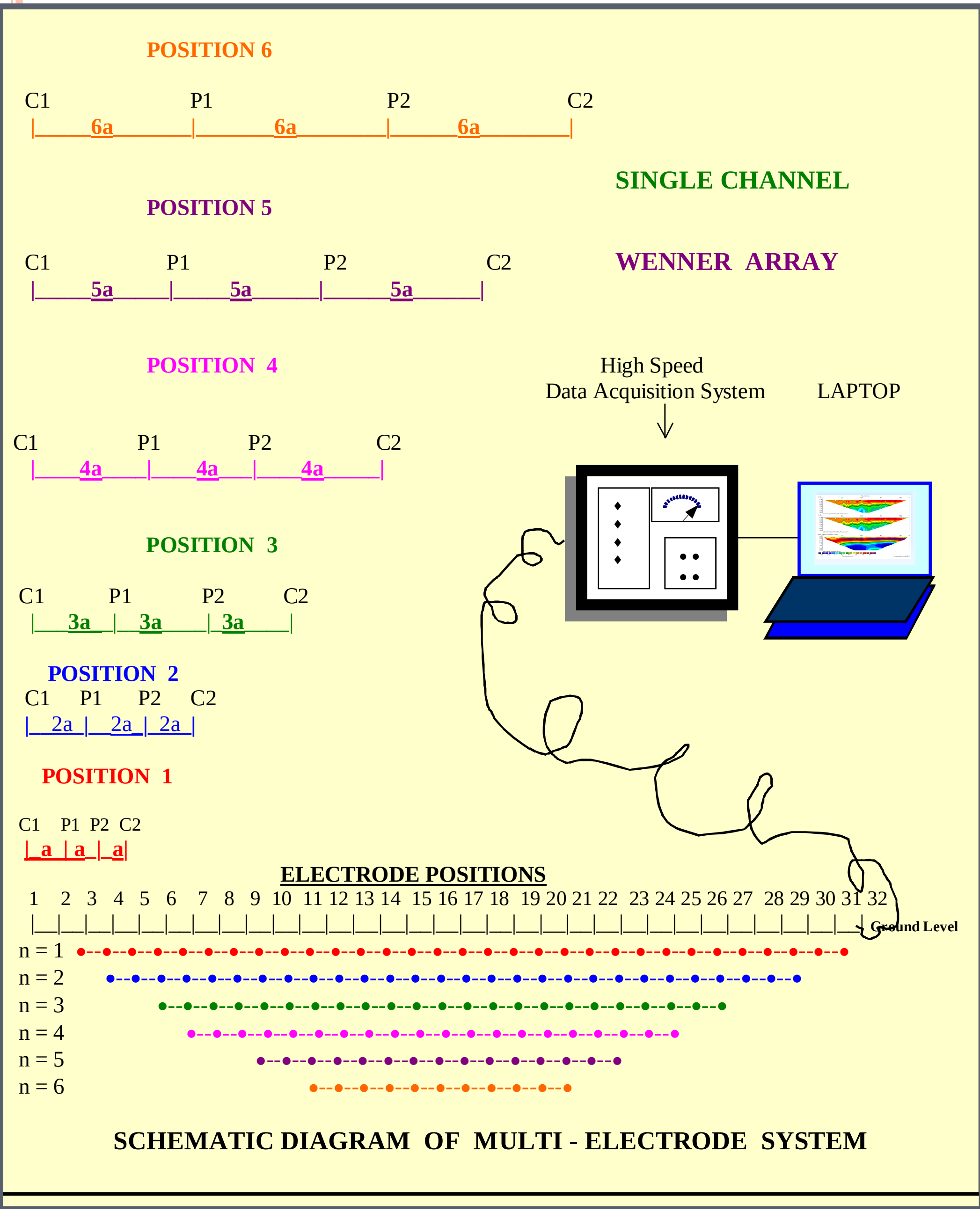
AB/2, m	(ft)	App. Res.	AB/2, m	(ft)	App. Res.
0.91	(3.00)	329.00	4.27	(14.00)	317.00
1.22	(4.00)	344.00	6.10	(20.00)	208.00
1.83	(6.00)	367.00	9.14	(30.00)	110.00
2.44	(8.00)	371.00	12.19	(40.00)	75.90
3.05	(10.00)	375.00	18.29	(60.00)	68.40
3.05	(10.00)	389.00	24.38	(80.00)	70.70
			30.48	(100.00)	69.10

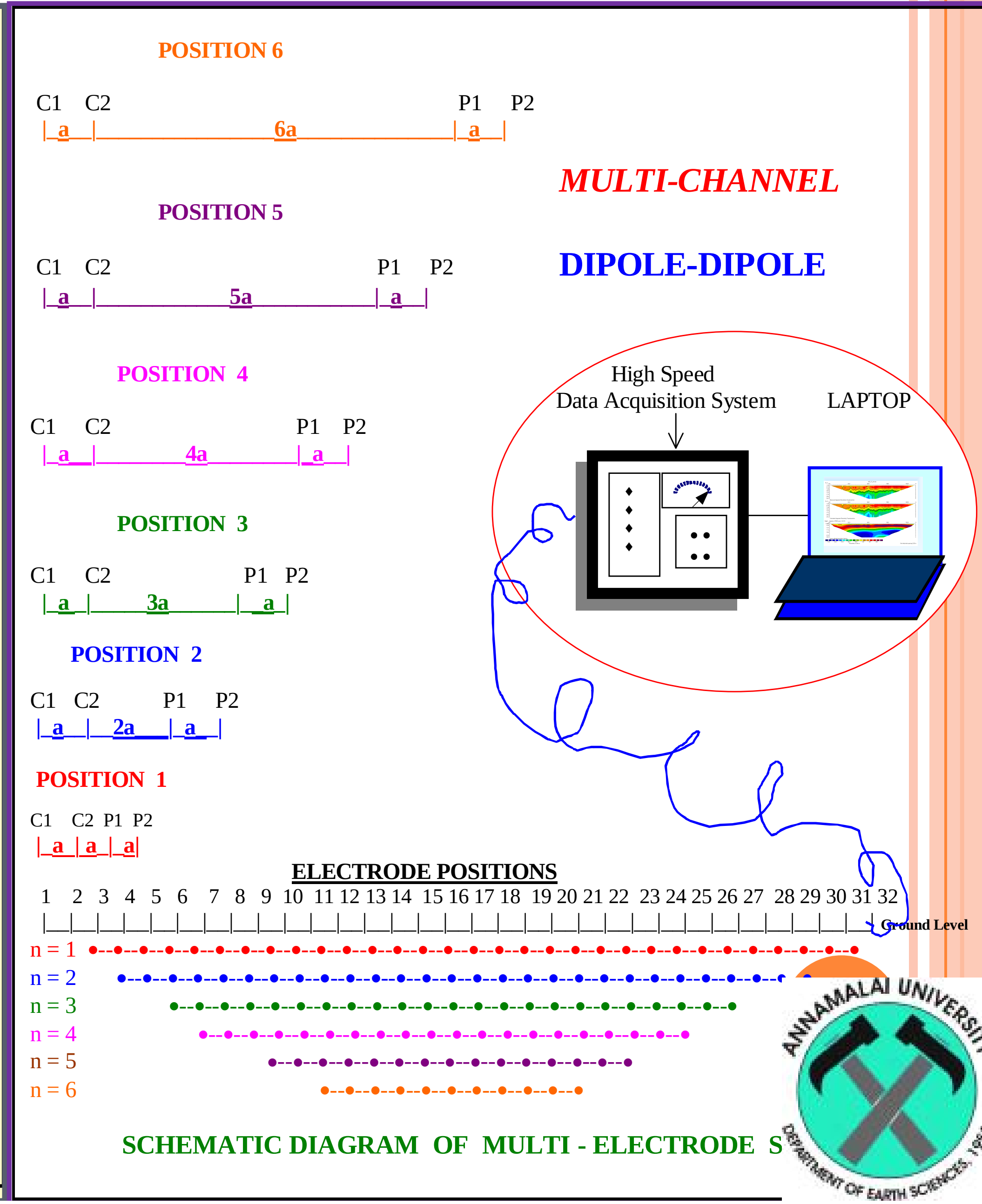
b). 2D Model



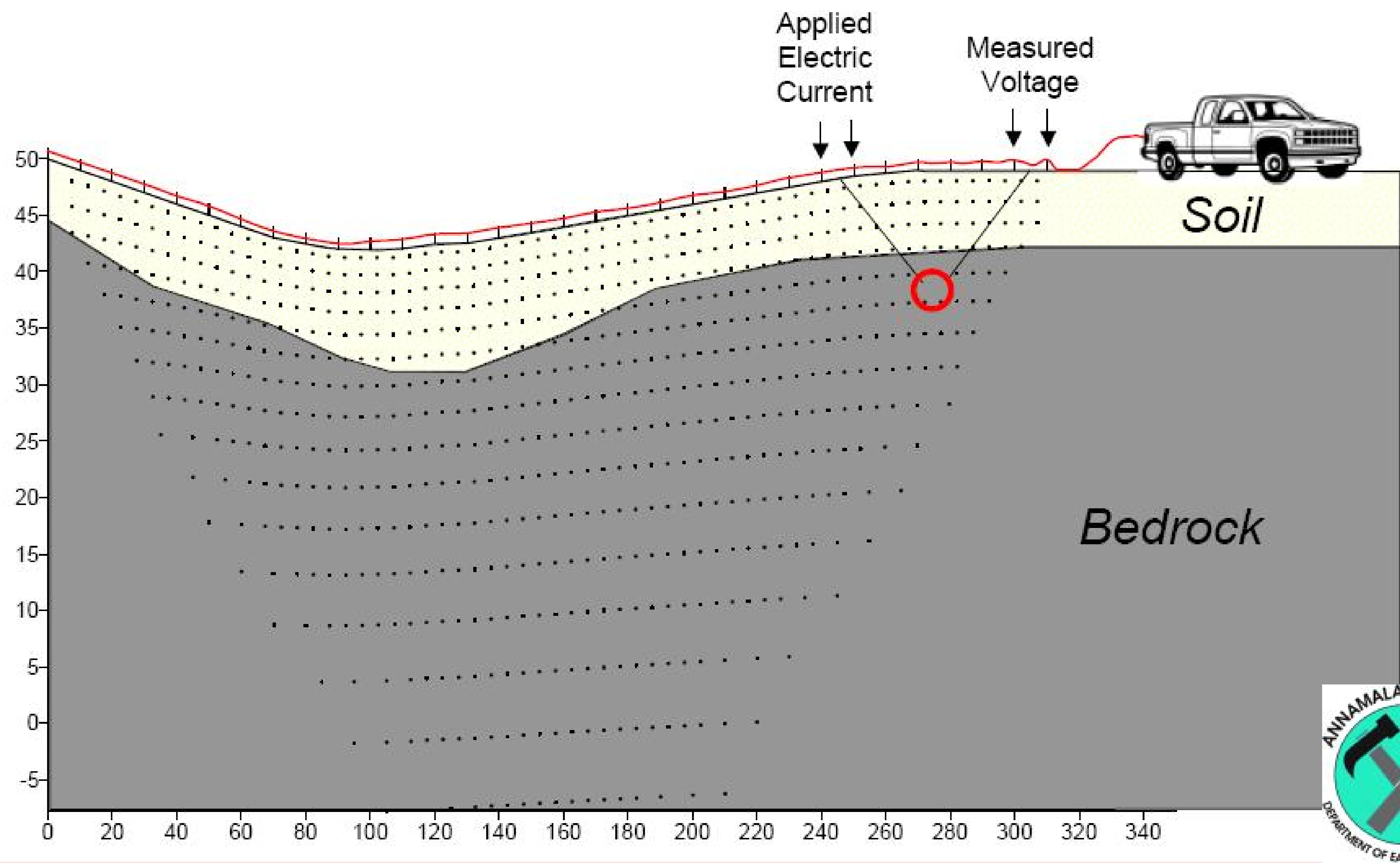
- The most severe limitation of the resistivity sounding method is that horizontal (or lateral) changes in the subsurface resistivity are commonly found.
- Lateral changes in the subsurface resistivity will cause changes in the apparent resistivity values which is misinterpreted as changes with depth in the subsurface resistivity.
- In many engineering and environmental studies, the subsurface geology is very complex where the resistivity can change rapidly over short distances. The resistivity sounding method might not be sufficiently accurate for such situations.
- A two- dimensional (2-D) model records resistivity changes both in vertical /horizontal direction along the survey line. Practiced with large number of electrodes (>25) connected to a multi core cable.

MEASUREMENT PROCEDURE IN 2D METHOD

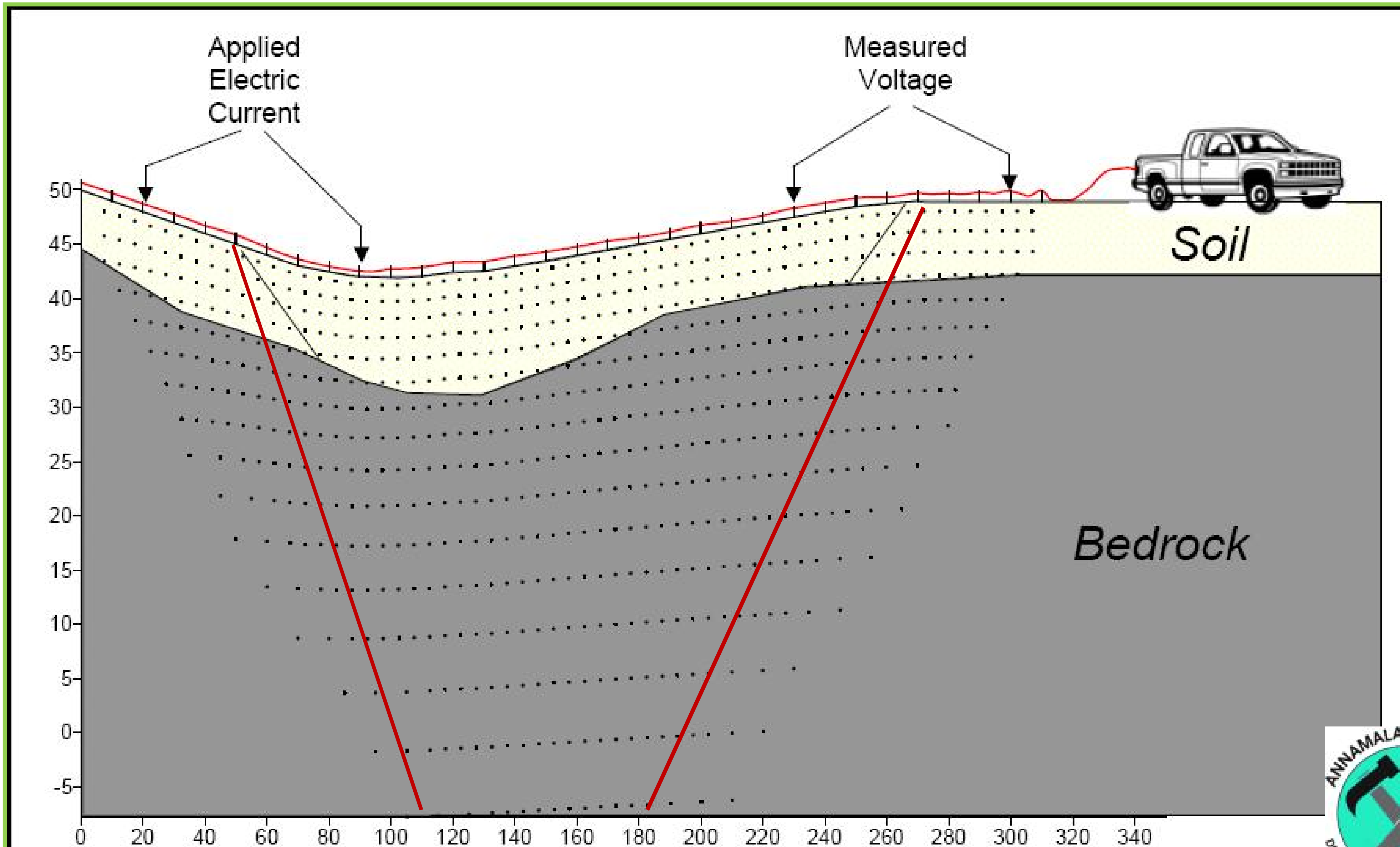




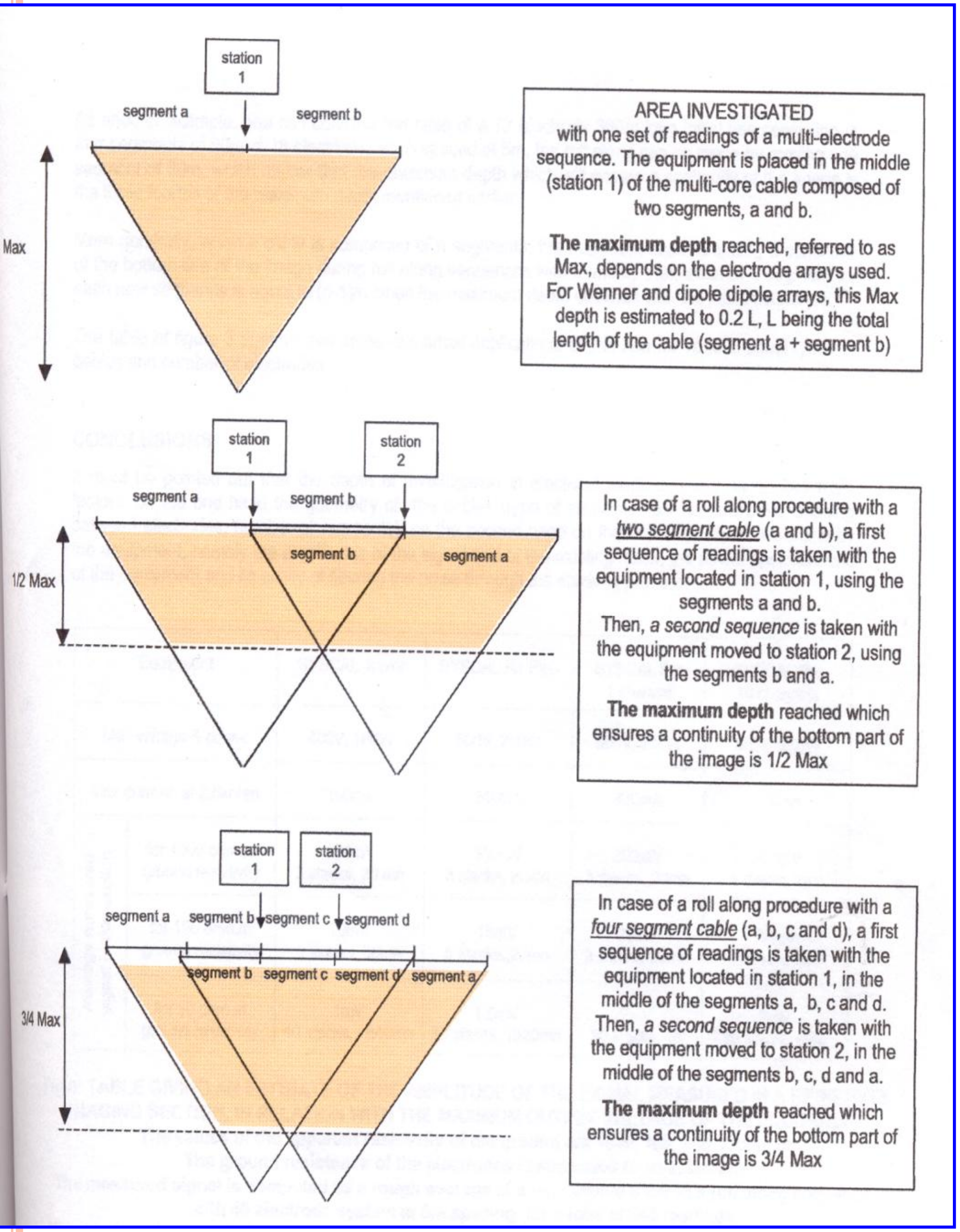
SHALLOW DATA ACQUISITION



DEEP DATA ACQUISITION

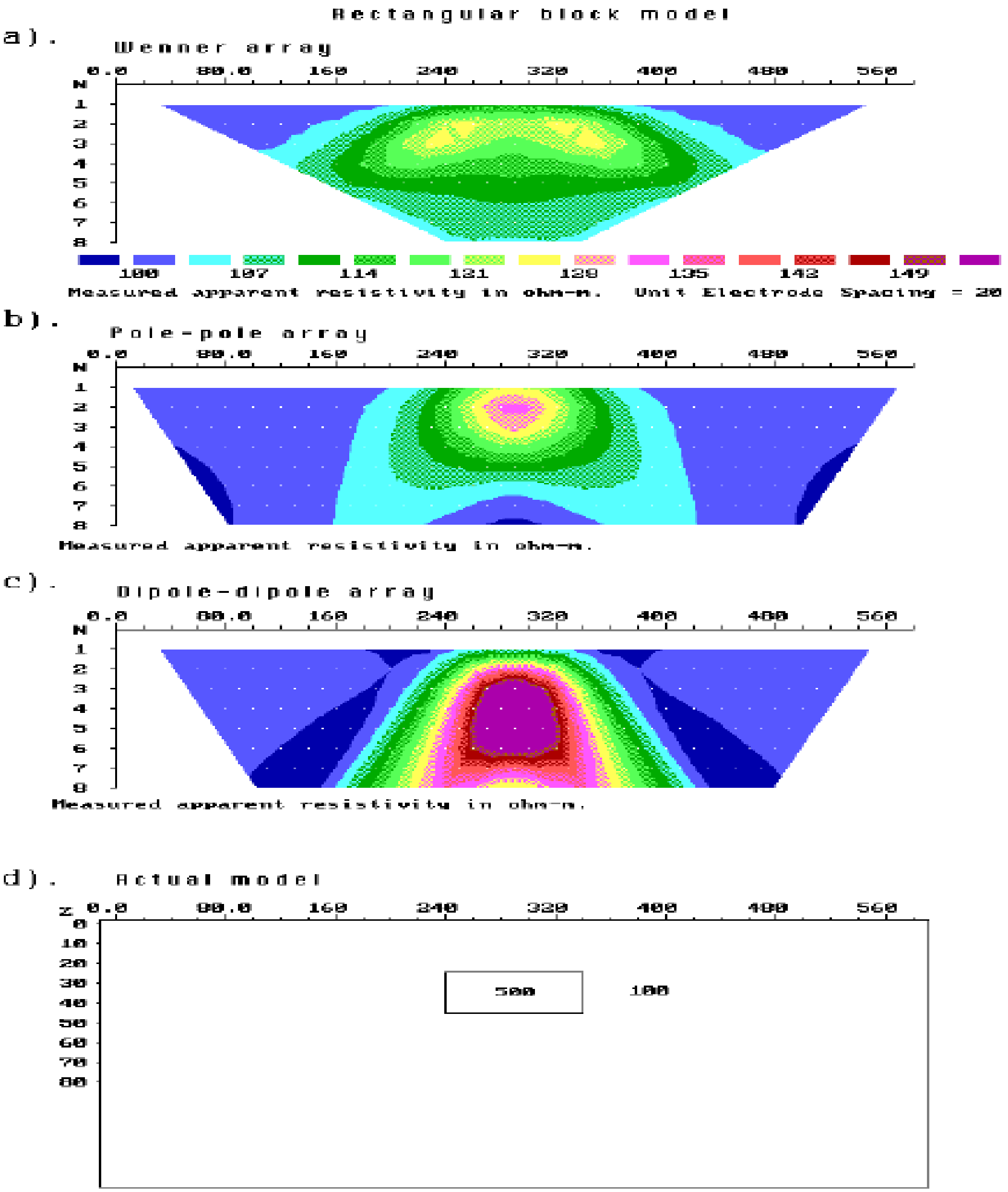


A SEQUENCE OF ROLL ALONG PROCEDURE



- One technique used to extend horizontally the area covered by the survey with a limited number of electrodes, is the roll-along method.
- After completing the sequence of measurements, the cable is moved past one end of the line by several unit electrode spacing.
- All the measurements which involve the electrodes on part of the cable which do not overlap the original end of the survey line are repeated.

PSEUDO SECTION DATA PLOTTING METHOD



- The pseudo section gives a very approximate picture of the true subsurface resistivity distribution.
- It gives a distorted picture of the subsurface because shape of contours depend on type of array used as well as the true subsurface resistivity .
- The pseudo section is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation.
- Note that the pole-pole array gives the widest horizontal coverage, while the coverage obtained by the Wenner array decreases much more rapidly with increasing electrode spacing.

FORWARD MODELING PROGRAM

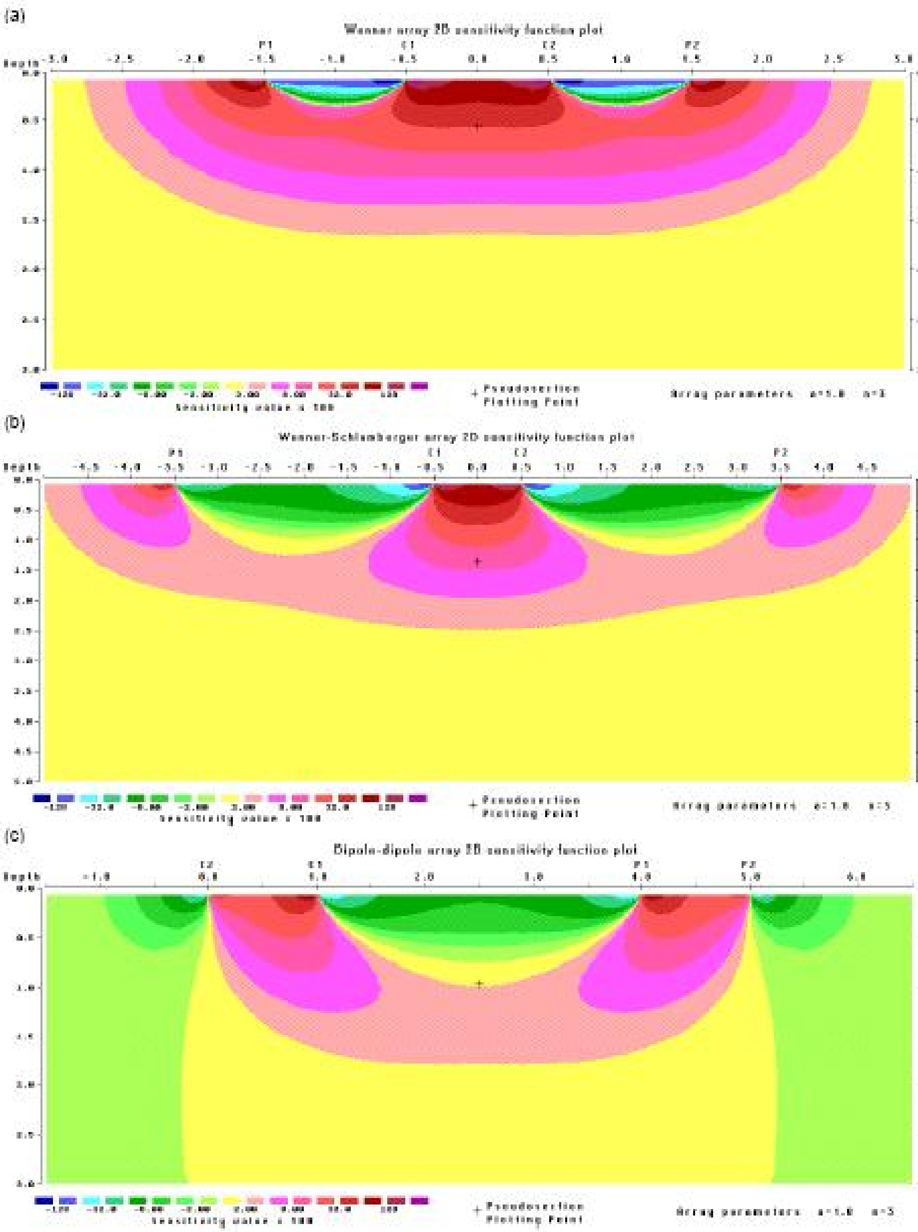
- The free program, RES2DMOD.EXE, is a 2-D forward modeling program which calculates the apparent resistivity pseudo section for a user defined 2-D subsurface model.
- The program chooses the finite-difference or Finite-element method to calculate the apparent resistivity values.
- In the program, the subsurface is divided into a large number of small rectangular cells.
- The program also assists in choosing the appropriate array for different geological situations or surveys.
- The arrays supported by this program are the Wenner (Alpha, Beta and Gamma configurations, Wenner-Schlumberger, pole-pole, inline dipole-dipole, pole-dipole and equatorial dipole-dipole .
- The Alpha configuration is normally used for field surveys and usually just referred to as the “Wenner” array).
- This program will help in choosing the "best" array for a particular survey area after carefully balancing factors such as the cost, depth of investigation, resolution and practicality.
- In practice, the arrays that are most commonly used for 2-D imaging surveys are the (a) Wenner, (b) dipole-dipole (c) Wenner-Schlumberger (d) pole-pole and (d) pole-dipole.

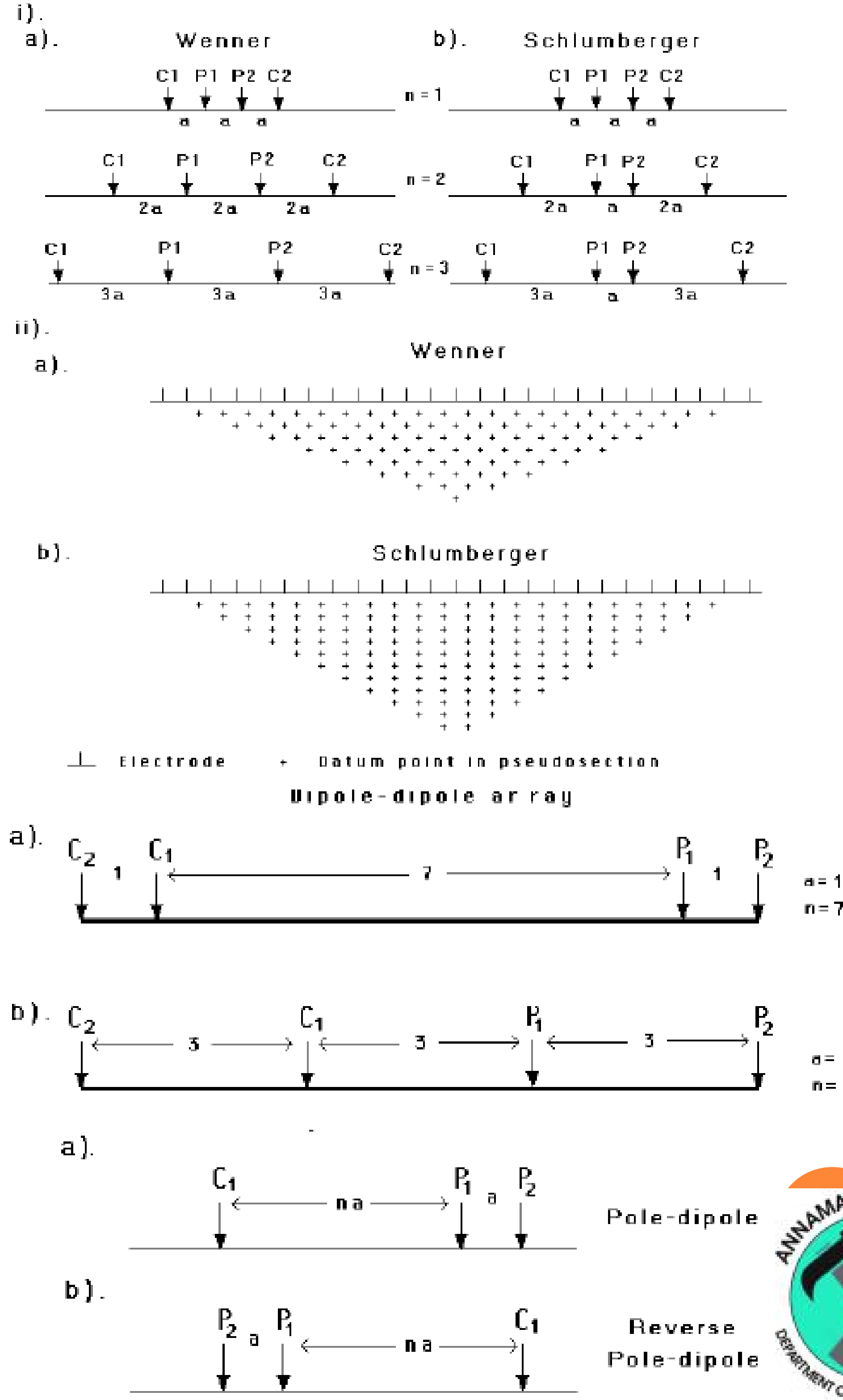
MEDIAN DEPTH OF INVESTIGATIONS

Array type		z_e/a	z_e/L
Wenner alpha		0.519	0.173
Dipole-dipole	n = 1	0.416	0.139
	n = 2	0.697	0.174
	n = 3	0.962	0.192
	n = 4	1.220	0.203
	n = 5	1.476	0.211
	n = 6	1.730	0.216
Equatorial dipole-dipole			
	n = 1	0.451	0.319
	n = 2	0.809	0.362
	n = 3	1.180	0.373
	n = 4	1.556	0.377
Wenner - Schlumberger			
	n = 1	0.52	0.173
	n = 2	0.93	0.186
	n = 3	1.32	0.189
	n = 4	1.71	0.190
	n = 5	2.09	0.190
	n = 6	2.48	0.190
Pole-dipole	n = 1	0.52	
	n = 2	0.93	
	n = 3	1.32	
	n = 4	1.71	
	n = 5	2.09	
	n = 6	2.48	
Pole-Pole		0.867	

The median depth of investigation (z e) for the different arrays. L is the total length of the array.

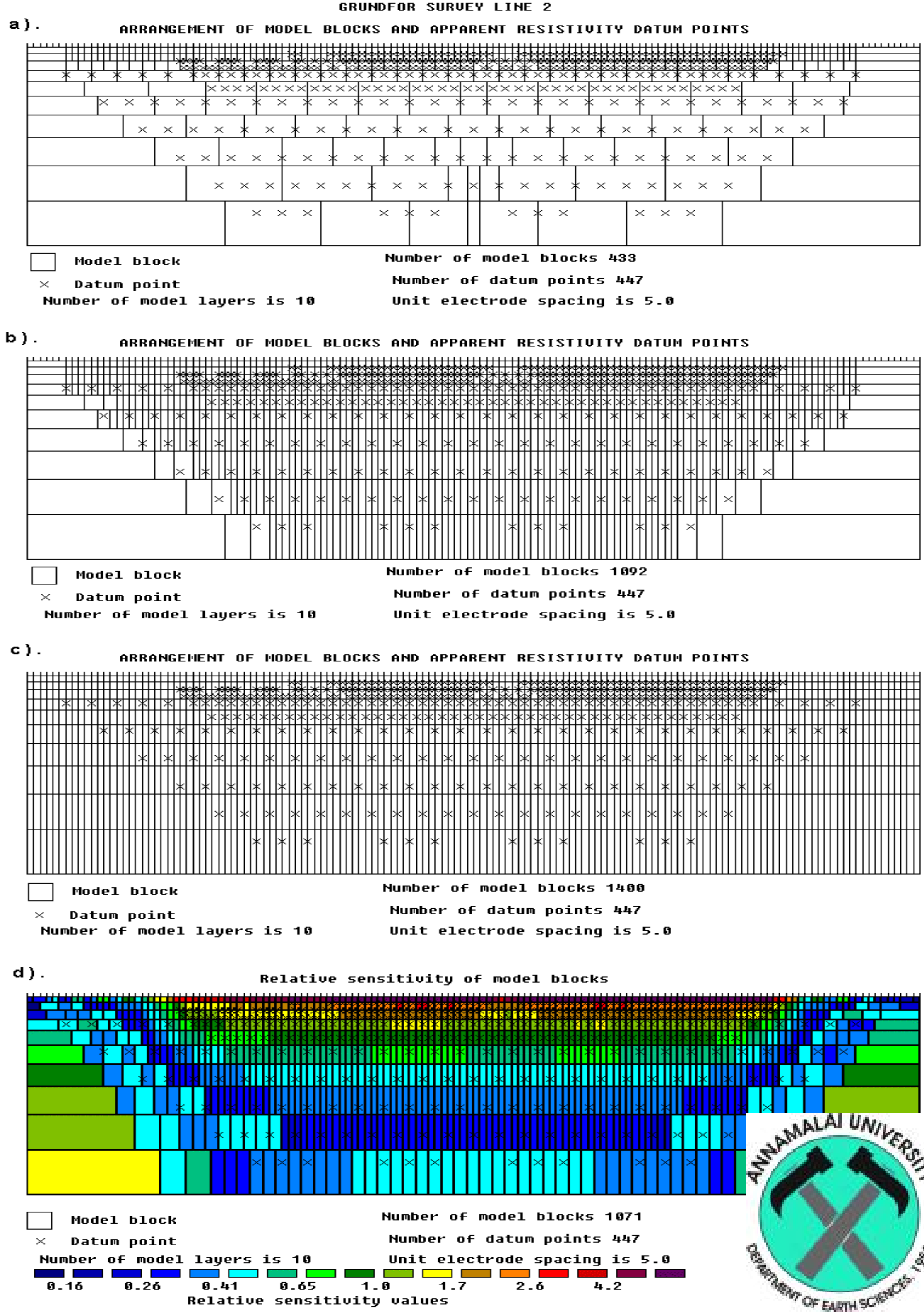
DIFFERENT ARRAYS





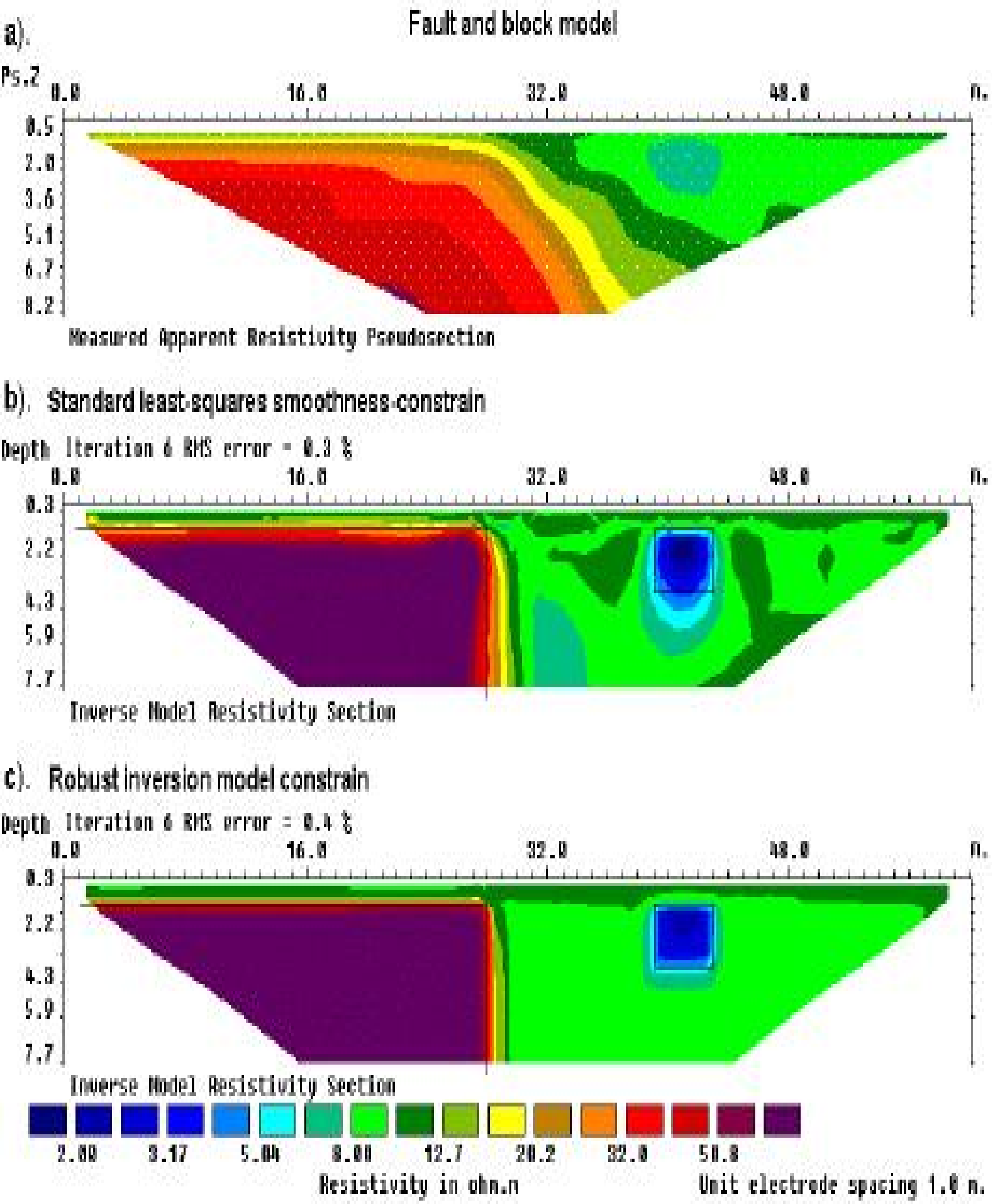
COMPUTER INTERPRETATION

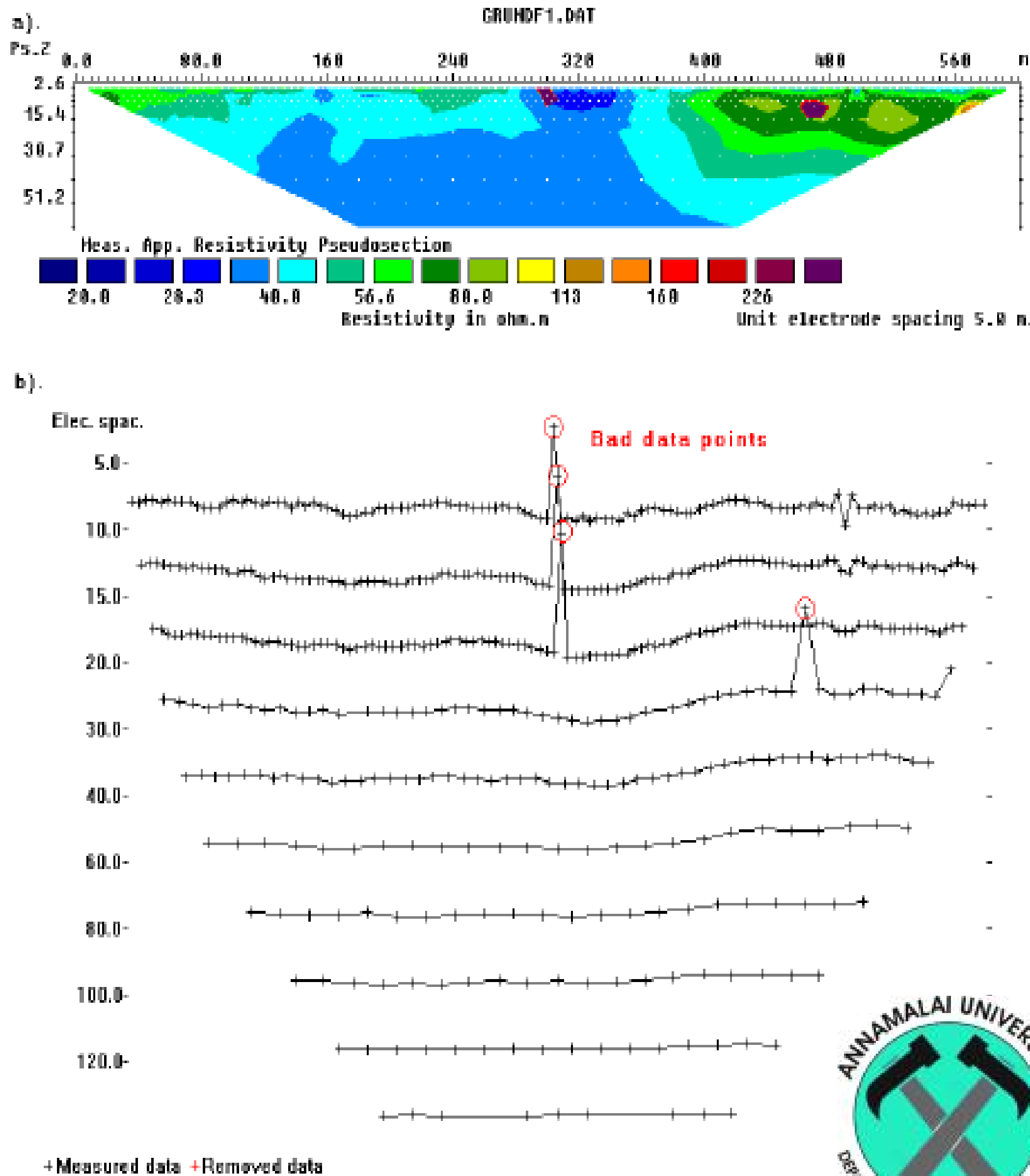
- After the field survey, the resistance measurements are reduced to apparent resistivity values.
- To interpret the data from a 2-D imaging survey, a 2-D model for the subsurface which consists of a large number of rectangular blocks is usually used.
- The computer program RES2DINV.EXE will automatically subdivide the subsurface into a number of blocks, and it then uses a least-squares inversion scheme to determine the appropriate resistivity value for each block.
- In almost all surveys, something is known about the geology of the subsurface.
- In some cases it is known whether the subsurface bodies of interest have gradational boundaries, such as pollution plumes or bedrock with a thick transitional weathered layer.
- In such cases, the conventional smoothness-constrained inversion method (deGroot-Hedlin and Constable, 1990) gives a model which more closely corresponds with reality.
- This is the default method used by the RES2DINV program.
- Most field data sets probably lie between the two extremes of a smoothly varying resistivity and discrete geological bodies with sharp boundaries.



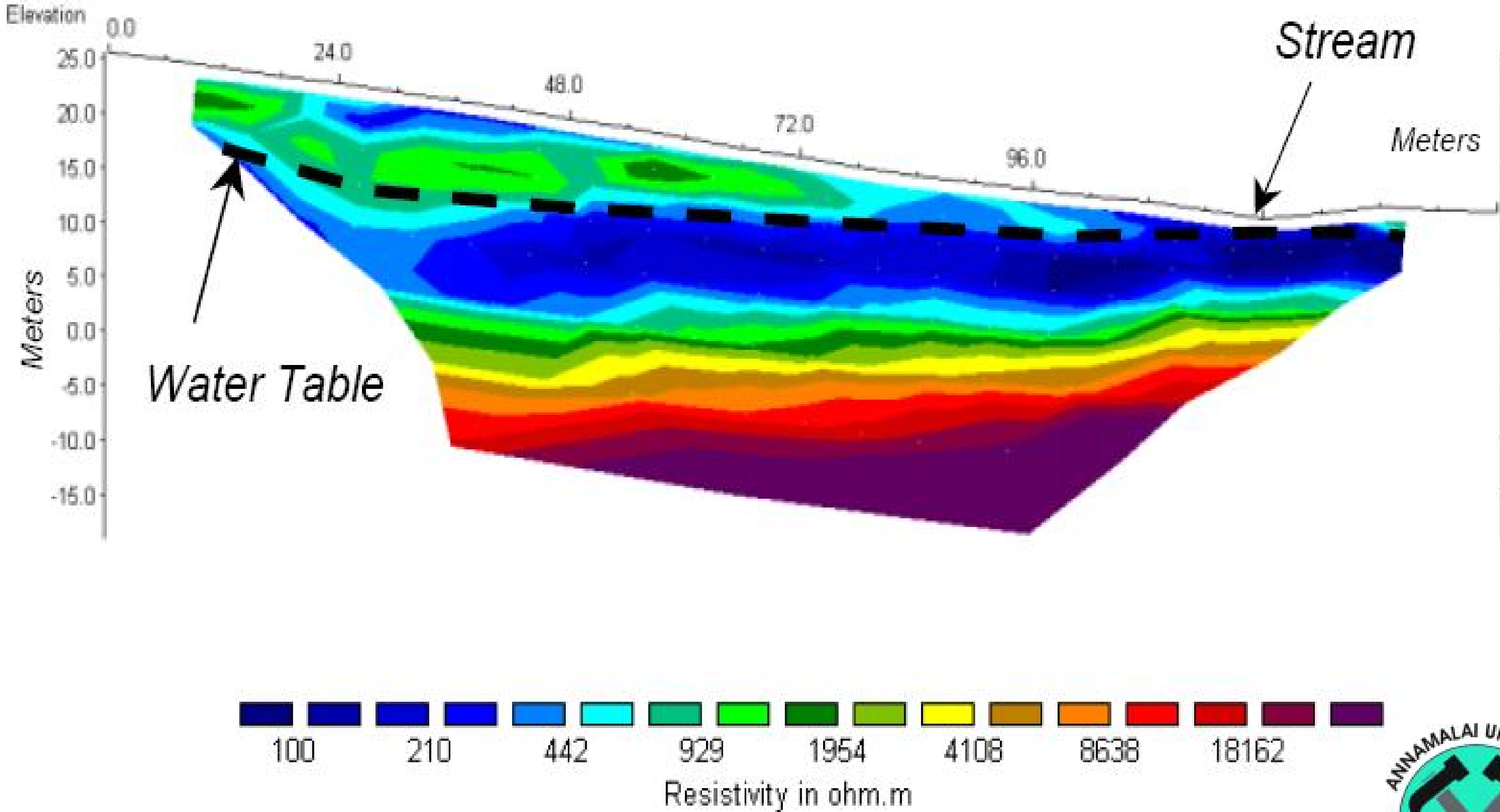
GENERAL TYPES OF INVERSION

absolute difference between measured and calculated apparent resistivity values.

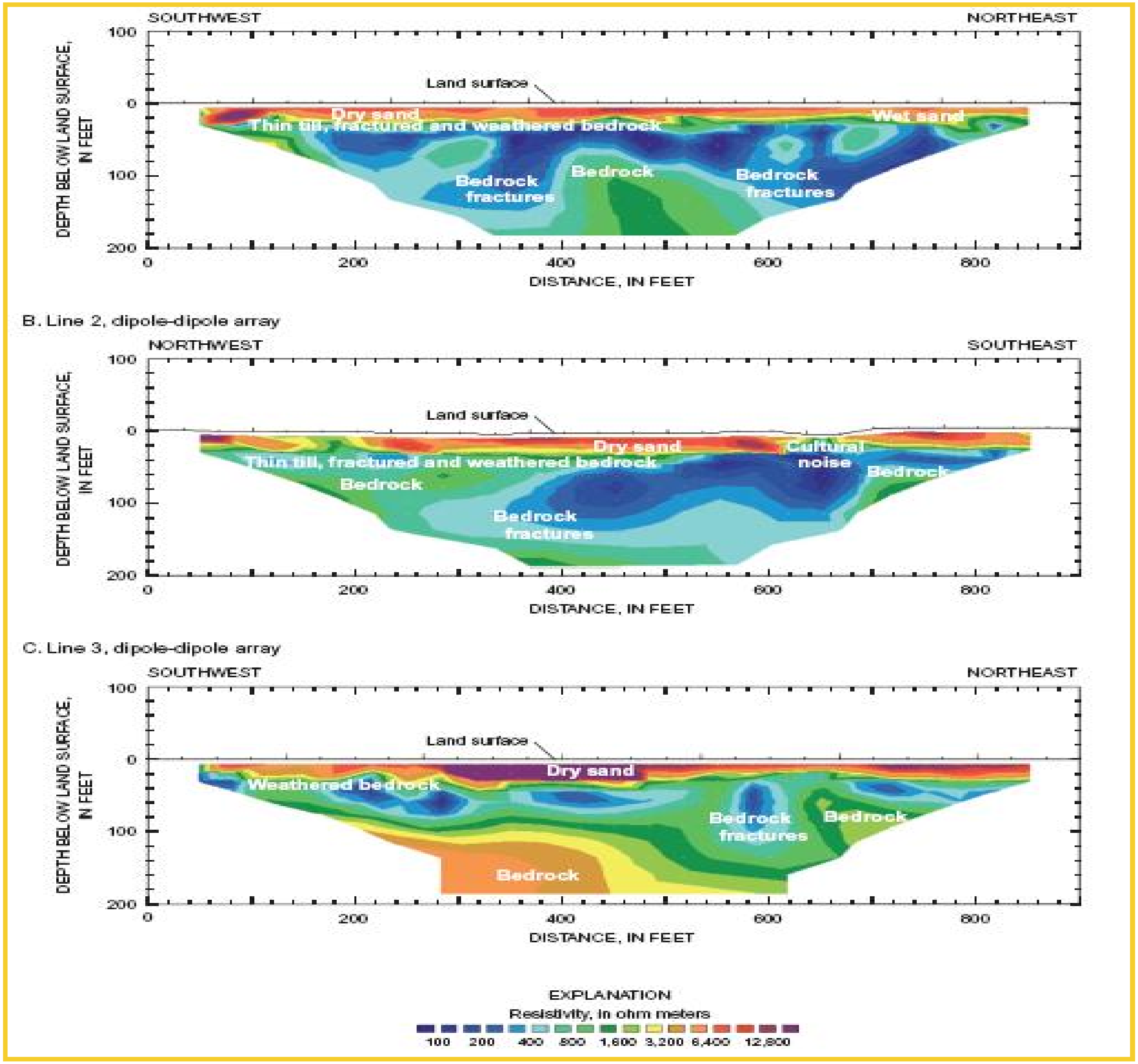




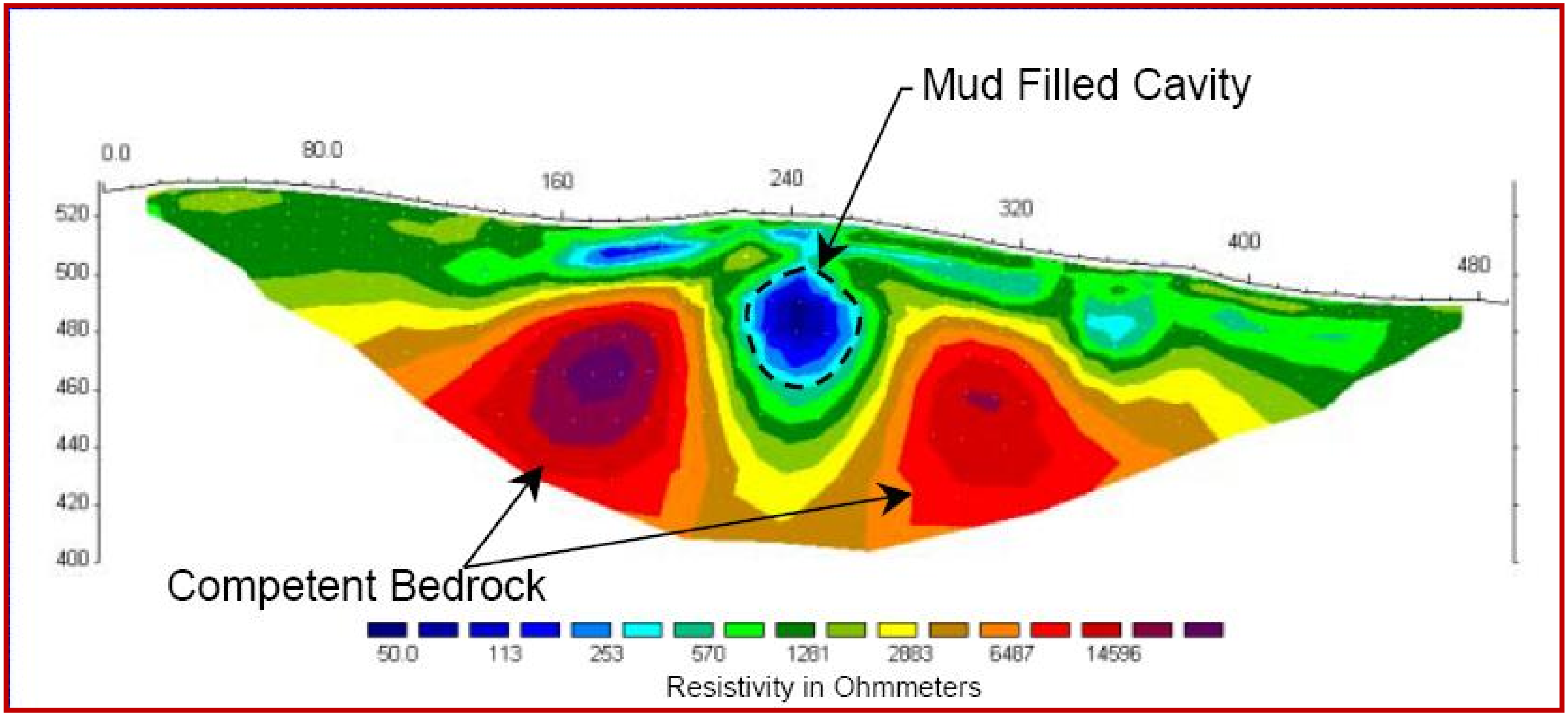
DEMARCATION OF WATER TABLE



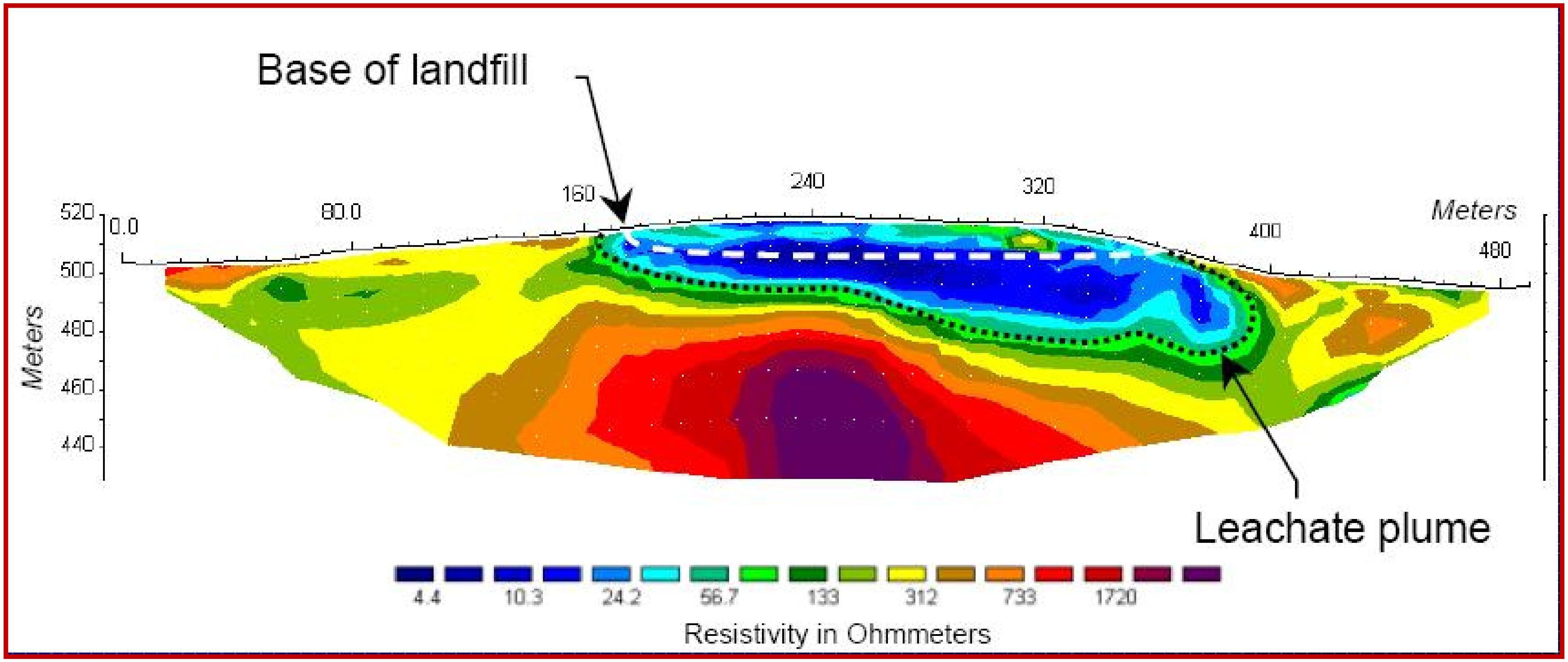
IDENTIFICATION OF DIFFERENT LITHOLOGY



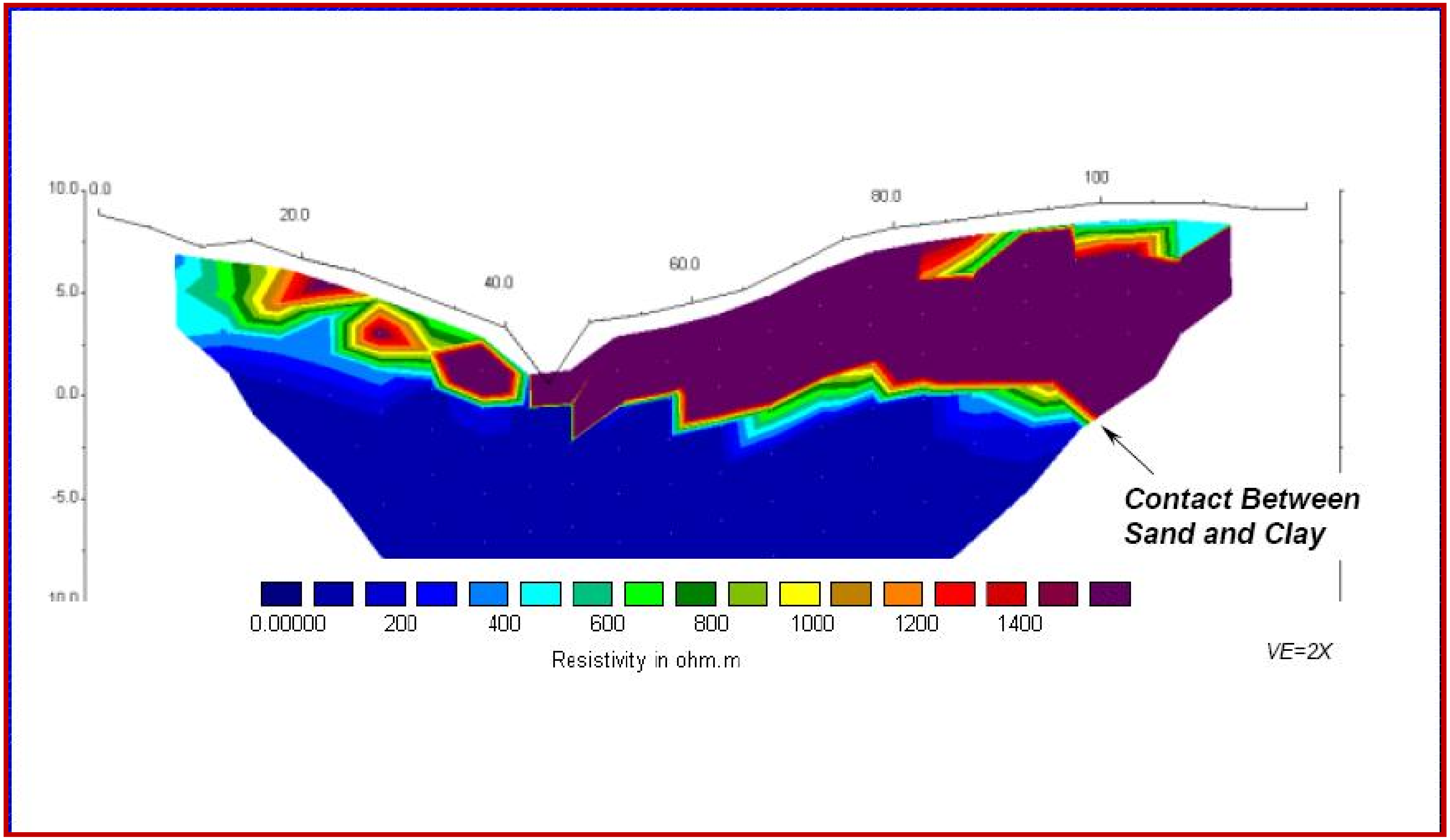
DETECTION OF VOIDS



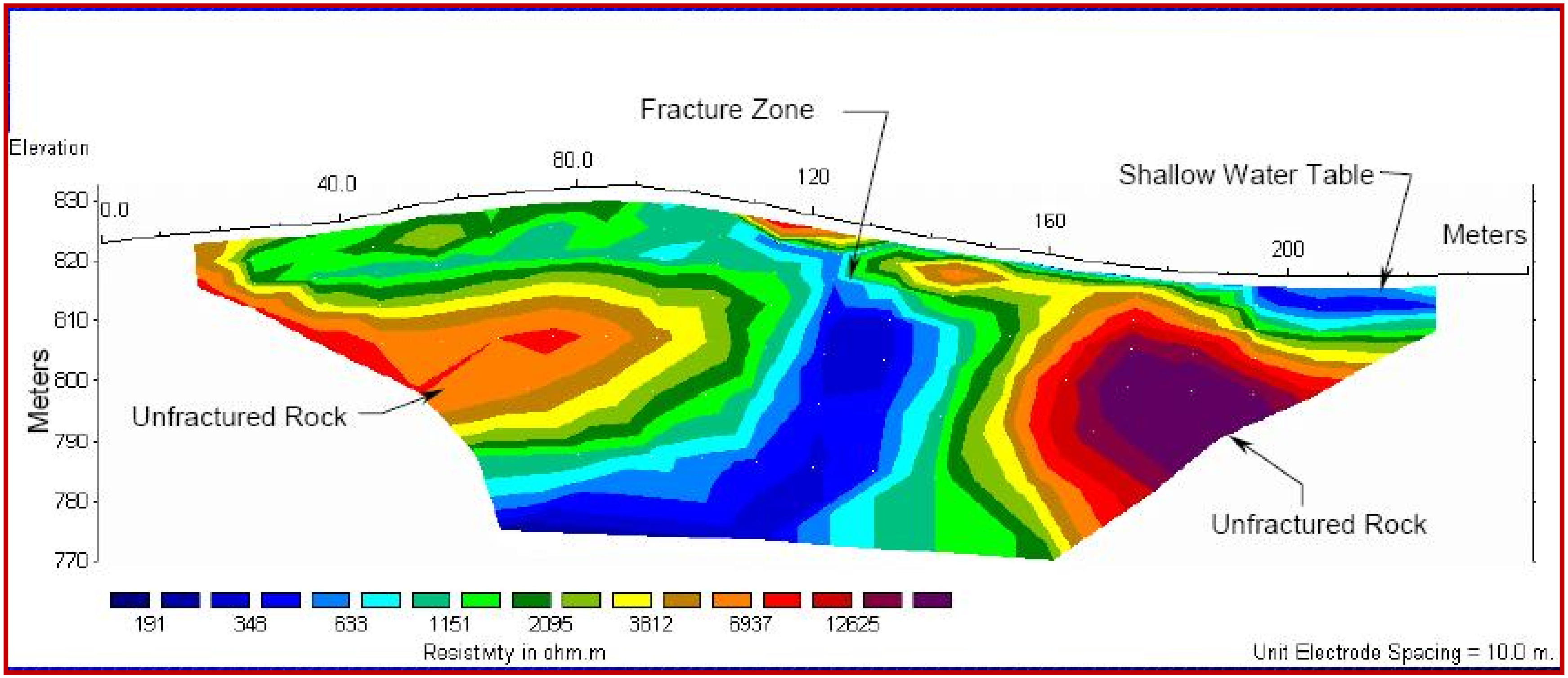
CONTAMINANT PLUME MIGRATION



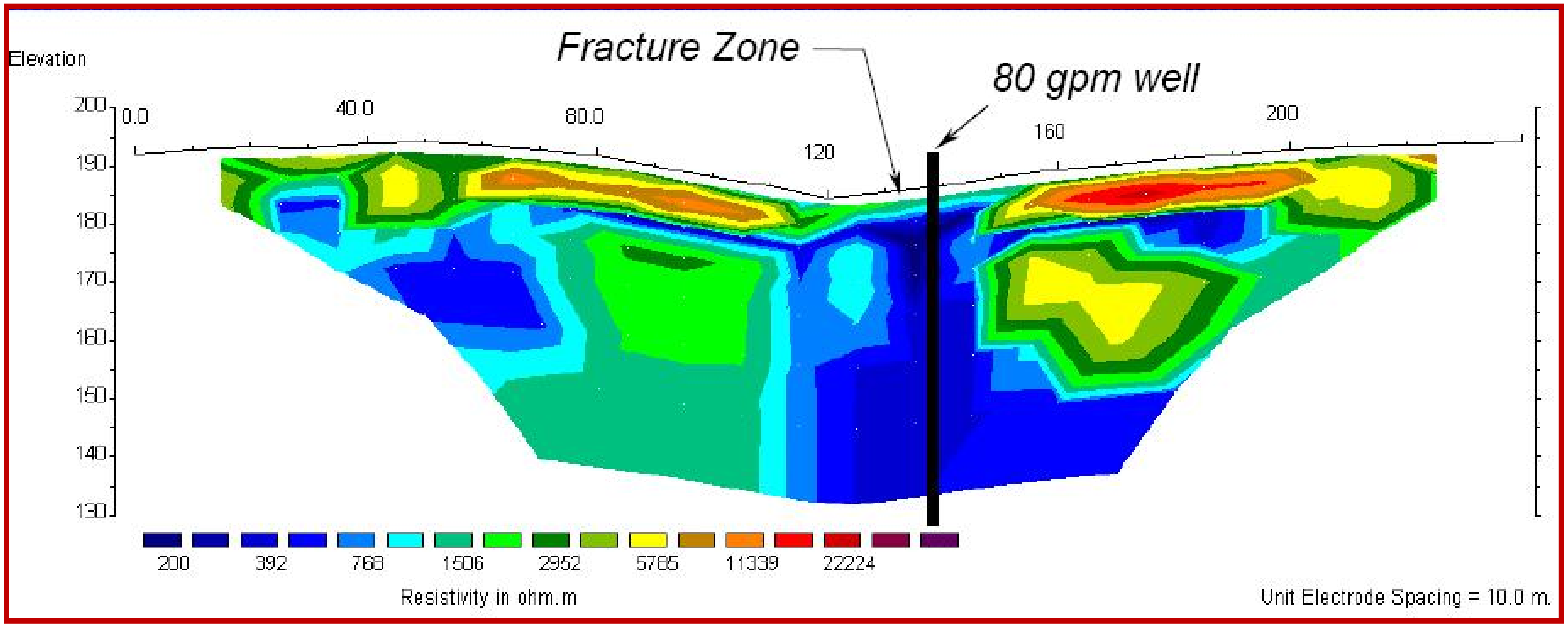
CHANGE IN SEDIMENT TYPE

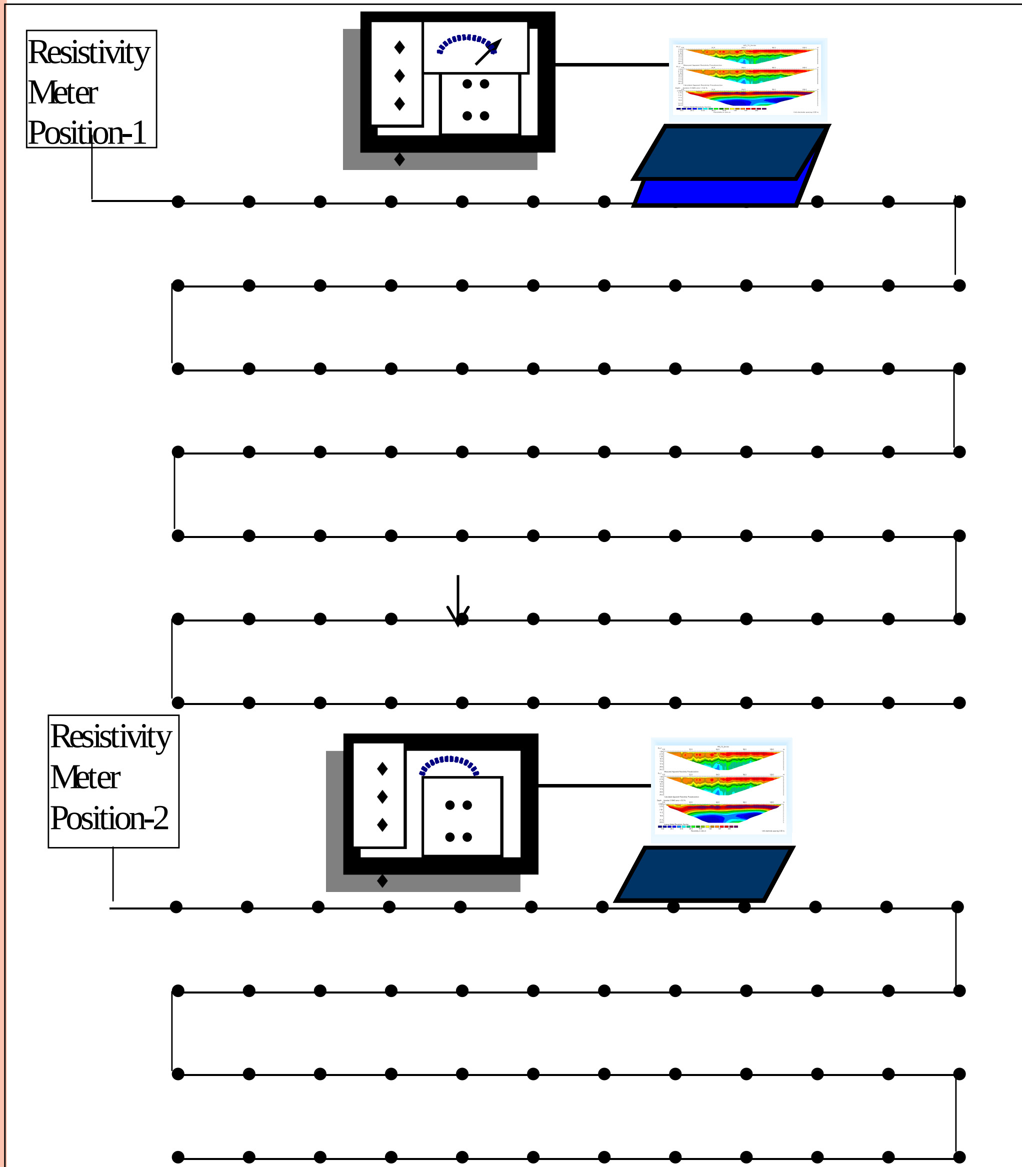


FINDING FRACTURES WITH RESISTIVITY

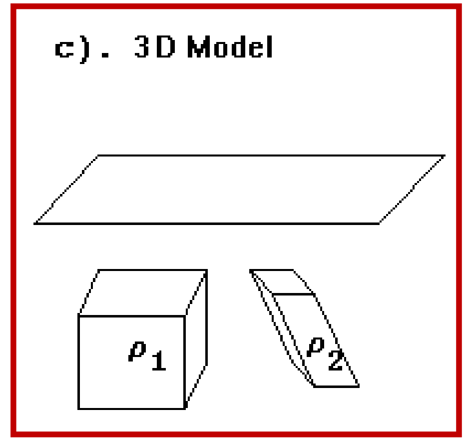


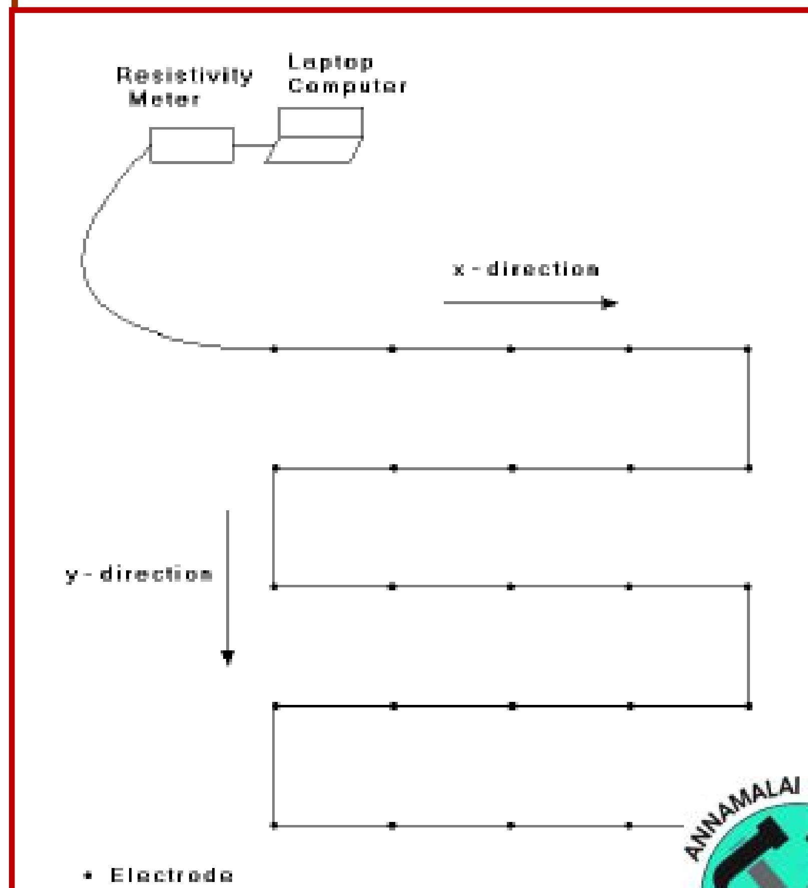
DEMARCATION OF FRACTURES AT SURFACES



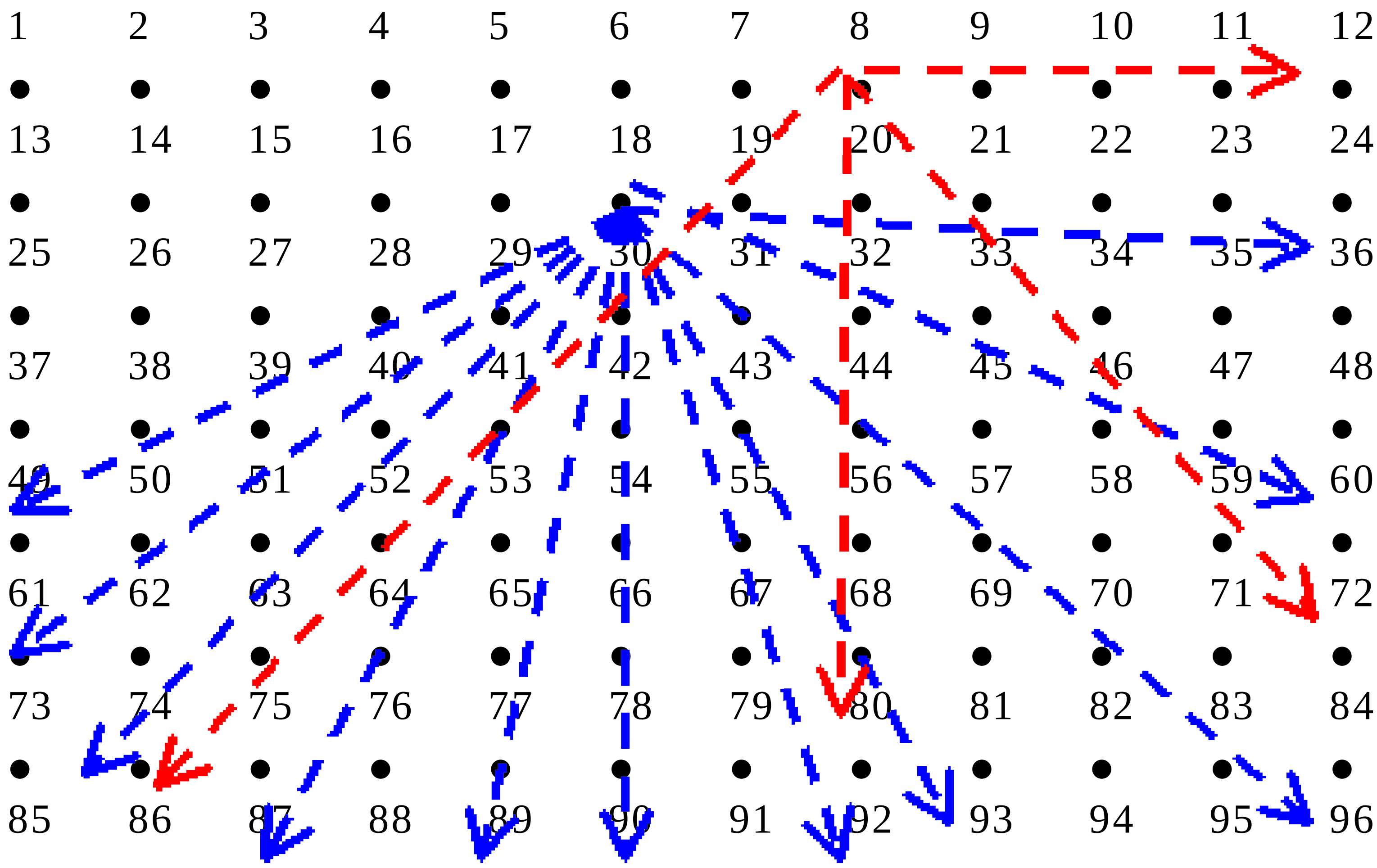

Resistivity
Meter
Position-1
Resistivity
Meter
Position-2

3D IMAGING

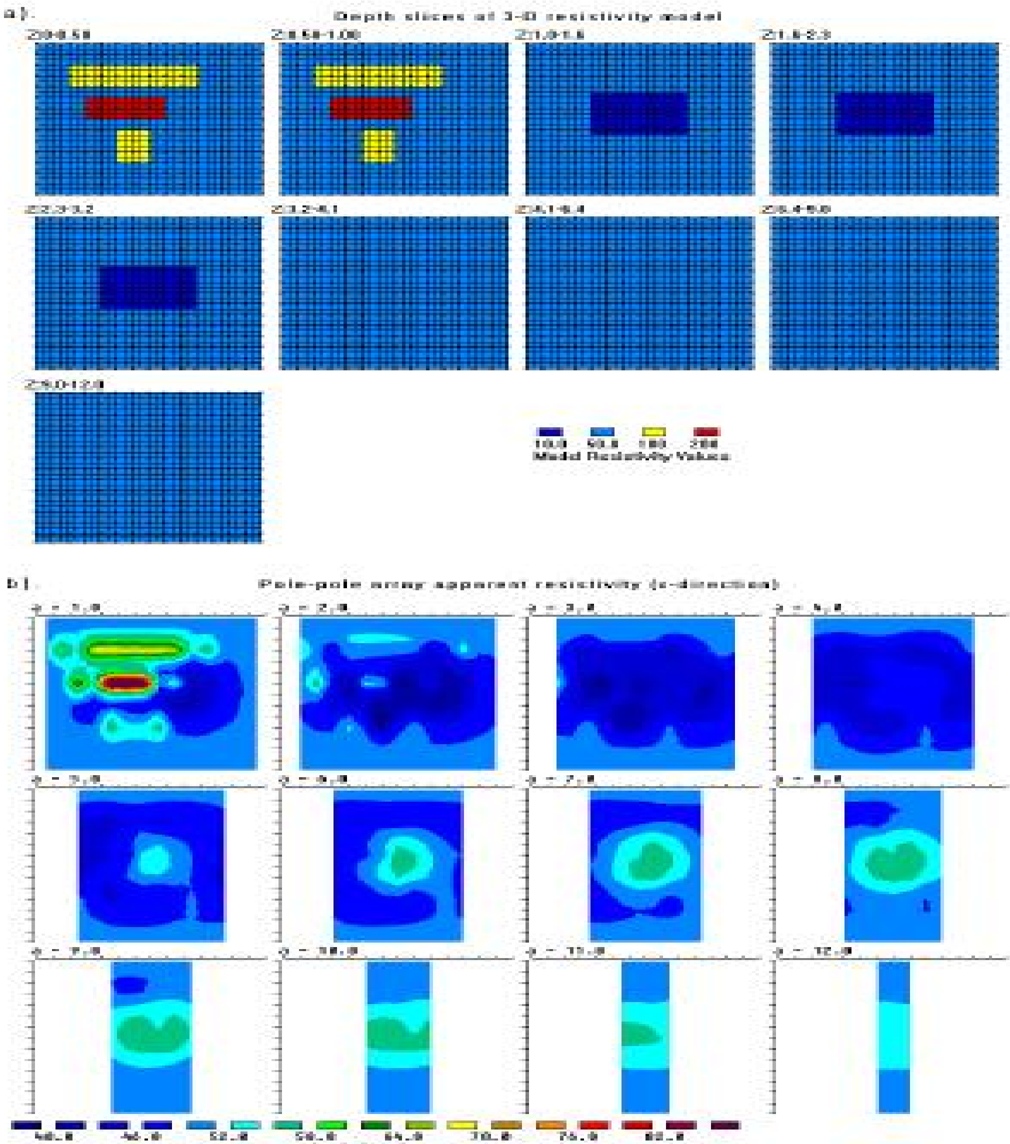

c). 3D Model
ρ1
ρ2

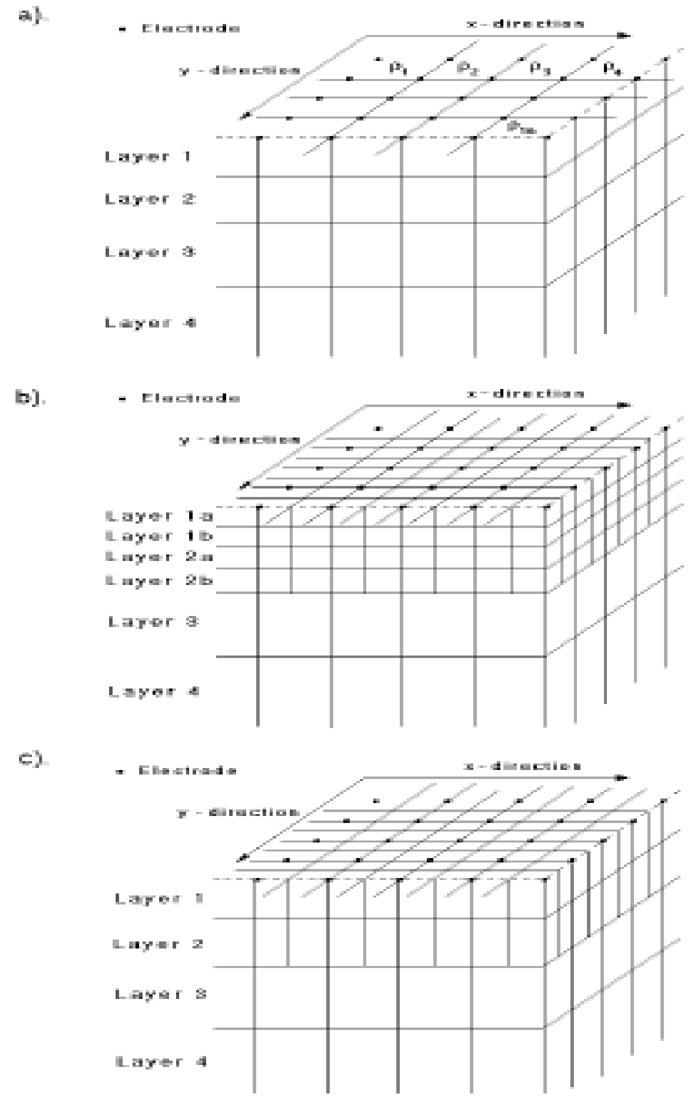

Resistivity
Meter
Laptop
Computer
x - direction
y - direction
• Electrode

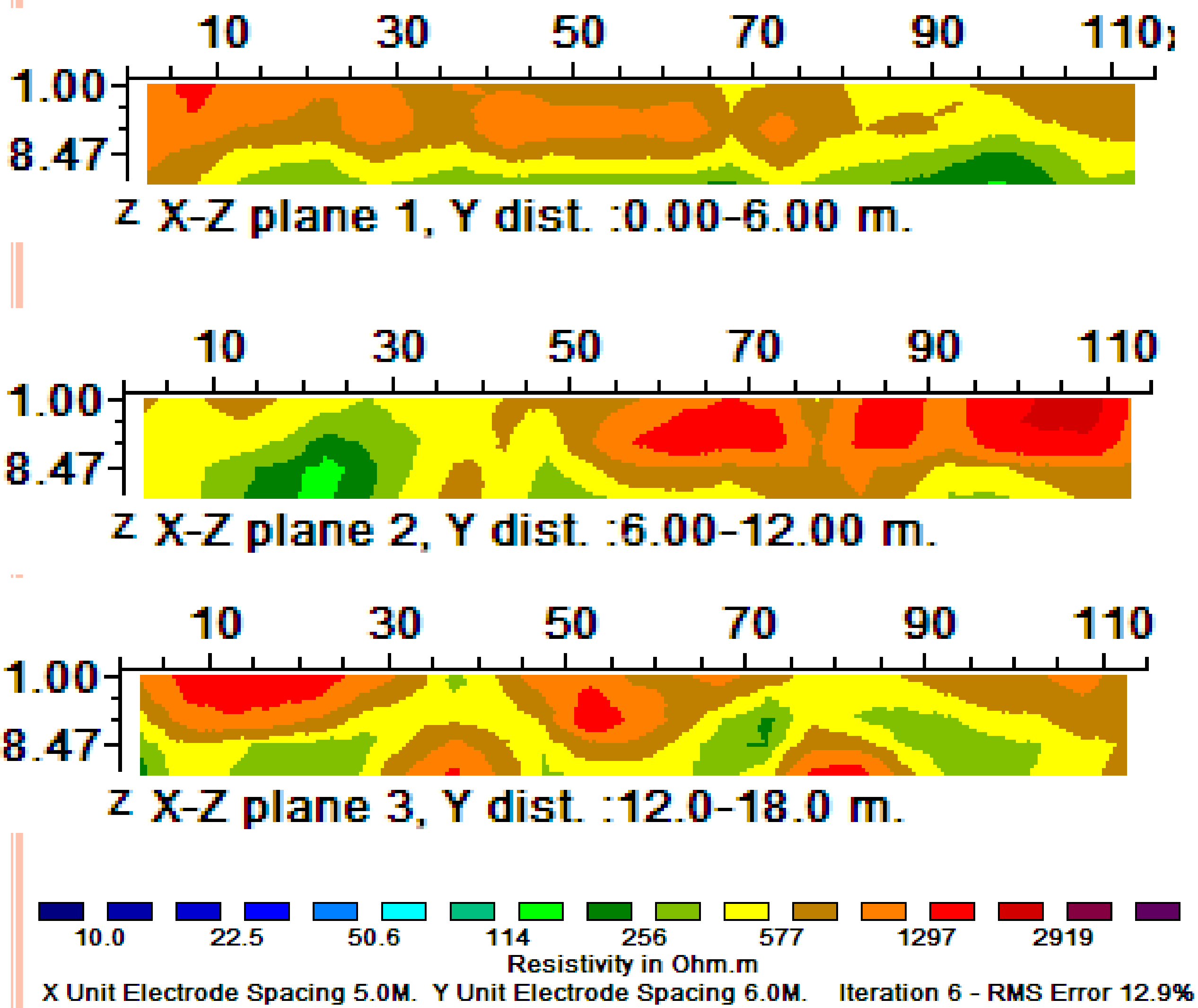
3D IMAGING

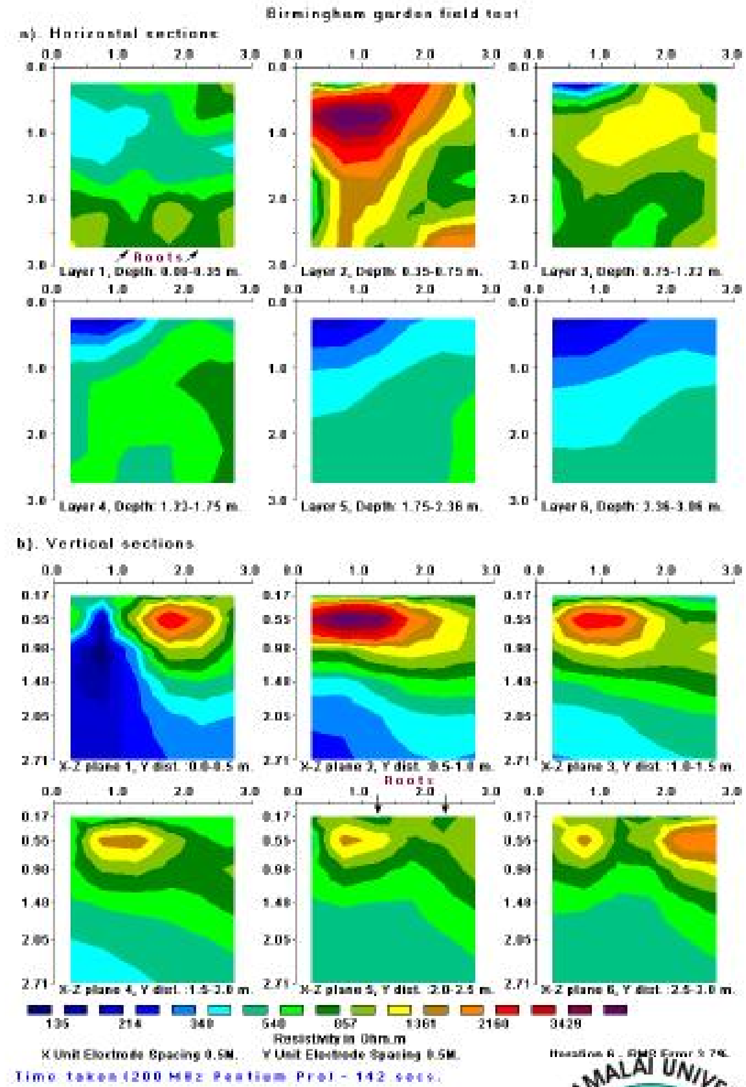


- Current Electrodes
- Potential Electrodes

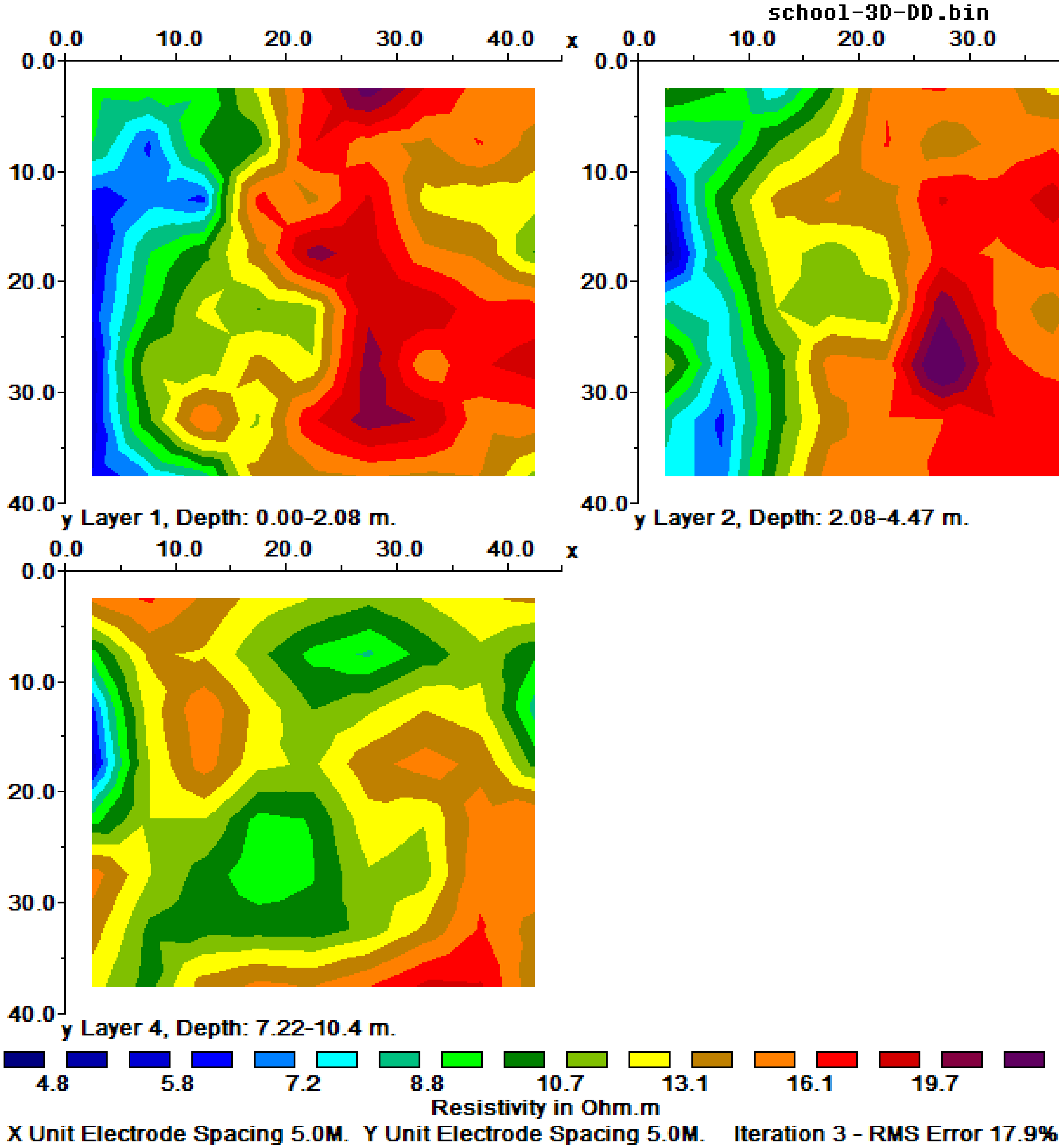

a).
Depth slices of 3-D resistivity model
Model Resistivity Values
b).
Pole-pole array apparent resistivity (x-direction)
Apparent Resistivity in ohm.m


a).
Electrode
x - direction
y - direction
Layer 1
Layer 2
Layer 3
Layer 4
b).
Electrode
x - direction
y - direction
Layer 1a
Layer 1b
Layer 2a
Layer 2b
Layer 3
Layer 4
c).
Electrode
x - direction
y - direction
Layer 1
Layer 2
Layer 3
Layer 4

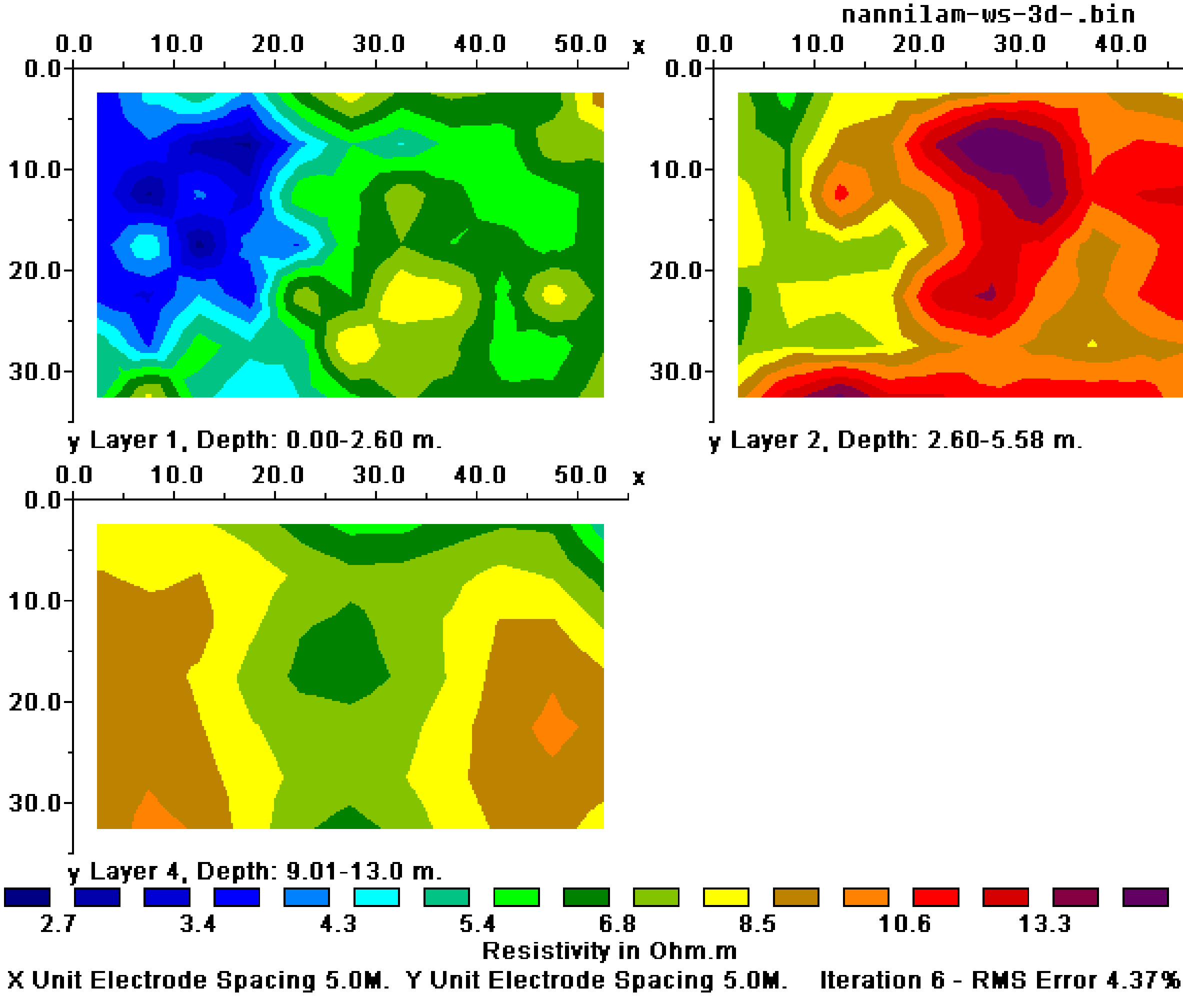




Vertical resistivity section at different X-Z planes

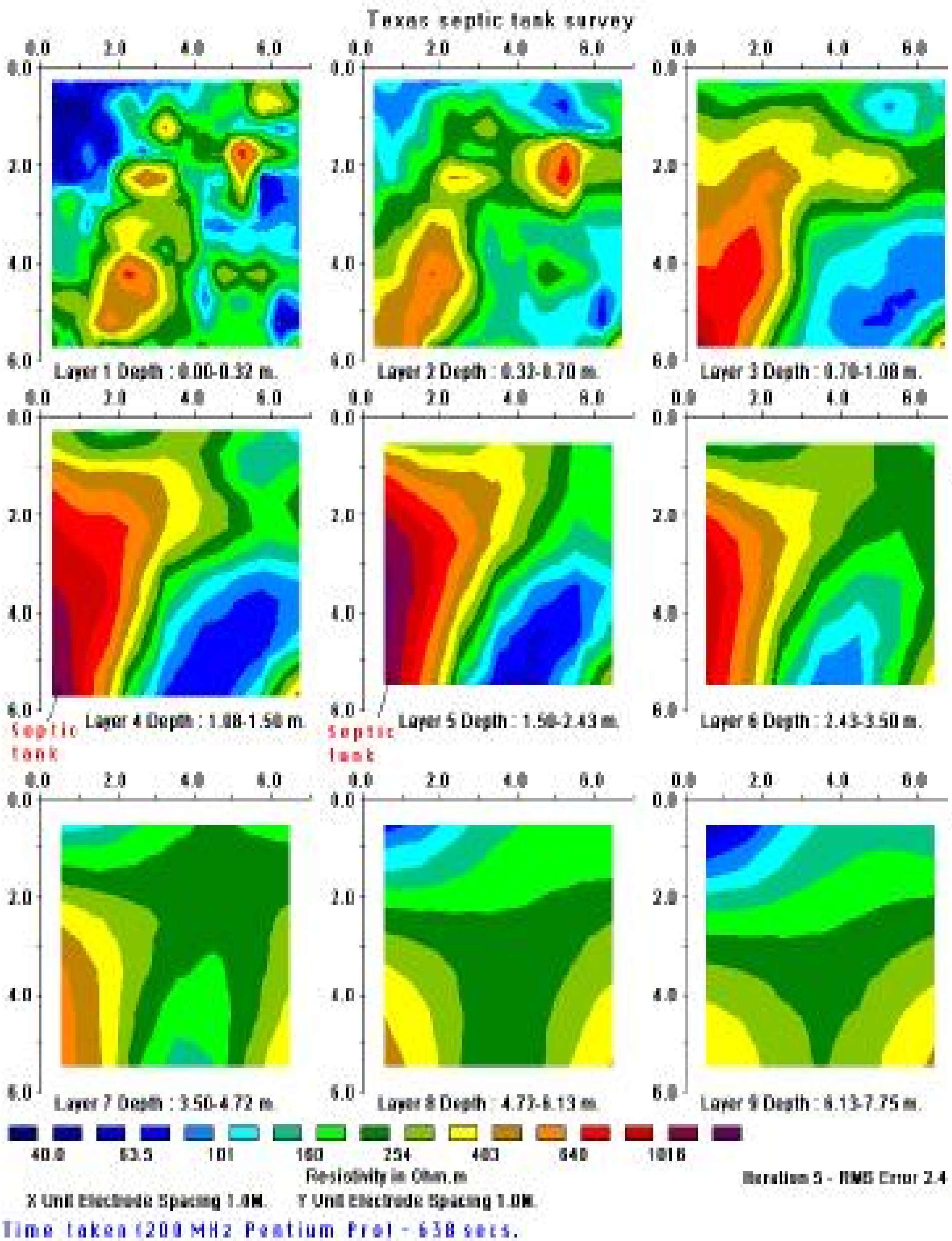


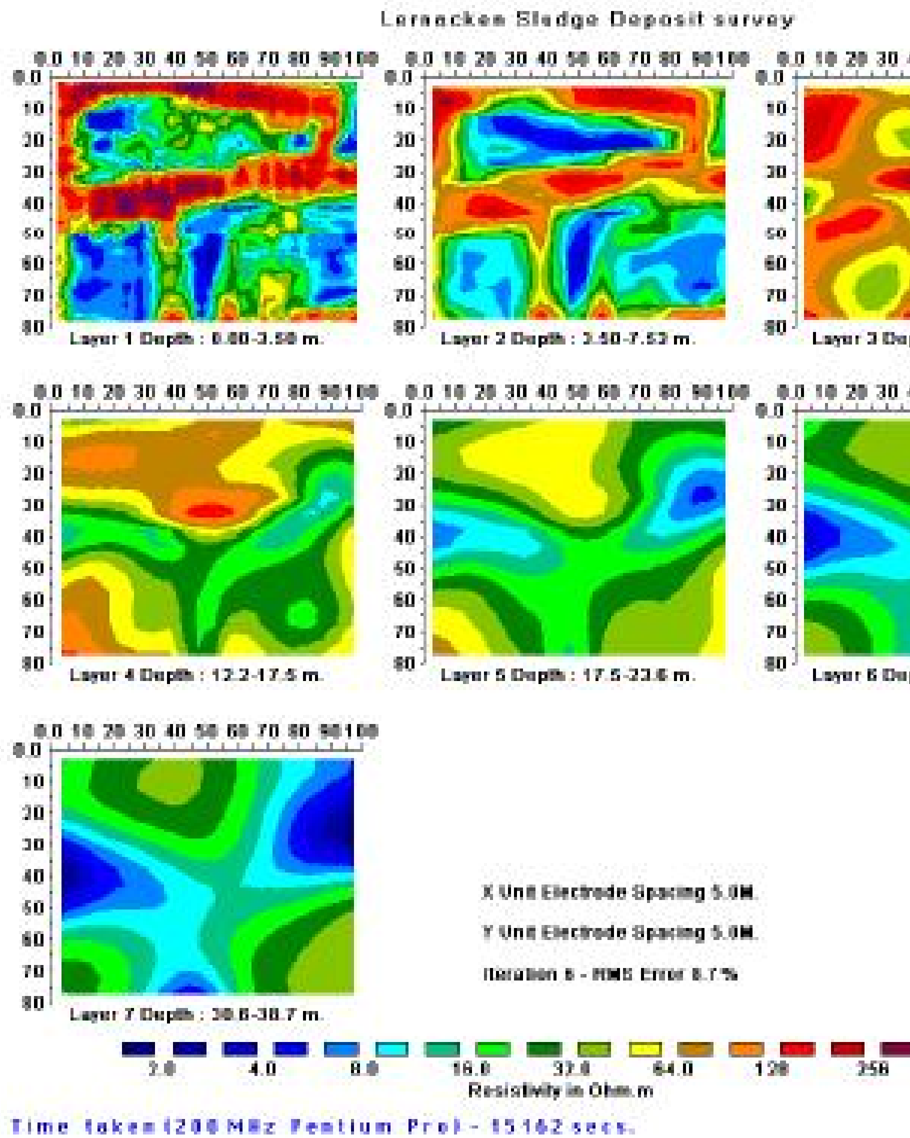
3D Imaging (Horizontal Sections)



3D Imaging (Wenner-Schlumberger Horizontal Sections)

EXAMPLES OF 3D SURVEYING





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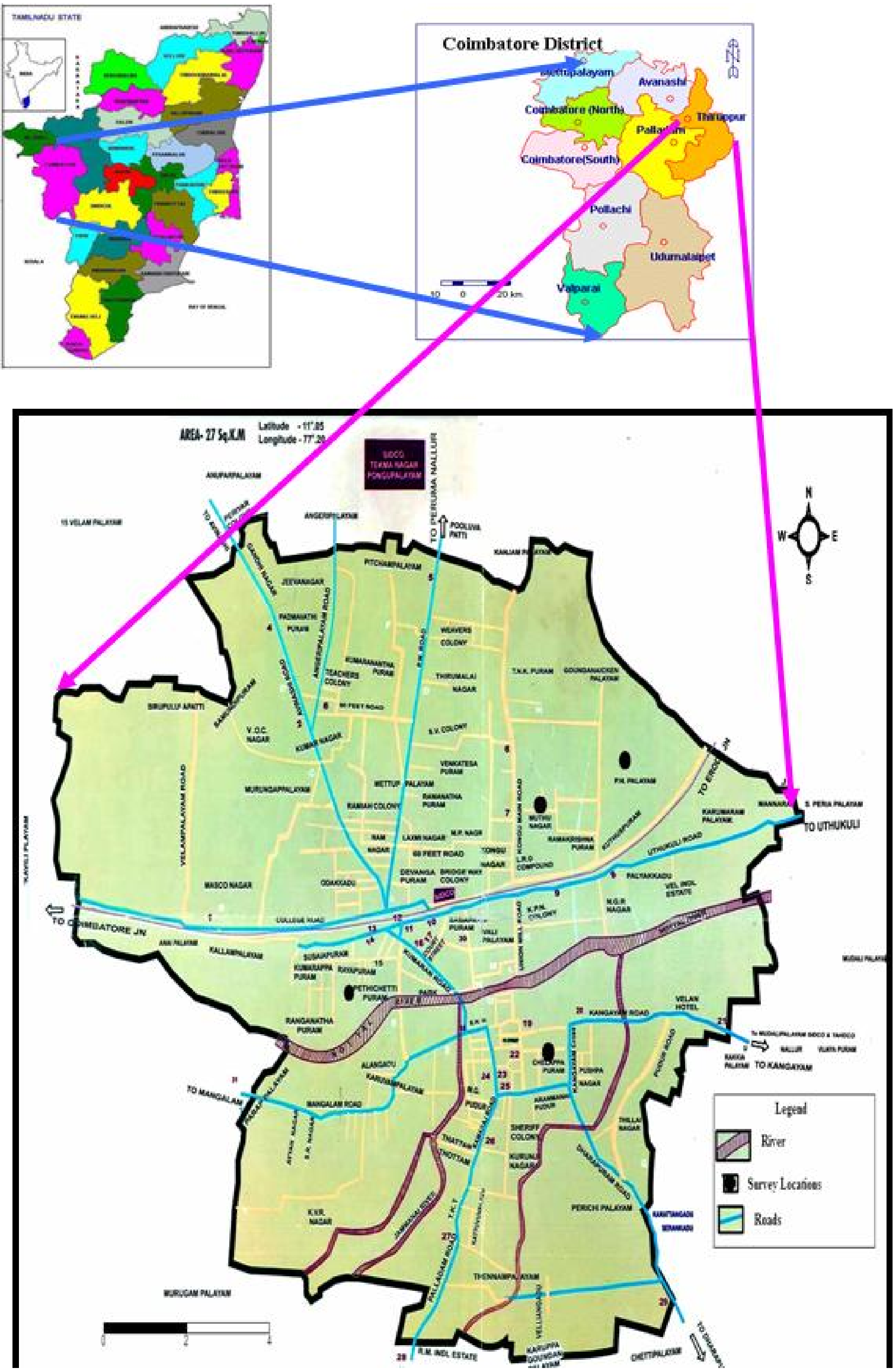


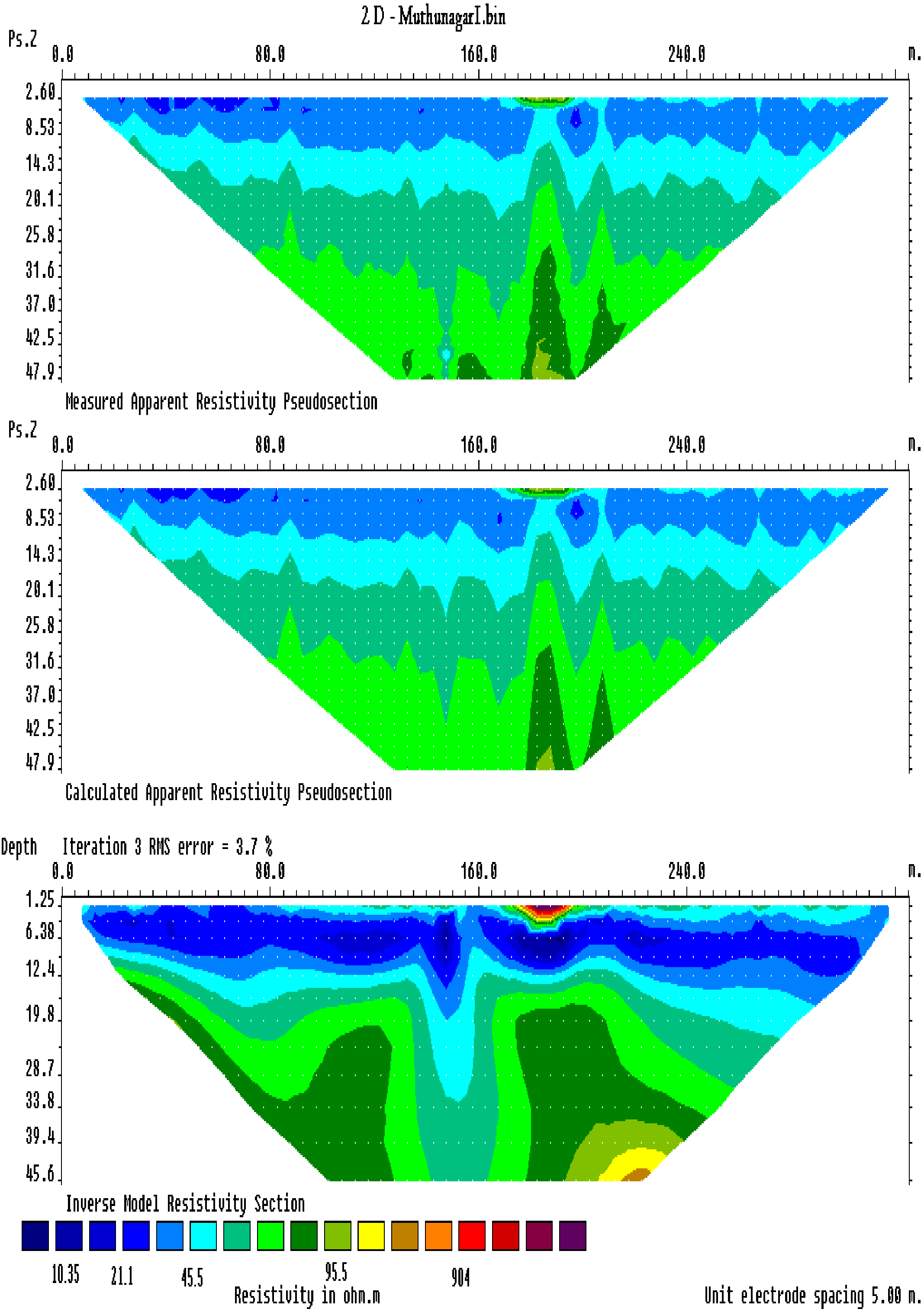
- Tirupur is located 50 Km east in Coimbatore district of Tamilnadu at latitudes and Longitudes 11.18° n 77.25° e with a total extent of 27 sq.km.
- The landmark of Tirupur is the Noyyal river a tributary of river Cauvery which divides the city into two halves, the north and the south.
- The bleaching and dyeing units in Tirupur have caused severe environmental pollution problems.
- These units discharge nearly 90 mld of effluents on land or into the Noyyal river, leading to contamination of the ground and surface water and soil in and around Tirupur and downstream.

DETAILS OF THE STUDY AREA

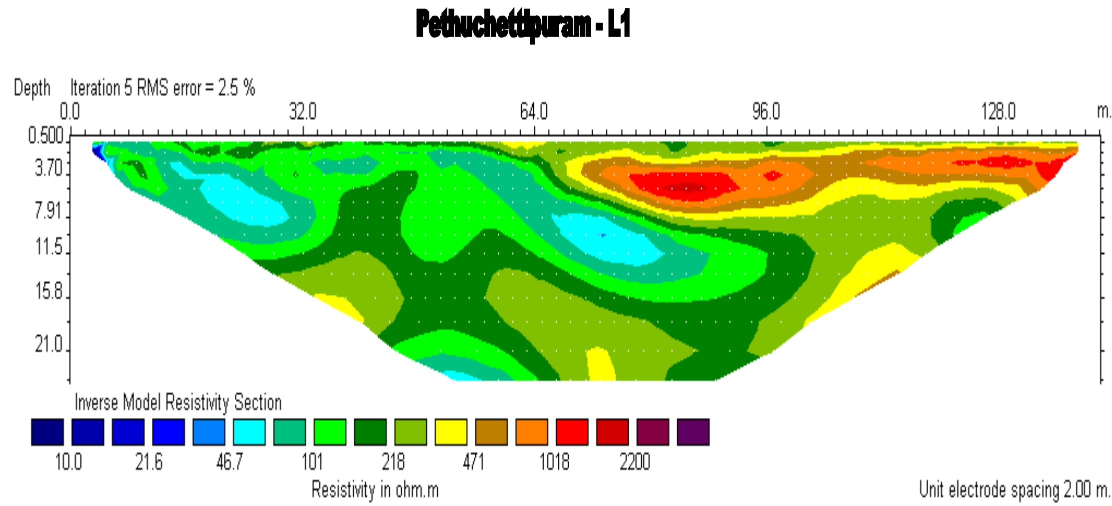
- The most common rock type in the study area is gneiss.
- The gneiss found in the Tirupur region is of high metamorphic grade and is mainly of the biotite type, but quartzo-feldspatic gneiss is also found.
- These rocks are thought to have been formed during the Archaean time period
- The annual average rainfall in the study area is 527.2 mm.
- Groundwater occurs in two different aquifers – shallow (weathered zones) and deeper (Fracture zones)
- These fractured zones extend down as 200mor more.
- The groundwater table more or less follows the topography, but with a smaller slope than the surface slope.
- The hydraulic gradient is approximately 2.8 m/km with a steeper slope of about 6.5 m/km towards the River Noyil.
- A SYSCAL Pro-96 resistivity meter has been used for the present survey.
- This is a multi-electrode system using 96 electrodes with 5 m inter electrode separation.
- 2-D imaging in all the sites were carried out.

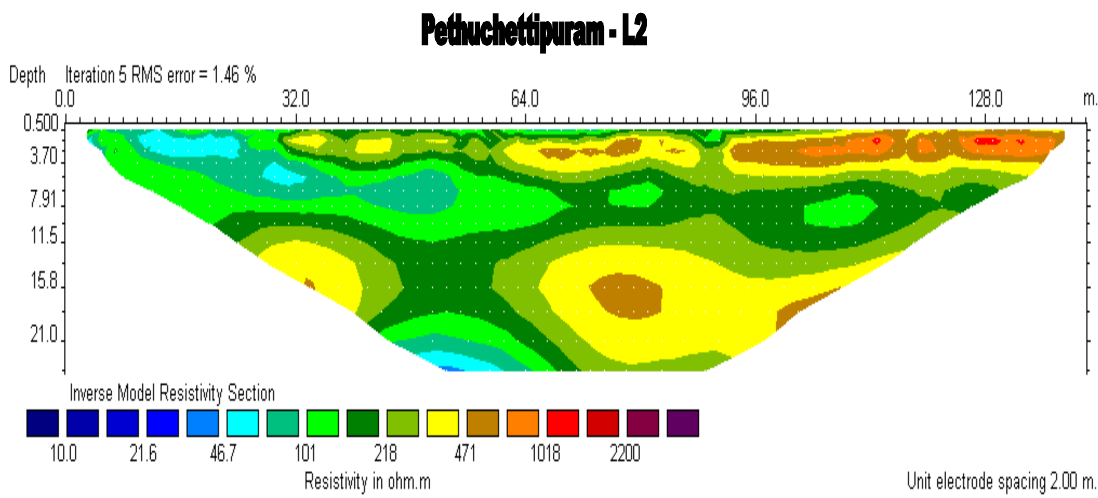
Physical parameter (unit)	Hydraulic conductivity (m/day)	Thickness (m)	Storativity	Porosity (%)
Shallow	9.2	3.7	$4.0*10^{-2}$	45
Vertical	1.8	97.3	$5.2*10^{-3}$	8.0
Horizontal	0.5	100.7	$6.6*10^{-4}$	8.0

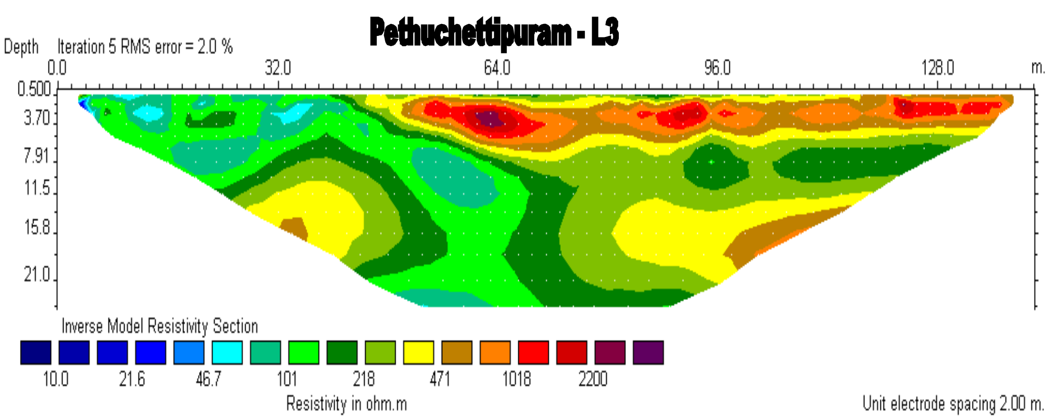
Table. Aquifer paramters of the study area



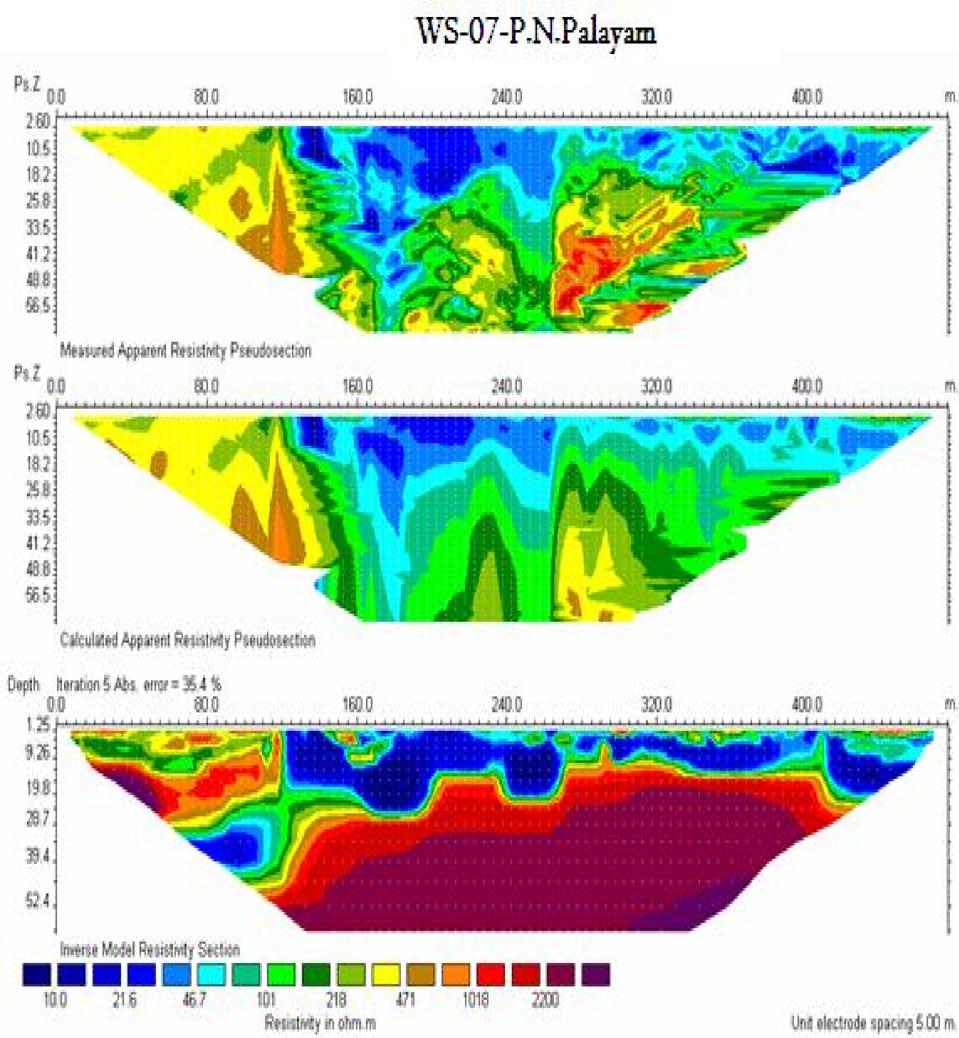
- The first survey was conducted at Valipalayam 1Km from river Noyyal .
- Resistivity was ranging from 10 to 100 Ωm, indicating presence of highly weathered rock materials.
- The basic concept of electrical resistivity method is to demarcate higher resistivity zones within the low electrical resistivity rocks at the sub surface.
- This is because; the very low resistivity is an indicator of highly weathered rock material.
- The regolith with a resistivity range of <10 Ωm is found at a depth of 8m indicating the contamination of top soil due to the discharge of effluents.
- The weathered and fractured zones were identified at a depth of 27 to 47mwith increase in resistivity from 46 to 95.5 m indicating that the deeper layers are exposed to groundwater contamination in the absence of clay materials.



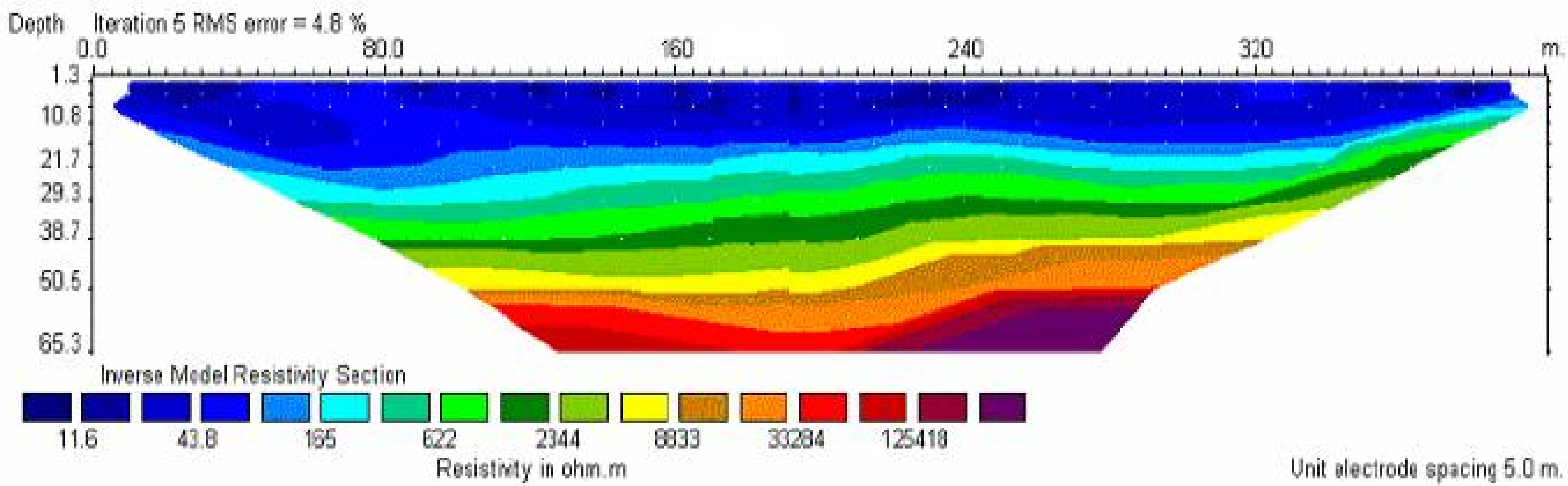




- The second survey at Pethichettipuram.
- The survey indicates source of contamination at left end corner with a drop in resistivity by <46.5 Ω m at a depth of 7.91m.
- The same trend was also noted at a depth of 11.5 m with a drop in resistivity by <21.6 Ω m indicating the contaminated zone at deeper regoliths.
- This is supported by a groundwater sample collected in a dug well to a depth of 15m showing higher TDS value >3,500 ppm.
- The fractured and massive rocks revealed higher resistivity varying from 46.7 to 2200 Ω m indicating the non polluted nature of deeper formations.
- In the central part of the profile a very low resistivity zone exist, indicating existence of an aquifer within the profile, based on its lower resistivity in relation to the background resistivity.



- The third survey at Palayakadu indicates contamination of regolith from 0 to 20m with low resistivity (<40 Ωm).
- Bed rock resistivity (>1058 Ωm) indicates massive rock at shallow depth.
- The profile gives three resistivity variations of layered rock.
- A thin subsurface layer with low resistivity (10 to 46.7 Ωm) at 15 m indicates weathered rock material.
- An intermediate zone (101 to 218 Ωm) at intermediate depth represents weathered to moderately weathered rock material.
- A thick layer with high resistivity (>218 Ωm) observed below low to intermediate resistivity rocks.
- This relatively high resistivity rock layer represents fresh rock , with no structural patterns like fractures and joints, as good indications for aquifers due to their sheared nature represented by the wavy pattern.
- The resistivity layers of the different rock materials in the range (180 to 1080 Ωm) and its contact with the fresh rock observed at a depth range of about 55 m was also accounted.



- The fourth survey at Chellapuram indicates area underlying varying high resistivity rockmaterials.
- The high resistivities observed are typical of fresh granite rocks.
- An overburden with low resistivity to a depth of about 29.3m with a resistivity range of (11to 45 Ω m) indicates weathered layer with greater risk of contamination.
- An intermediate zone with resistivity range (663 to 3328 Ω m) at a depth of 21.1 to 38.7 m is noted.
- A very high resistivity zone (125418 Ω m) observed at a depth of 55 m indicates fresh rock material without any structural pattern like folds and faults.
- The profile therefore could be interpreted as the different layering of weathering resistivity values on the surface and higher resistivity values are confined to the fresh resistant rock materials.

- From a total of four profiles the first, third and fourth showed top 10 to 25 m of regolith has resistivity of less than 10 Ω m , with top 5 m having a resistivity of less than 10 Ω m indicating soil with greater contamination.

- The second profile has shown low resistivity at pockets at shallower depth and resistivity of above 100 Ω m is not contaminated.

- None of the five images measured across the contaminated sites show any strong lateral change in resistivity and it must be admitted that similar information could be obtained with resistivity sounding.

- A few soundings over the area can indicate likely sites for low resistivity regolith and heavy contamination.

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SYSCAL R1 Plus Switch 48
imaging resistivity system

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THANK YOU