CHAPTER 2

RESEARCH METHODOLGY

2.1 Equipment

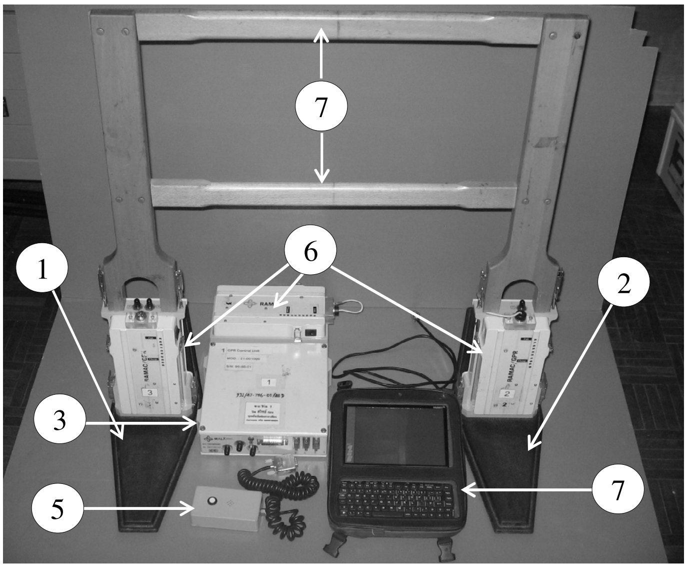
2.1.1 Ground Penetrating Radar

The Malå system RAMAC/GPR used in this study is shown in Figure 2.1. The system comprises the following items;

1) A transmitter unit for sending electromagnetic pulse wave into the ground and a receiver unit for receiving the electromagnetic pulse wave reflected back from the ground
2) The controller unit for controlling the sending, receiving and storing signals
3) The display unit is a potable PC computer used for displaying the radargram both time of the pulse signal traveling from the transmitter to receiver unit and the amplitude of the reflected pulse.
4) The trigger box for starting measurement
5) Optic fiber for sending signal though between control unit and transmitter and receiver unit
6) Antenna handles for fixing distance between the transmitter and receiver antenna
7) Alkaline batteries (12.0 V) for the power supply of the GPR instrument

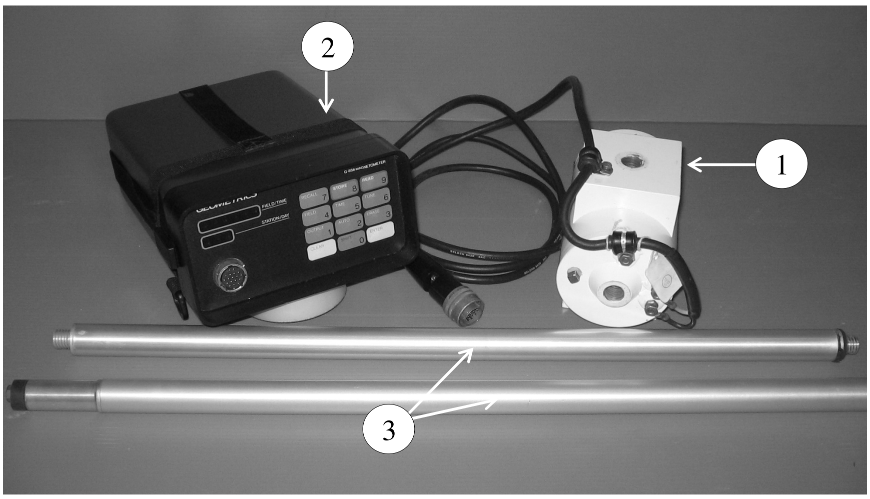
2.1.2 Magnetic Mapping

1) Proton Precession Magnetometer G-856 as shown in Figure 2.2
2) Compass for determining the direction of measurement lines
3) GPS for determining position of the study areas
4) 4 measuring tapes of 50 m long



1. Transmitter Antenna 2. Receiver Antenna 3. Controller Unit
4. PC computer 5. Trigger 6. Batteries
7. Antenna Handles

Figure 2.1 Malå System RAMAC/GPR.



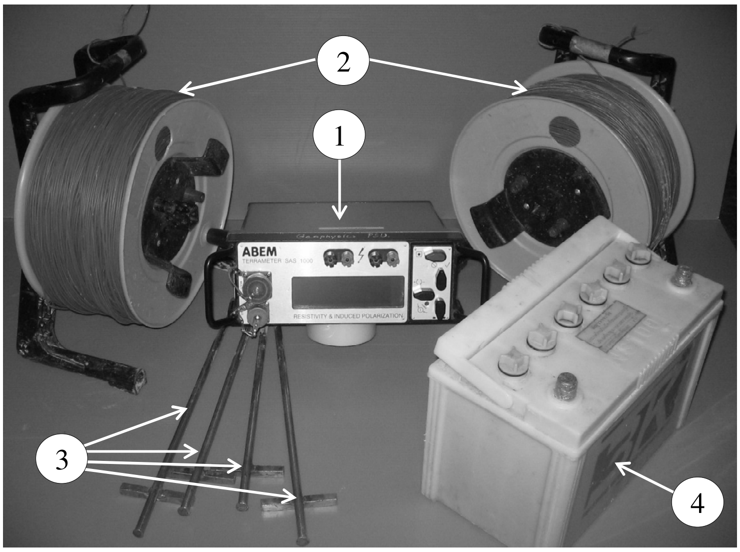
1. Sensor 2. Control Unit and Recorder 3. Staffs

Figure 2.2 Proton Magnetometer G-856.

2.1.3 Resistivity mapping and continuous vertical electrical sounding method

The equipment for the resistivity mapping and Continuous vertical electrical sounding method are the following;

1) ABEM Terrameter SAS 1000 as shown in Figure 2.3
2) Four electrodes, two of them for sending current into the ground and other for measuring potential difference
3) Four cables, each is approximately 50 m long, for connecting between ABEM Terrameter SAS 1000 and electrodes.
4) Four hammers for forcing electrodes into the ground
5) Tapes used wrapping the cables with the electrodes
6) Four measuring tapes, each 50 m long
7) A car battery (12 V, 60 Ah)



1. ABEM Terrameter SAS1000 2. Cables
3. Electrodes 4. Car battery

Figure 2.3 Geoelectrical equipment.

2.2 Materials

2.2.1 Software

1) MapInfo Professional Version 8 (MapInfo Corporation, 2005)
2) Surfer Version 8 (Golden Software, Inc.2002)
3) Grapher Version 3 (Golden Software, Inc.2000)
4) Gradix Version 1.08 (INTERPEX LIMITED,1997)
5) RES2DINV Version 3.55.99
6) Geosoft Software for the Earth Science Version 3.05.06
7) Microsoft Excels 2003

2.2.2 Computer materials

1) Laptop
2) PC computer
3) CD Rom
4) USB
5) Diskettes

2.2.3 Field materials

1) Recording data paper

2.3 Methodology

The research project is carried out both in the field and in laboratory.

2.3.1 Field work measurement

The data was measured in the archaeological site, Lao Pako locates in Phonekham Village, Pak Ngum district, Vientiane Capital at 102 51′ 28.038″ E and 18 09′ 29.904″ N. The study area is divided into two sub-areas, called sub-areas A and B. The sub-area A is 23 m x 32 m and sub-area B is 32 m x 29 m (Figure 2.7).

Four geophysical methods conducted this study are ground penetrating radar measurement, magnetic mapping, resistivity mapping and continuous vertical electrical sounding. The detail of each measurement is explained in the followings;

Figure 2.4 GPR measurement at Lao Pako archaeological site.

Figure 2.5 Magnetic measurement at Lao Pako archaeological site.

Figure 2.6 Resistivity measurements at Lao Pako archaeological site.

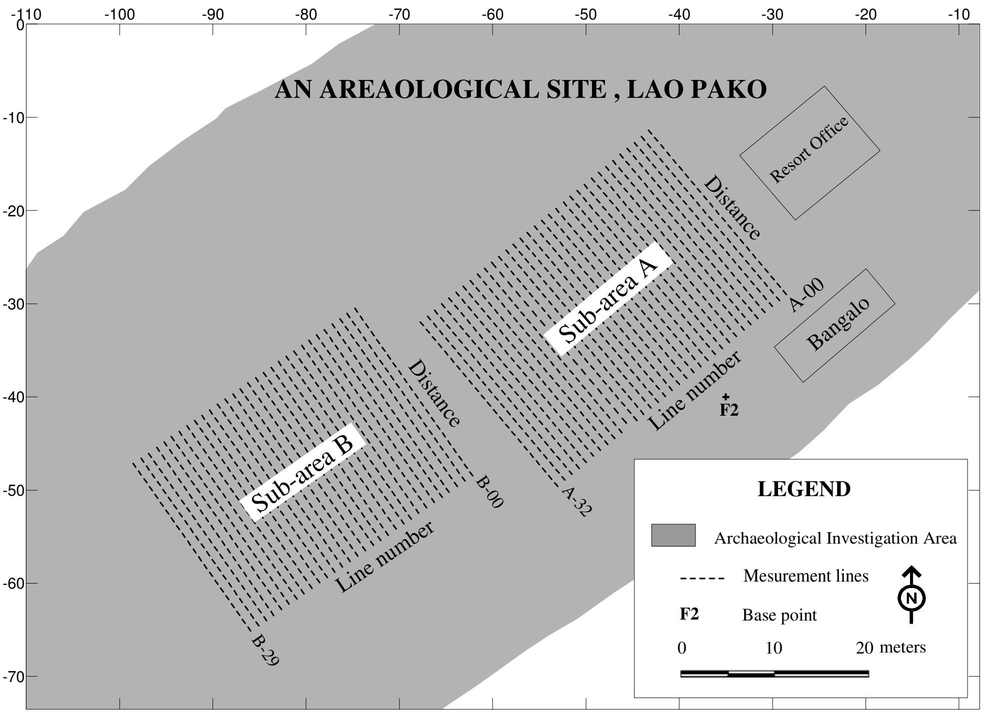


Figure 2.7 Map of study area showing sub-area A and sub-area B and lines of measurement within the study area.

2.3.1.1 GPR measurement

The measurement was carried out with a RAMAC/GPR system. Unshielded antenna of 200 MHz central frequency with common offset configuration was employed in the measurement. The sub-area A comprises 33 measuring lines (line A-00 to line A-32) and each line is 23.0 m long. In sub-area B, there are 30 measuring lines (line B-00 to line B-29) and each line is 22.0 m long (Figure 2.4). The point spacing along a line was 0.2 m and the line spacing was 1.0 m. Figure 2.3 shows GPR measurement in the field.

2.3.1.2 Magnetic Mapping

The magnetic measurement was carried out with a proton-precession magnetometer, GEOMETRICS G-856. The heights of the sensor were 1.25 m and 1.85 m above the ground in both sub-areas. The direction of line measurement was determined by a compass and location of the study areas was determined by GPS.

At the sub-area A, the measurement was conducted along parallel lines with line spacing of 1.0 m. with station spacing of 1.0 m. The total number of measurement lines is 33 as shown in Figure 2.7 (staring from line A-00 to line A-32). Firstly, we measured magnetic field at the base station, F2 (Figure 2.7). Then, measurement was started from the beginning to the end of the first line (line A-00). After finishing measurement on the first line, we measured magnetic field at the base station again. Then, we continued measuring on the second lines (line A-01). After finishing measurement on the second lines, we measured the field at the based station again and so on. After finishing measurement in all lines, we stared to measure the total magnetic field again by changing height of the sensor from 1.25 m to 1.85 m and repeated the measurement as above. The same of measurement procedure was applied for sub-area B which comprises 30 measurement lines.

TABLE 2.1 A sample of recoding data table for magnetic measurement.

Line No.	Total field (nT)	Time (h)	Drift (a loop)	Corrected field in a loop	$B_{base,f} - B_{base,i}$	Corrected field (nT)
Base	**43664.4**	**11.684**	**20.51**	**43664.4**		**43664.4**
0	43690.8	11.700		43690.5		43690.5
0	43685	11.705		43684.6		43684.6
0	43680.8	11.711		43680.2		43680.2
0	43676.8	11.714		43676.2		43676.2
0	43672.6	11.717		43671.9		43671.9
0	43671.2	11.720		43670.5		43670.5
0	43667	11.723		43666.2		43666.2
0	43661.4	11.726		43660.6		43660.6
Base	**43666.4**	**11.782**		**43664.4**		**43664.4**
Base	**43666.4**	**11.782**	**-43.64**	**43666.4**	**-2**	**43664.4**
1	43688.8	11.791		43689.2		43687.2
1	43680.8	11.796		43681.42		43679.4
1	43675.6	11.799		43676.35		43674.4
1	43672.4	11.802		43673.27		43671.3
1	43667.8	11.804		43668.78		43666.8
1	43666.6	11.807		43667.7		43665.7
1	43663.6	11.809		43664.81		43662.8
Base	**43662.8**	**11.864**		**43664.4**		**43664.4**

2.3.1.3 Resistivity Mapping

The resistivity measurement was carried out with a Terrameter SAS 1000 in two sub-areas. The sub-area A comprises 17 measuring lines, each line is 23.0 m long and spacing between lines is 2.0 m. However, in sub-area B, there are 14 measuring lines, each line is 22.0 m long and spacing between lines is 2.0 m as shown in Figure 2.7. The chosen electrode configuration was Wenner array with electrode spacing of 1.0 m ($a = 1.0$ m), as shown in Figure 1.15(a). Two electrodes, C1 and C2, were used for injecting electric current into the ground and two potential electrodes, P1 and P2, for measuring electric potential. All electrodes are moved from the beginning of line (the first position of C1 is 0.0 m) to the end of lines. The data were recorded by manually and automatically in the Terrameter SAS 1000.

TATBLE 2.2 A sample of recoding data table for Wenner array.

Sub-area: **A**						Location: Lao Pako	Date: 26th May 2007	
						Operator: Sounthone		
Line no.	Electrode Positions in meters				a	TERRAMETER Reading in Ohms		Calculated App. Res.
	C1	P1	P2	C2		R	Mid point	ρ_a (Ωm)
0	0	1	2	3	1	194.2	1.5	1219.9
0	1	2	3	4	1	219.1	2.5	1376.7
0	2	3	4	5	1	151.6	3.5	952.6
0	3	4	5	6	1	205.5	4.5	1291.4
0	4	5	6	7	1	209.1	5.5	1313.6
0	5	6	7	8	1	369.9	6.5	2324.0
0	6	7	8	9	1	279.6	7.5	1756.5
0	7	8	9	10	1	392.5	8.5	2466.1
0	8	9	10	11	1	461.7	9.5	2900.9
0	9	10	11	12	1	368.7	10.5	2316.9
0	10	11	12	13	1	432.6	11.5	2717.8
0	11	12	13	14	1	363.1	12.5	2281.4
0	12	13	14	15	1	374.1	13.5	2350.5
0	13	14	15	16	1	239.0	14.5	1501.9
0	14	15	16	17	1	264.6	15.5	1662.4
0	15	16	17	18	1	292.0	16.5	1834.6
0	16	17	18	19	1	228.4	17.5	1435.2
0	17	18	19	20	1	226.6	18.5	1424.0
0	18	19	20	21	1	252.2	19.5	1584.7
0	19	20	21	22	1	272.6	20.5	1712.9
0	20	21	22	23	1	343.0	21.5	2155.0

2.3.1.4 Continuous vertical resistivity sounding (CVES)

The resistivity measurement was used by a Terrameter, ABEM SAS 1000 along 8 lines in two sub-areas; namely, line A-06, A-17, A-25, A-26, A-27 and A-28 in sub-area A and line B-04, B-07 and B-08 in sub-area B. They are measurement lines where GPR and resistivity mapping showed up. The dipole-dipole electrode configuration with electrode spacing of 1.0 m was chosen for the measurement. First, all electrodes were placed on ground with spacing of 1.0 m. With the current electrodes, Next both current electrodes, C1 and C2 fixed, at x=0, and x=3.0 m respectively potential electrodes, P1 and P2 were moved away from current electrodes by increasing n from n=1 to 6. After that two current electrodes and two potential electrodes were moved toward 1.0 m. Then, two potential electrodes were moved to back toward current electrodes decreasing from n=6 to 1. The same procedures were repeated until all measurement lines were measured.

TABLE 2.3 A sample of recoding data table for dipole-dipole array.

Sub-Area: B							Location: Lao Pako	Date: 26th May 2007	
Line no. B-07							Operator: Sounthone	Time: 9 am	
Loop	n	Electrode Positions in meters				*a*	TERRAMETER Reading in Ohms	error %	Calculated App. Res.
		C1	C2	P1	P2		*R*	st	ρ_a (Ωm)
1	1	0	1	2	3	1	213.77		4029.47
	2	0	1	3	4	1	38.814		2926.51
	3	0	1	4	5	1	6.5158		1228.20
	4	0	1	5	6	1	1.6231		611.89
	5	0	1	6	7	1	0.62569		412.79
	6	0	1	7	8	1	0.30115		317.89
2	6	1	2	8	9	1	0.40533		427.86
	5	1	2	7	8	1	0.78704		519.24
	4	1	2	6	7	1	1.7503		659.85
	3	1	2	5	6	1	5.4006		1017.99
	2	1	2	4	5	1	26.68		2011.62
	1	1	2	3	4	1	233.99		4410.61
3	1	2	3	4	5	1	149.31		2814.43
	2	2	3	5	6	1	23.53		1774.12
	3	2	3	6	7	1	6.2708		1182.02
	4	2	3	7	8	1	2.3635		891.02
	5	2	3	8	9	1	1.1562		762.78
	6	2	3	9	10	1	0.4819		508.68
4	6	3	4	10	11	1	0.52553		554.74
	5	3	4	9	10	1	1.6402		1082.10
	4	3	4	8	9	1	4.2306		1594.90
	3	3	4	7	8	1	9.4198		1775.59
	2	3	4	6	7	1	27.38		2064.40

2.3.2. Laboratory processing and analysis

All field data used correction and processing before significant information of the surface clearly shows up. The processing involved in this thesis work is as follows;

2.3.2.1 Ground Penetrating Radar

In following processing steps were applied to GPR data by utilizing Interprex Gradix software, version 1.08;

(1) SET TIME ZERO: to mark the signal starting of the signal.

(2) DEWOW: for removing the low frequency noise. It results from saturation of the recording instrument's electronics. High pass filter was applied in this process.

(3) VELOCITY ANALYSIS: Hyperbola fitting method was used for determining RMS velocity at any two-way time. (See Section 1.1.1.8)

(4) BACKGROUND REMOVAL FILTER: an average trace of all traces in a profile subtracts to from remove the background.

(5) ATTENUATION REMOVAL: the function $g(t)$ is applied to the radar section. The function $g(t)$ consists of linear and exponential component as follows (Gradix Manual, 1997) ;

$$g(t) = \frac{t}{\delta t} e^{(\alpha + \beta . weight . t)} \quad \text{for } t > 0 \tag{2.1}$$

$$g(t) = e^{\alpha} \quad \text{for } t < 0 \tag{2.2}$$

Where t is the time of current sample;

δt is the sample interval;

α is a empirical constant;

β is a empirical constant;

Weight is the weight parameter specified in dialog in dB/m.

(6) Depth estimation (See Section 1.1.1.8).

2.3.2.2 Magnetic mapping

(1) Drift correction: the magnetic field varying in time called *diurnal variation,* so that drift correction need to be done for correcting the total field. The drift correction for one loop of measurement can calculated by

$$Drift = \frac{B_{base,f} - B_{base,i}}{t_{base,f} - t_{base,i}} \tag{2.4}$$

Where $Drift$ is the drift of measurement in a loop.

$B_{base,i}$ and $B_{base,f}$ are the initial and final total magnetic field at the base station.

$t_{base,i}$ and $t_{base,f}$ are the initial and final at the base station.

Drift corrected field at any station in a loop: The drift collected field is calculated from

$$B_{drift,n} = B_n - Drift \times \left(t_n - t_{base}\right) \tag{2.5}$$

Where $B_{drift,n}$ is the drift corrected magnetic field at the n^{th} station in a loop.

B_n is the total magnetic field at the n^{th} station.

t_n is the measuring time at the n^{th} station.

t_{base} is the measuring time at the first station of the loop.

(2) Residual magnetic field is calculated by

$$B_{Res} = B_{drift,l} - B_{drift,h} \tag{2.7}$$

Where $B_{drift,l}$ is the drift corrected magnetic field at sensor elevation of 1.25 m.

$B_{drift,h}$ is the drift corrected magnetic field at sensor elevation of 1.85 m.

2.3.2.3 Resistivity mapping

For Wenner configuration, apparent resistivity of the ground was calculated by using equation as follows,

$$\rho_a = 2\pi a \frac{\Delta V}{I} \tag{2.8}$$

Where ρ_a is the apparent resistivity.

a is the electrode spacing.

$\frac{\Delta V}{I}$ is the voltage difference over current ratio in Ohm unit.

For electrode spacing of 1.0 m, effective penetration depth is approximately 0.52 m. This depth is called the effective depth (Edwards, 1977). The apparent resistivity maps of the study area were by using surfer 8 (Golden Software, Inc. 2002).

2.3.2.4 CVES

RES2DINV version 3.55 (Loke, 1999) is an inversion program employed to determine a two dimensional (2-D) resistivity model of subsurface in the study area from electrical image survey (Griffiths and Barker 1993). In this inversion program, the subsurface is divided into small rectangular blocks as shown in Figure 2.8. The depth of the bottom row of the block is equal to the effective depth of investigation (Edwards, 1977). The number of blocks normally does not exceed the number of data points. The inversion program will create a model of resistivity in pseudo-section (Figure 2.9) and adjust this model by applying a non-linear least square optimization technique (deGrood-Hadlin and Constable 1990, Loke and baker 1996a). Obviously, the program attempts to get the best fitting between the calculated apparent resistivity and measured apparent resistivity by adjusting the resistivity model blocks until minimum the root-mean square (RMS) is obtained. However the obtained model with low RMS error may not represent the actual subsurface condition. It is, therefore, recommended that prior information should be used as constraints in modeling. In practice, the error is not less than 3% due to noise in the raw data. Otherwise, the RMS error reduction can be done by removing some bad data points which is abnormal comparing with the nearest data points. The best model RMS errors should be lower than 5%.

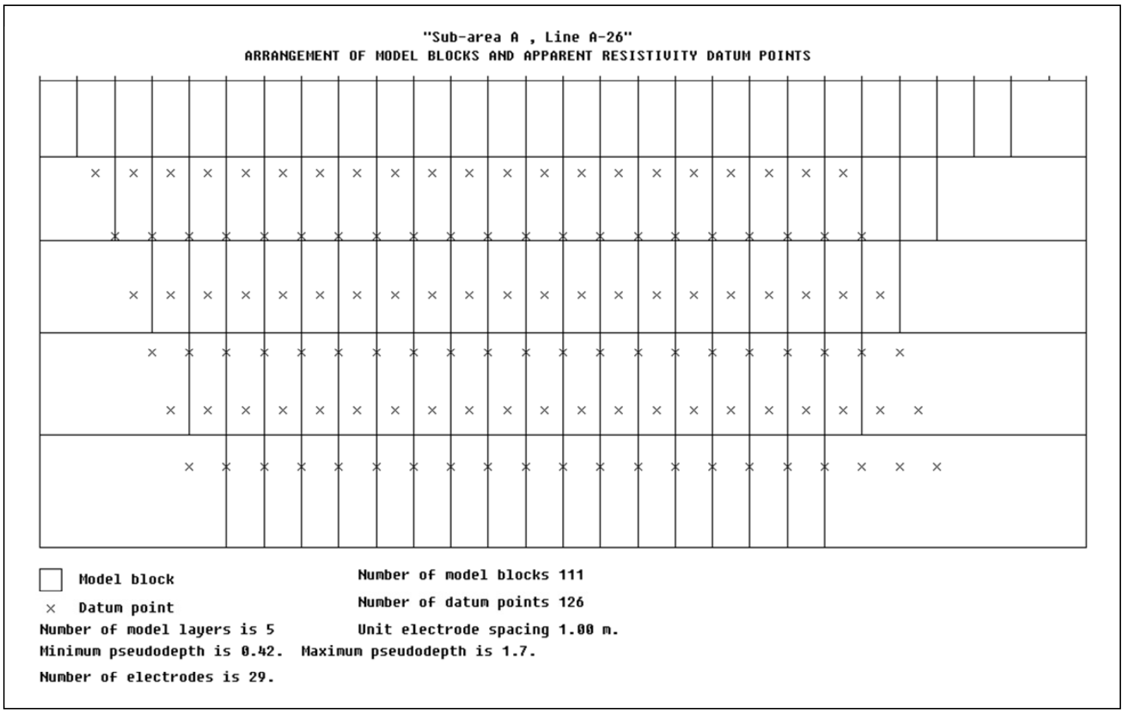


Figure 2.8 Arrangement of model blocks and apparent resistivity data points for Line A-26.

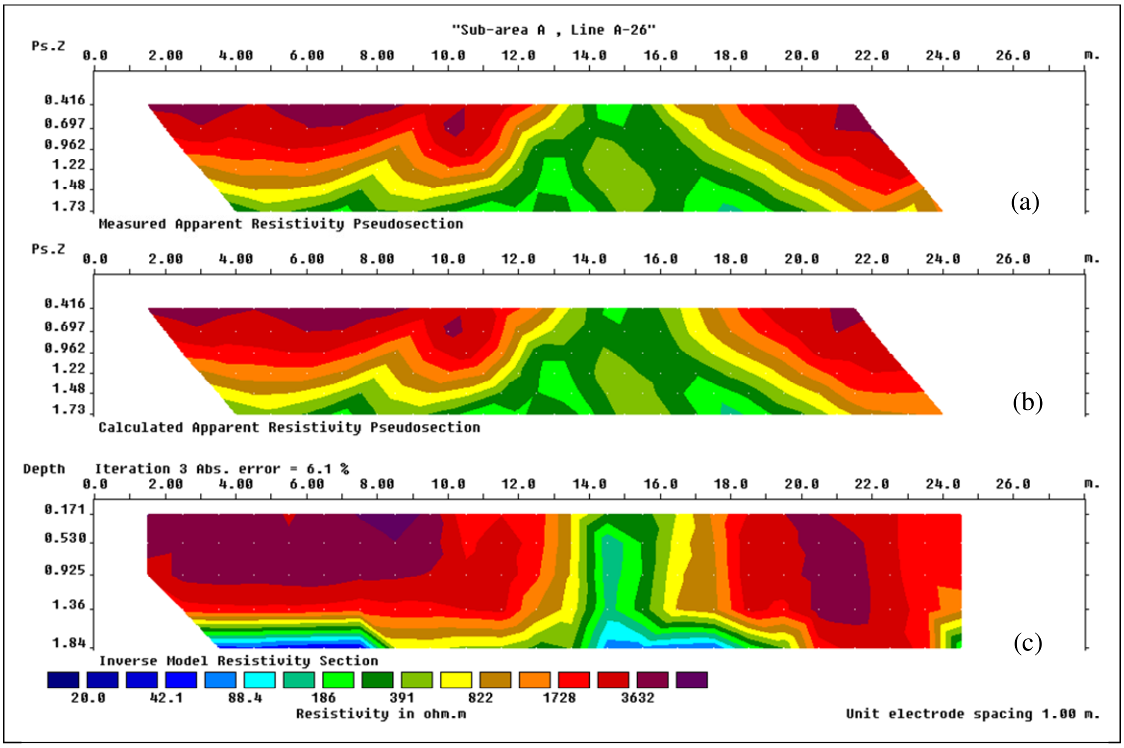


Figure 2.9 The measured apparent resistivity pseudosection (a), resistivity pseudosection (b) and the inverse model resistivity section (c) under the Line A-26, calculated with 15 iterations (RMS error = 6.1%).