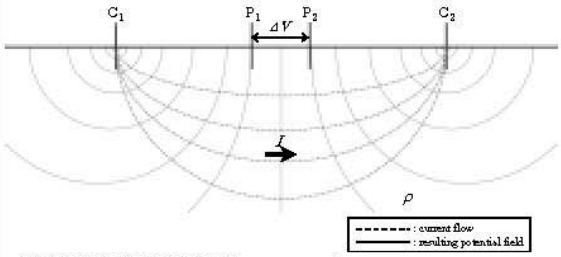
Appendix D

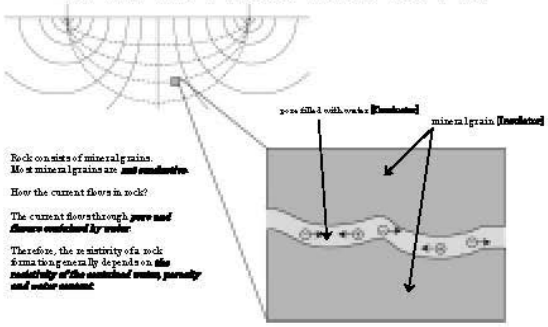
Slides for Water Resources Institute

Principle of Electrical Survey



Schematic section about electrical survey.
The current ***I*** is injected through the current electrodes, C1 and C2.
The potential difference ***ΔV*** between the potential electrodes, P1 and P2, is measured.
If the underground is homogeneous, the resistivity ***ρ*** is calculated by ***I*** and ***ΔV***.

Electrical conduction in rock



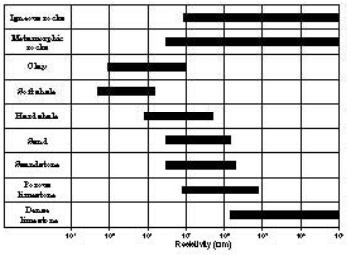
Rock consists of mineral grains.
Most mineral grains are **not conductive**.

How the current flows in rock?

The current flows through **pore and fissure contained by water**.

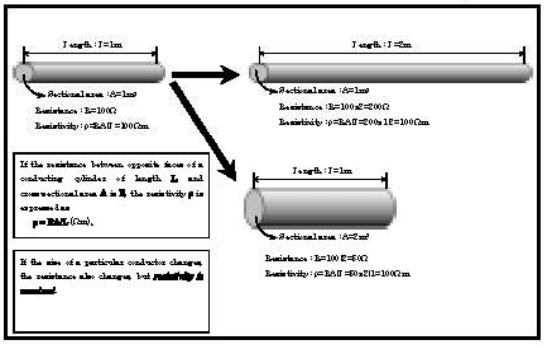
Therefore, the resistivity of a rock formation generally depends on **the conductivity of the contained water, porosity and water content**.

Resistivity Ranges of some Rock Types



In general, the porosity increases in order of igneous rock, metamorphic rock., sedimentary rocks, sand and clay.
Therefore, the resistivity increases in reverse order.

Resistance and Resistivity



Resistivity and Apparent Resistivity

If the underground is **homogeneous** the resistivity is expressed as

$\rho = GV/I$

where, V is potential difference between potential electrodes (P1, P2), I is current injected through current electrodes (C1, C2) and G is called ***geometric factor*** *depending on the configuration of electrodes.*
The table shows commonly used electrode configurations and geometric factor corresponding to each configuration.

Name of configuration	Geometric factor	Configuration
Pole-pole	$2\pi a$	C1 P1 ... a ... P2
Pole-dipole	$3\pi a$	C1 P1 ... a ... P2 ... a ... C2
Wenner	$2\pi a$	C1 P1 a P2 C2
Schlumberger	$\pi(L^2-b^2)/2b$, $L \geq 5b$	C1 P1 ... b ... P2 ... L ... C2
Dipole-dipole	$n(n+1)(n+2)\pi a$	C1 C2 ... a ... P1 P2

if *homogeneous*, ρ = True Resistivity
if *inhomogeneous*, ρ ≠ True Resistivity = *Apparent Resistivity*

In most case, the underground is **inhomogeneous**, therefore ρ is ***apparent resistivity***.

Apparent resistivity is a formal and artificial concept and does not indicate true resistivity. Nevertheless, apparent resistivity is very useful for analysis of electrical survey because we can estimate true resistivity structure from apparent resistivity.

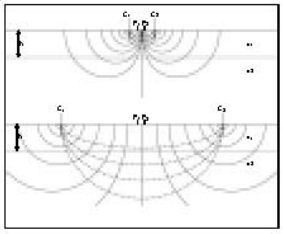
Vertical Electrical Sounding - 1

Vertical variation of resistivity is investigated by vertical electrical sounding method.
In this method, the data are measured with a number of separations of current electrodes keeping the center of electrodes at the measurement point.

If the separation of current electrodes is very small compared to the thickness of upper layer ($C_1C_2 \ll h_1$), the current is confined to the upper layer.

↓

The underground is regarded as homogeneous with resistivity ρ_1.

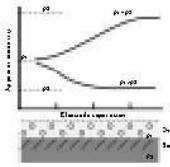


If the separation is very large compared to the thickness of upper layer ($C_1C_2 \gg h_1$), the current penetrates deeper and the effect of the current flowing within the upper layer is negligible.

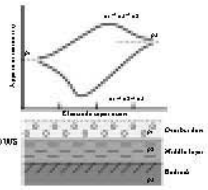
↓

The underground is regarded as homogeneous with resistivity ρ_2.

Vertical Electrical Sounding - 2



The Case of Two layer.
The apparent resistivity shows ρ_1 at the separation is very small.
As the separation increase, the apparent resistivity approaches ρ_2.



The Case of Three layer.
The apparent resistivity shows ρ_1 at the separation is very small and ρ_3 at very large.
At the intermediary separation, the apparent resistivity shows nearly ρ_2.

Principle of McOHM-EL

McOHM-EL is a geophysical equipment for electrical survey and electrical logging.

Available method:

- Electrical survey — DC resistivity method, e.g. Schlumberger, Wenner, etc.
- Electrical logging — Normal logging; Temperature logging; Caliper logging

Specification:

Transmitting section		Data memory section	
Output current	2, 20, 60 or 120mA	RAM capacity	96kB (approximately 4000 data can be stored
Max output voltage	400V		
Duration time	2, 5or 4sec		
Data acquisition section		FDD capacity	512(Header) + 46 x N(Data number) [bytes]. In case of 1.2MB disk, max N is about 26200.
Input impedance	10MΩ		
Max input voltage	±8V		
Min detective voltage	1μV		
Stacking	1, 4, 16 or 64		

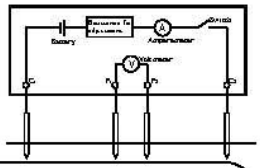
Principle of McOHM-EL

The Inside of McOHM-EL

The equipment consists of **transmitting section** and **data acquisition section**.

Transmitting section consists of battery, adjustable resistance, amperemeter and switch. The current value is monitored by amperemeter.

Data acquisition section consists of voltmeter. The potential difference between P_1 and P_2 is measured by voltmeter.



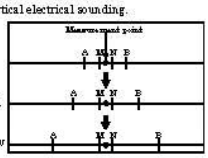
General Procedure

1. Connection
1.1 Connect the 12V battery to the power supply connector.
1.2 Connect wires from four electrodes to current (C_1, C_2) and potential (P_1, P_2) terminal.
2. Setting Parameter
2.1 Turn on the power supply switch.
2.2 Press **[F1]** key to display VES menu.
2.3 Set parameter of CURR, PERI., WAVE, STACK and PRINT.
3. Measurement
3.1 Press **[ENTER]** key after setting parameter to start measurement.
3.2 The measurement will be done in several seconds, and the result is displayed on LCD.
3.3 Press **[ENTER]** key to save the data into the memory. Pressing **[CANCEL]** key cause returning to the setting parameter menu without saving the data.

Schlumberger Method

Schlumberger method is most commonly used for vertical electrical sounding.

In this method, four electrodes are placed in the ground on one line symmetrically around the mid-point, the measurement point.



The Current is injected through the outer electrodes (A, B), and the potential difference between the inner electrodes (M, N) is measured simultaneously.

The electrodes are moved out around the midpoint and a new measurement is taken.
The apparent resistivity is calculated as,

$$\rho = \pi\left(L^2 - l^2\right)\frac{V}{I} \quad [\,L \geq 5l\,]$$

where L and l are the length of AB and MN, respectively. V is the potential difference between the electrodes M and N. I is the current injected through the electrodes A and B.

Note that L must be grater than $5l$

Schlumberger Method

The procedure of Schlumberger method

1. Stretch measuring tapes along the line. Set the mid-point 0m.
2. Place the electrodes in the ground at predetermined spacing (Start from small separation.).
3. Connect the cables between electrodes and the terminals on McOHM-EL.
4. Taking data. ***Plot data on a double logarithmic diagram in order to ensure data quality.***
5. Move out the current electrodes, and take new data.
6. Save the data into the floppy disk when the measurement is completed.

List of items for Schlumberger method
McOHM-EL
12V battery with cable
Cables
Electrodes
Hammer
Measuring tape
Calculator
Tester
GPS
Field note
Water container
Umbrella

Parameter for normal condition.
- Curr. : Set low current like **[2]** or **[20]**mA when the current electrodes are close together. As the separation of AB increases, the signal decreases. Therefore, you should set high current like **[60]** or **[120]**mA.
- PERI. : Set **[2]** seconds.
- WAVE : Set [+ −].
- Stack : Set **[4]** (at least).
- PRINT : Set **[OFF]**.

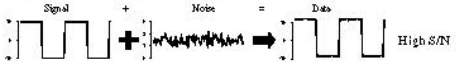
Schlumberger Method

How to take good data

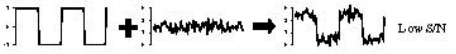
The operation of McOHM-EL is very simple and the procedure of Schlumberger is very easy. Anybody can take data using this equipment, but we must take ***good data***.
There are some technique in order to take good data.

What is good data?

Good data has a high ***S/N ratio***. *S/N* ratio is ***signal to noise ratio***.
Data consists of ***signal*** and ***noise***. If signal is large compared to noise, data is good.



If signal is too small, data is bad.



Schlumberger Method

In order to improve S/N ratio.

1. Increase the current

The resistivity is calculated using the potential difference, V, and the current, I, as,

$$\rho = G\frac{V}{I}$$

where G is geometric factor. The equation above is modified as follows,

$$V = \frac{\rho I}{G}$$

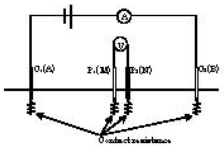
As indicated in this equation, in order to enlarge the potential difference, it is necessary to increase the current.

2. Decrease the contact resistance

The contact resistance is resistance between the electrode and the ground. The current and the contact resistance have a relation as follows,

$$I = \frac{V_o}{R_c}$$

where Vo is the output voltage, Rc is the contact resistance. In order to increase the current, the contact resistance must be decreased.
In general, the contact resistance should be ***below 2kΩ***.



In order to decrease the contact resistance, plant the electrode more deeply and pour water around the electrode

Schlumberger Method

In order to improve S/N ratio.

3. Stacking

Stacking : averaging waves from 1 to 6

Noisy data

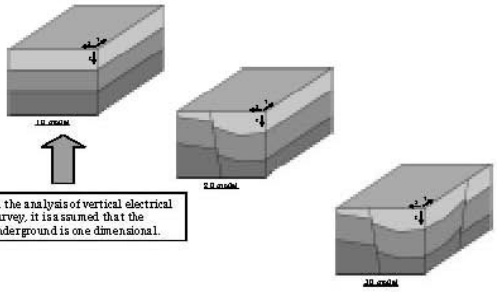
Good data

If the noise is random, the data quality is improved by Stacking.

The cause of noise
Artificial : Power line, automobile, pipeline.
Natural : SP, thunder, rainwater.
Another : Cross talk between current and potential cables (electromagnetic induction).

In order to decrease the effect of noise
Select the measurement point as to keep distance from artificial construction.
Stop the measurement during rain or thunder.
Increase stacking number.
Place the current cable and potential cable at distance from each other

Assumed Model for Electrical Survey



1E model

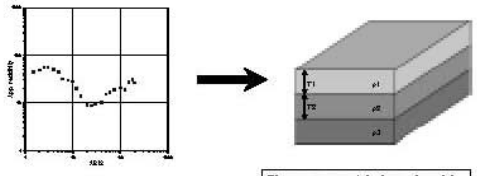
2E model

3E model

In the analysis of vertical electrical survey, it is assumed that the underground is one dimensional.

The Objective of the Analysis

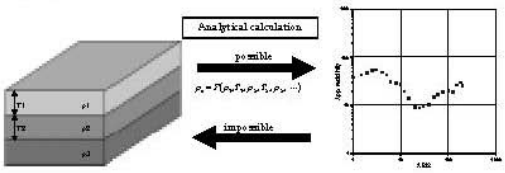
The objective of the analysis is to estimate the parameter of the layered model from the apparent resistivity.



The parameter of the layered model is ***resistivity*** and ***thickness*** of each layer

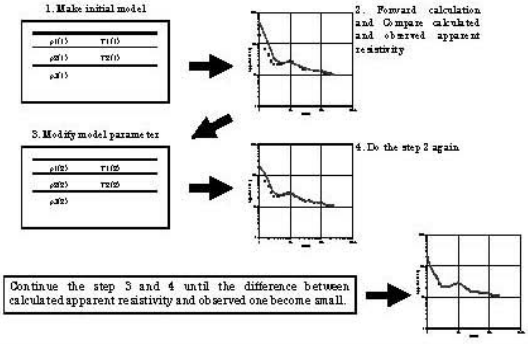
The Inversion Method

The apparent resistivity can be calculated from the parameter of the layered model analytically. It is called *forward calculation*.
On the other hand, the parameter of the layered model can not be calculated from the apparent resistivity analytically.



In order to estimate the parameter of the layered model, we use ***the Inversion method***

The Inversion Method



Continue the step 3 and 4 until the difference between calculated apparent resistivity and observed one become small.

Digital Data Filing

Filing data in a computer makes the following works easy.

- Search data
- Drawing observed data
- Drawing analysis results
- Further analysis

Contents of Digital Data

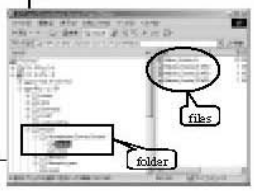
Digital Data consists of the following data.

- General Information
  Project name, Area name, Station No., Coordinates, Elevation, Azimuth, Operator, Date, Geology and Remarks.
- VES Data
  Observed data and Analyzed data.

Utilization of Folder Structure

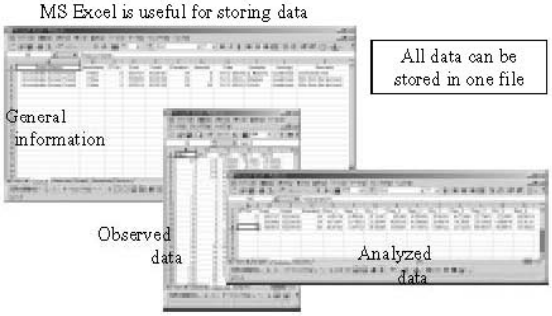
Example of folder structure

```
Project
    ├── [Project Name 1]
    |       ├── [Area Name 1]
    |       |       └── files
    |       |
    |       ├── [Area Name 2]
    |       |       └── files
    |
    ├── [Project Name 2]
    |       ├── [Area Name 1]
    |       |       └── files
    |       |
```



Data File

MS Excel is useful for storing data

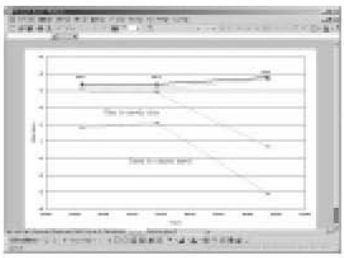


All data can be stored in one file

Drawing 1

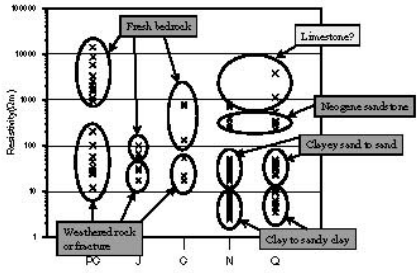
Draw VES curve using observed data

Drawing 2



Draw interpreted section using analyzed data

Example of Further Analysis



Appendix E

Borehole Log

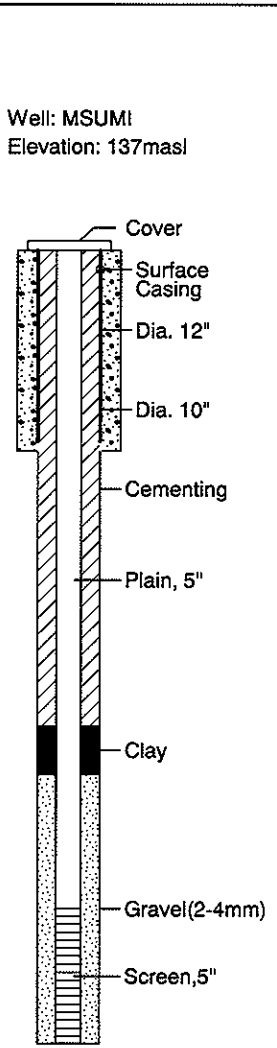
The Study
on Water Supply Improvement
in Coast Regionand Dar es Salaam Peri-Urban
in the Republic of Tanzania

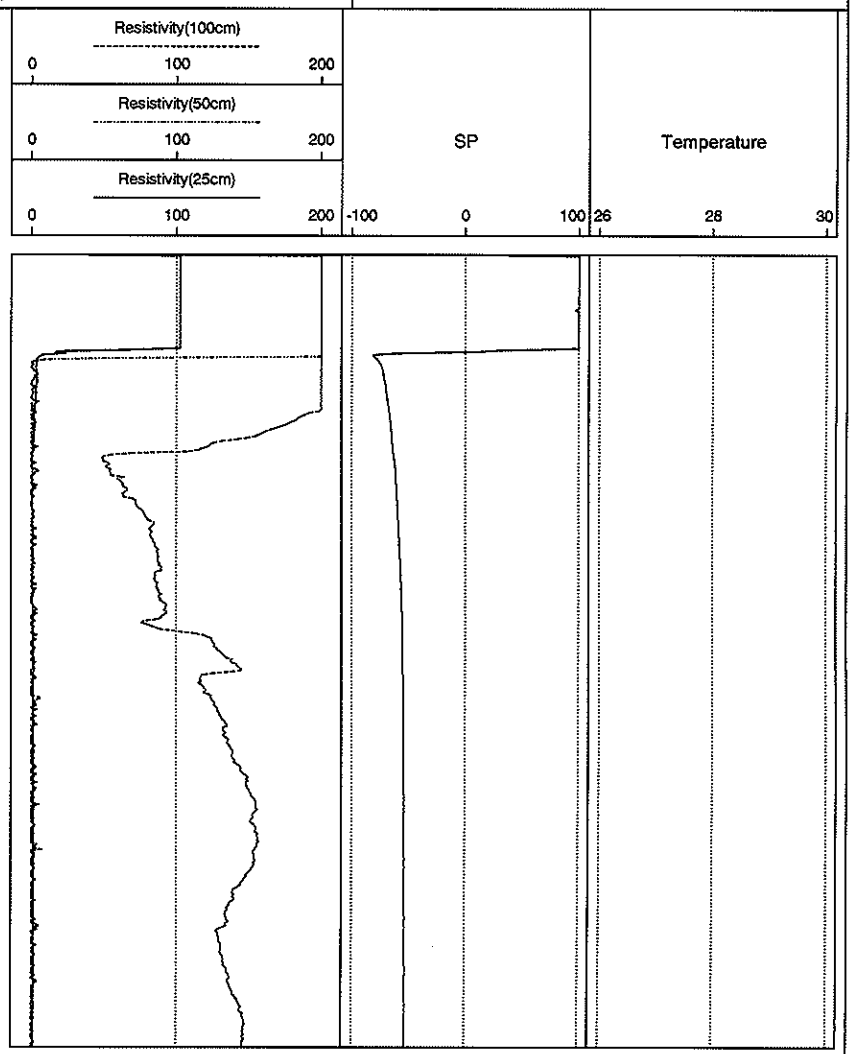
Borehole Log: J-1 BH No. DSM 644/2004 Msumii Village

(page 1 of 2)

Longitude	: 39.10750	Commenced date	: 10,November,2004
Latitude	: 6.71139	Completed date	: 14,November,2004
Elevation	: 137 masl	Pumping test date	: 05,December,2004
SWL	: 67.87mbgl	Yield	: 20.89 Liter/min
Drillling depth	: 91mbgl	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	Formation	GRAPHIC	DESCRIPTION
0	132	SP		SAND, Grey-brown, fine to medium grained,
5	127			
10	122			
15	117			
20	112			
25	107	GT		SAND,grey, medium to coarse grained, intercalated with limestone.
30	102			
35	97			
40	92			
45	87			
50				





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(page 2 of 2)

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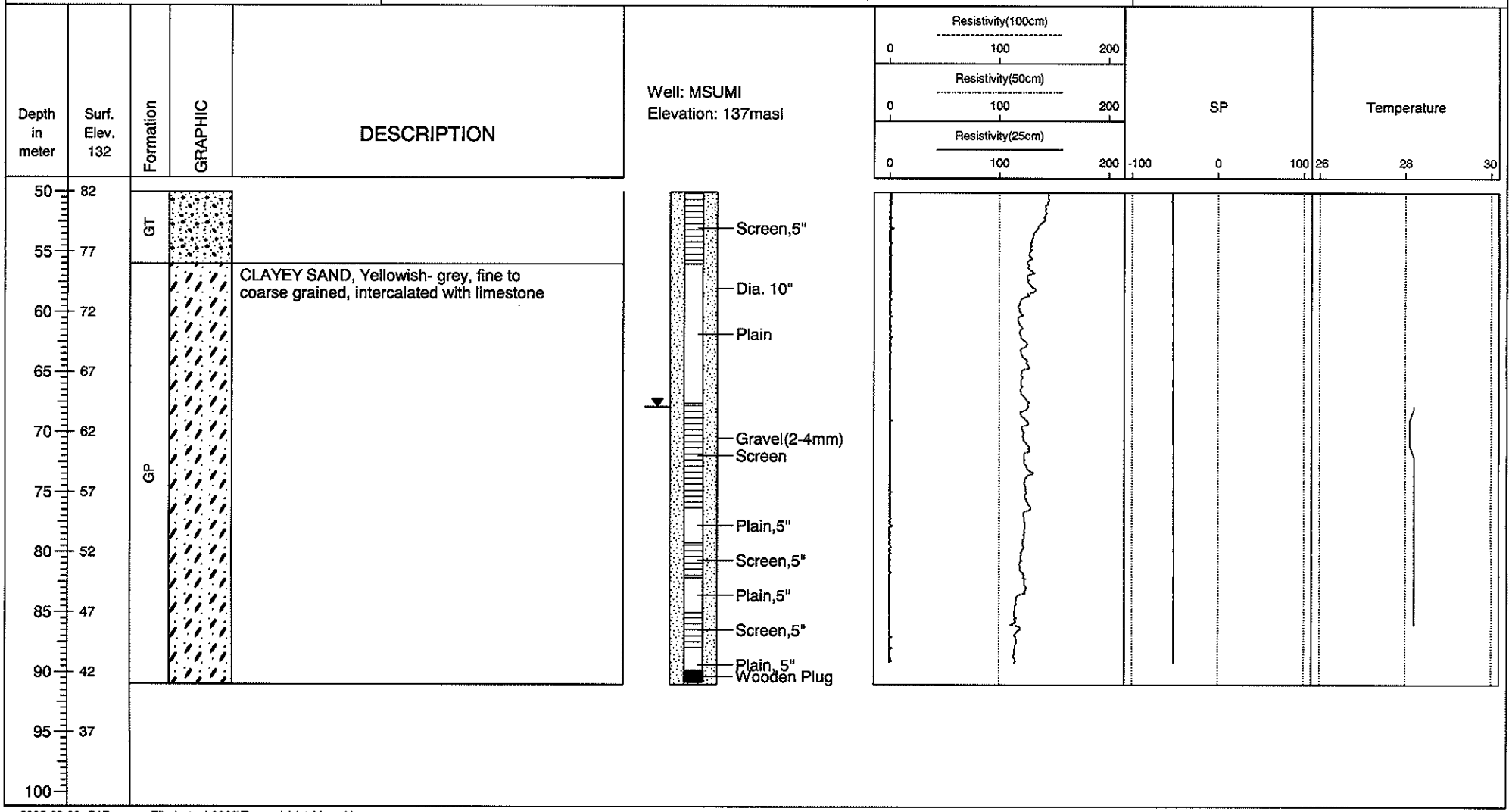

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The Study
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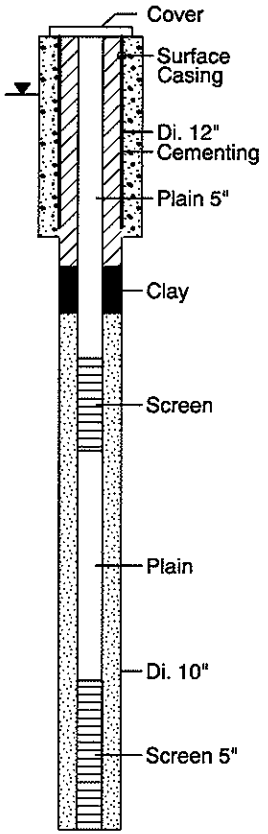
Coast Regional and Dar es Salaam Peri-Urban
in the Republic of Tanzania

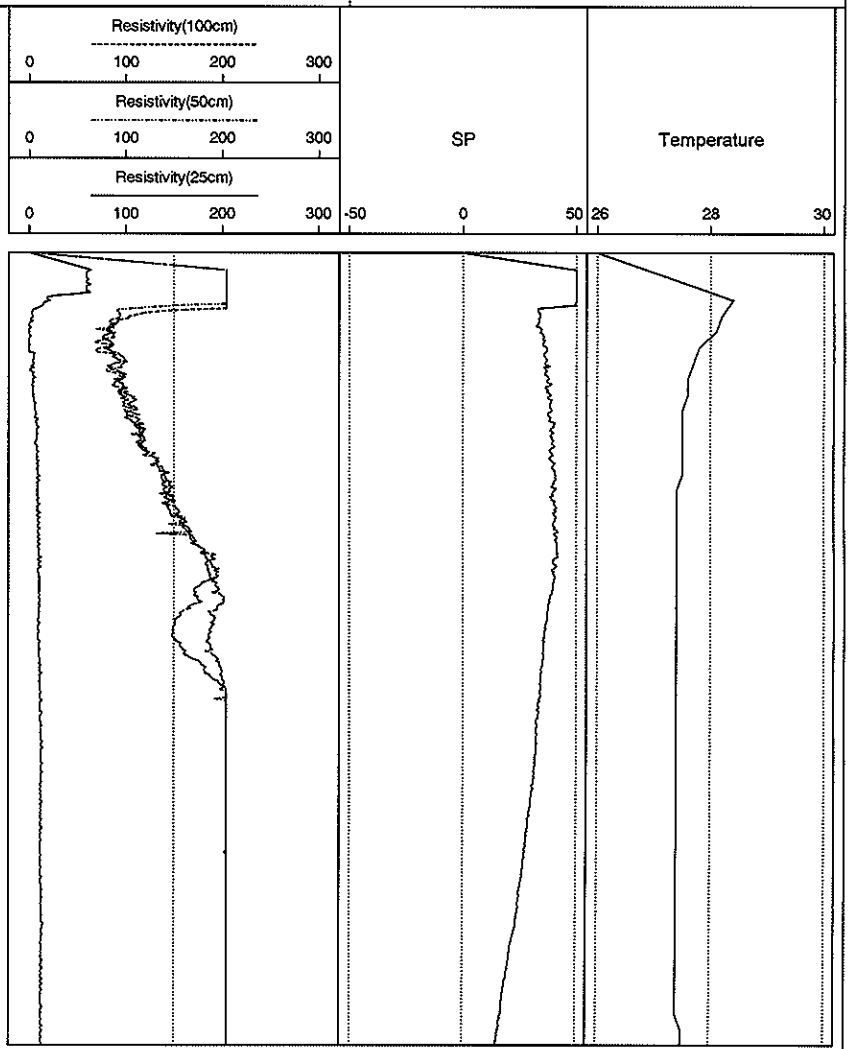
Borehole Log: J-2 DSM 771/2004 Buyuni VILLAGE

Longitude	: 39.10194	Commenced date	: 22,November,2004
Latitude	: 6.1164	Completed date	: 30,November,2004
Elevation	: 102 masl	Yield	: 16.5 liter/min
SWL	: 3.65 mbgl	Pumping test date	: 05,December,2004
Drilling depth	: 80 mbgl	Performed by	: DDCA

Depth in meter	Surf. Elev. 126	Formation	GRAPHIC	DESCRIPTION
0 – 5	126 – 121	GW		SAND, grey, fine to medium grained,
5 – 15	121 – 111	QU		CLAY-KAOLINITIC, grey-white,traces of quartz gravel,
15 – 25	111 – 101	GC		SANDY CLAY, grey-white,medium to coarse grained,traces of kaolin.
25 – 50	101 – 81	CG		SAND, Grey-green, medium to very coarse grained, traces of gravel, Poorly Graded, intercalated with limestone.

Well: BUYUNI
Elevation: 102 masl





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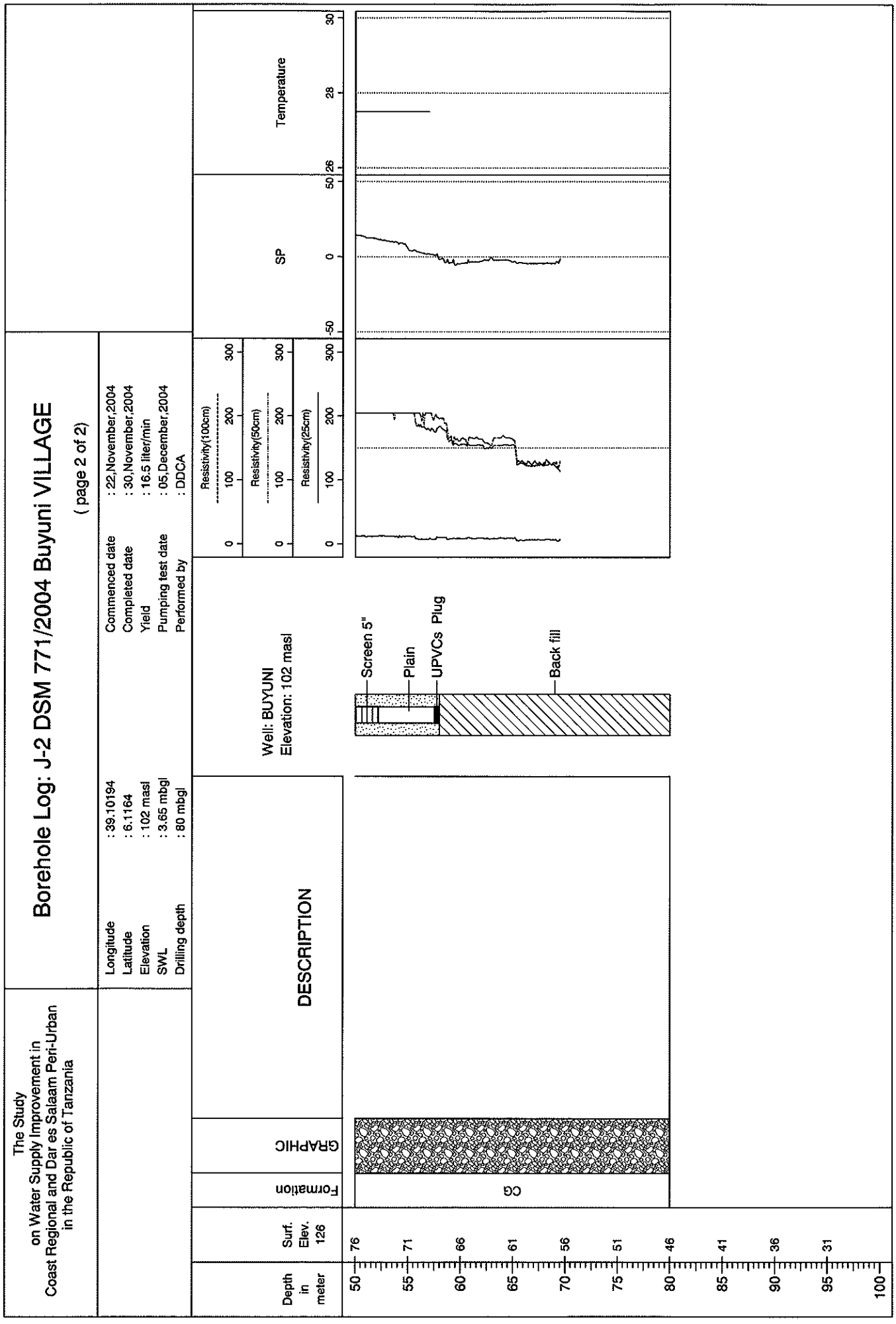
The Study
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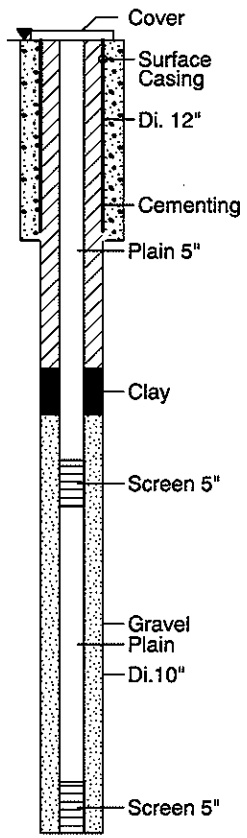
Performed by : DDCA
Well: BUYUNI
Elevation: 102 masl
Depth in meter
Surf. Elev. 126
Formation
GRAPHIC
DESCRIPTION
CG
Screen 5"
Plain
UPVCs Plug
Back fill
Resistivity(100cm)
Resistivity(50cm)
Resistivity(25cm)
SP
Temperature
2005-09-20 C:\Program Files\mtech2002\Tanzania\J-2 Buyuni.bor

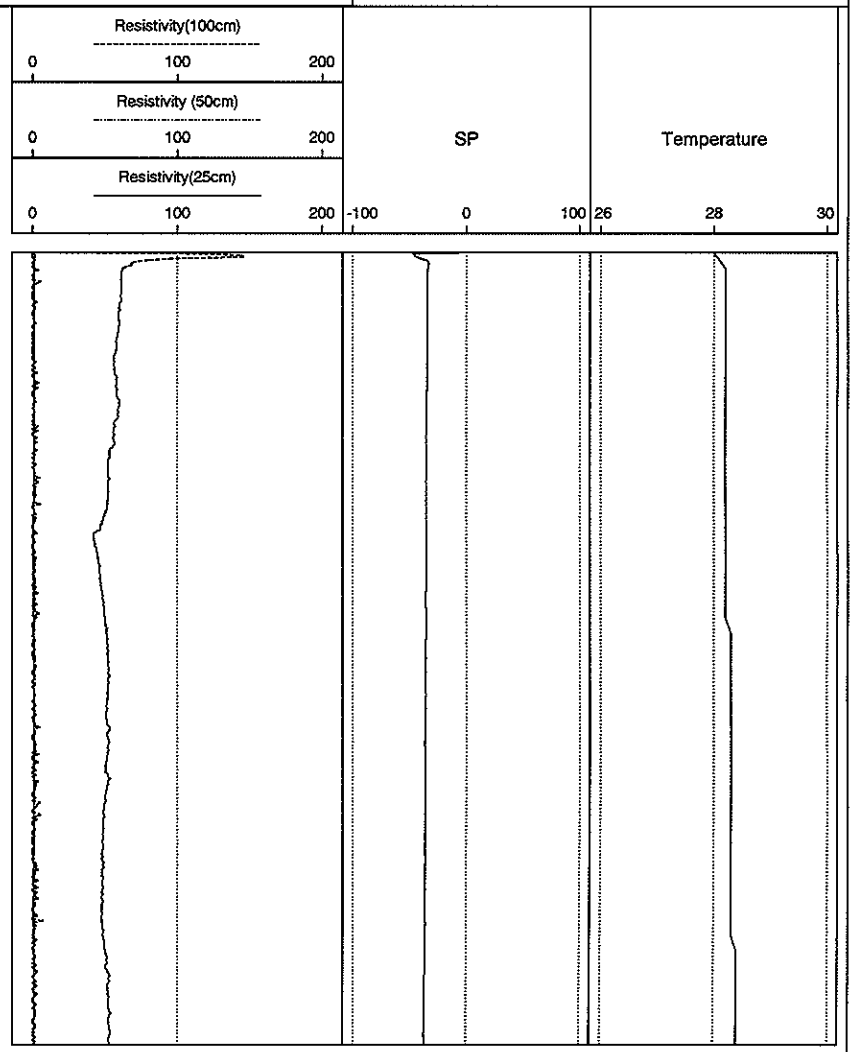
The Study
on Water Supply Improvement in
Coast Region and Dar es Salaam Peri-Urban
in the Republic of Tanzania.

Borehole Log: J-3 DSM 699/2004 Potea VILLAGE

Longitude	: 39.10750	Commenced date	: 7,November,04
Latitude	: 7.05472	Completed date	: 18,November,04
Elevation	: 75 masl	Pumping test	: 11,December,04
Drilling depth	: 75 mbgl	Yield	: 264 liter/min
SWL	: 0 mbgl	Performed by	: DDCA

Depth in meter	Surf. Elev. 87	Formation	GRAPHIC	DESCRIPTION
0 – 5	87 – 82	SP		SAND, reddish-orange,fine to medium grained,
5 – 10	82 – 77	SP		
10 – 15	77 – 72	SP		
15 – 20	72 – 67	SP		CLAY, yellowish - grey, with yellow traces.
20 – 25	67 – 62	GW		
25 – 30	62 – 57	GW		
30 – 35	57 – 52	FB		CLAYEY SAND, grey, fine to medium grained
35 – 40	52 – 47	FB		
40 – 45	47 – 42	CG		
45 – 50	42	CG		





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in the Republic of Tanzania.

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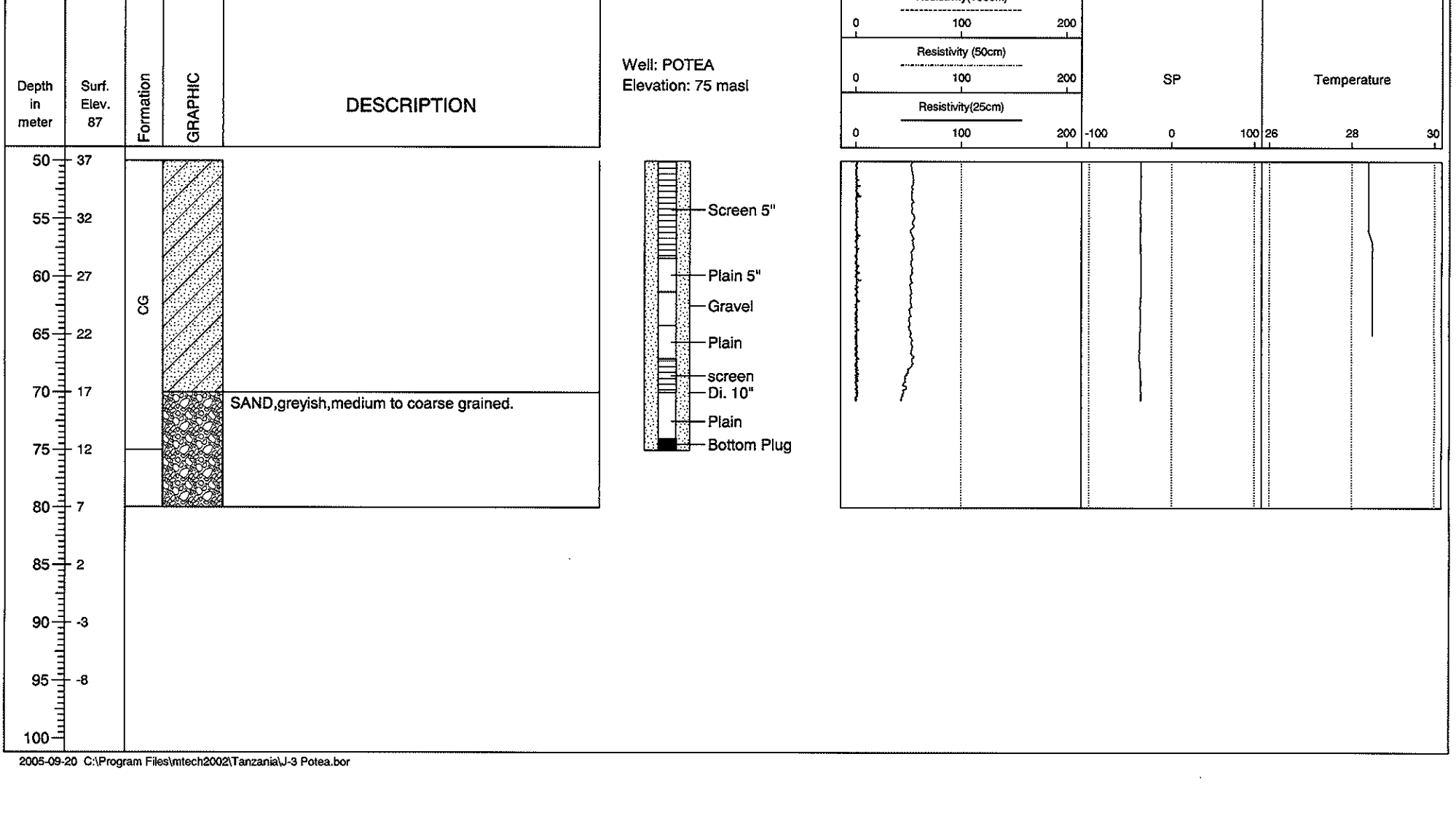
Latitude	: 7.05472	Completed date	: 18,November,04
Elevation	: 75 masl	Pumping test	: 11,December,04
Drilling depth	: 75 mbgl	Yield	: 264 liter/min
SWL	: 0 mbgl	Performed by	: DDCA



The Study
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Borehole Log: J-4 BH No.CO 774/2004 Kwamduma Village

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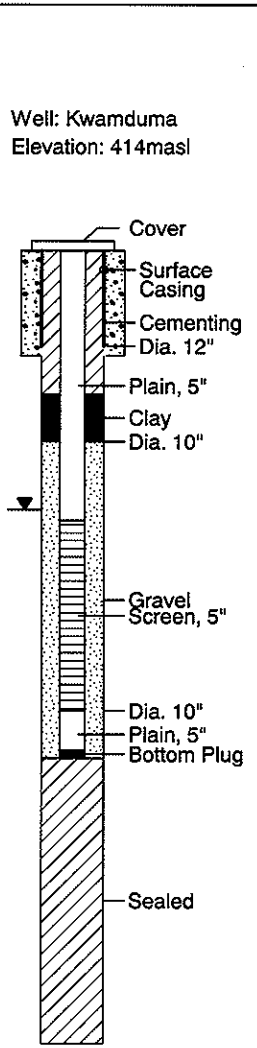
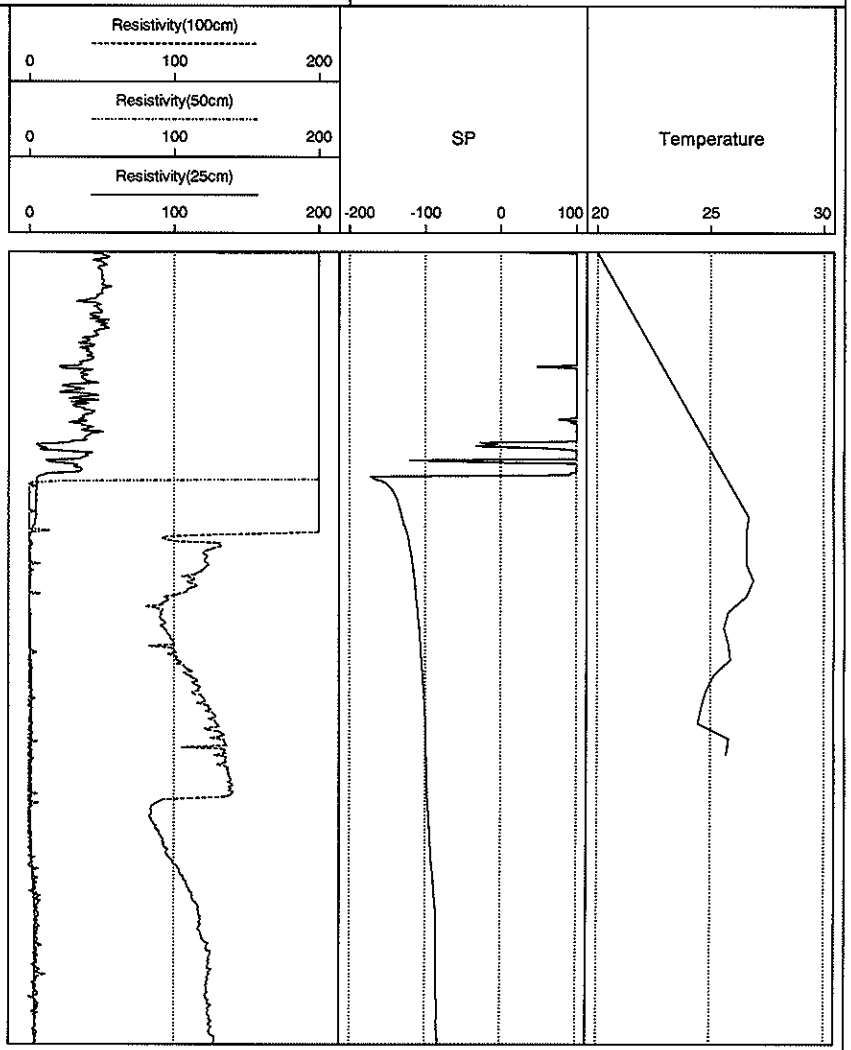
Longitude	: 38.07806	Commenced date	: 23,December,2004
Latitude	: 6.01000	Completed date	: 29,December,2004
Elevation	: 414masl	Pumping test date	: 31,December,2004
SWL	: 16.3m	Yield	: 58.9 liter/min
Drilling depth	: 70m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	USCS	GRAPHIC	DESCRIPTION
0	132	F38		Greyish,weathered gneiss
5	127			
10	122			
15	117			
		QU		Greyish,fractured gneiss
20	112	SC		Greyish, slightly weathered gneiss rich in quartz
25	107			
30	102			
35	97			
40	92			
45	87			
50				





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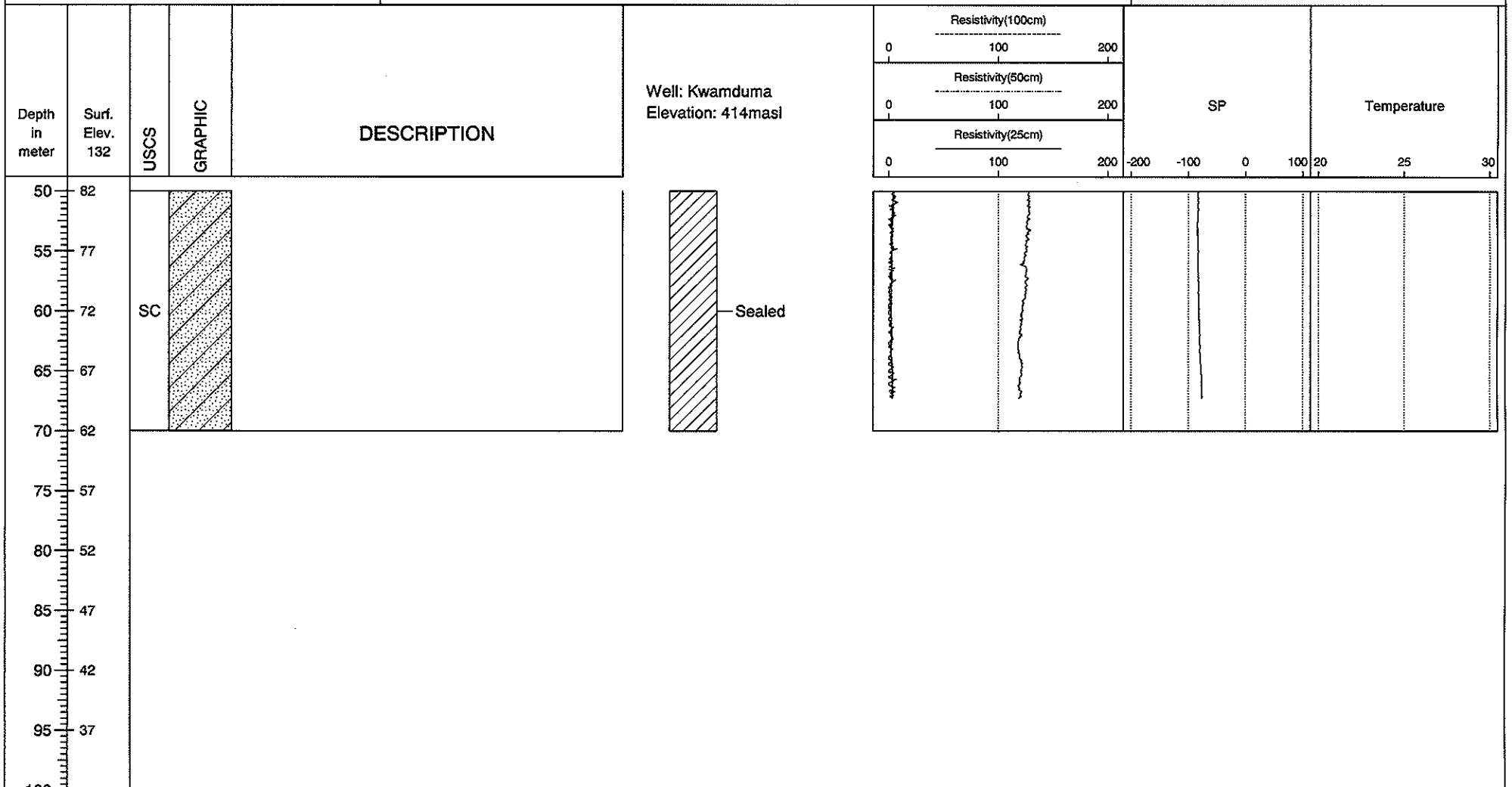
Borehole Log: J-4 BH No.CO 774/2004 Kwamduma Village

Longitude	: 38.07806	Commenced date	: 23,December,2004
Latitude	: 6.01000	Completed date	: 29,December,2004
Elevation	: 414masl	Pumping test date	: 31,December,2004
SWL	: 16.3m	Yield	: 58.9 liter/min
Drillling depth	: 70m	Performed by	: DDCA



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The Study
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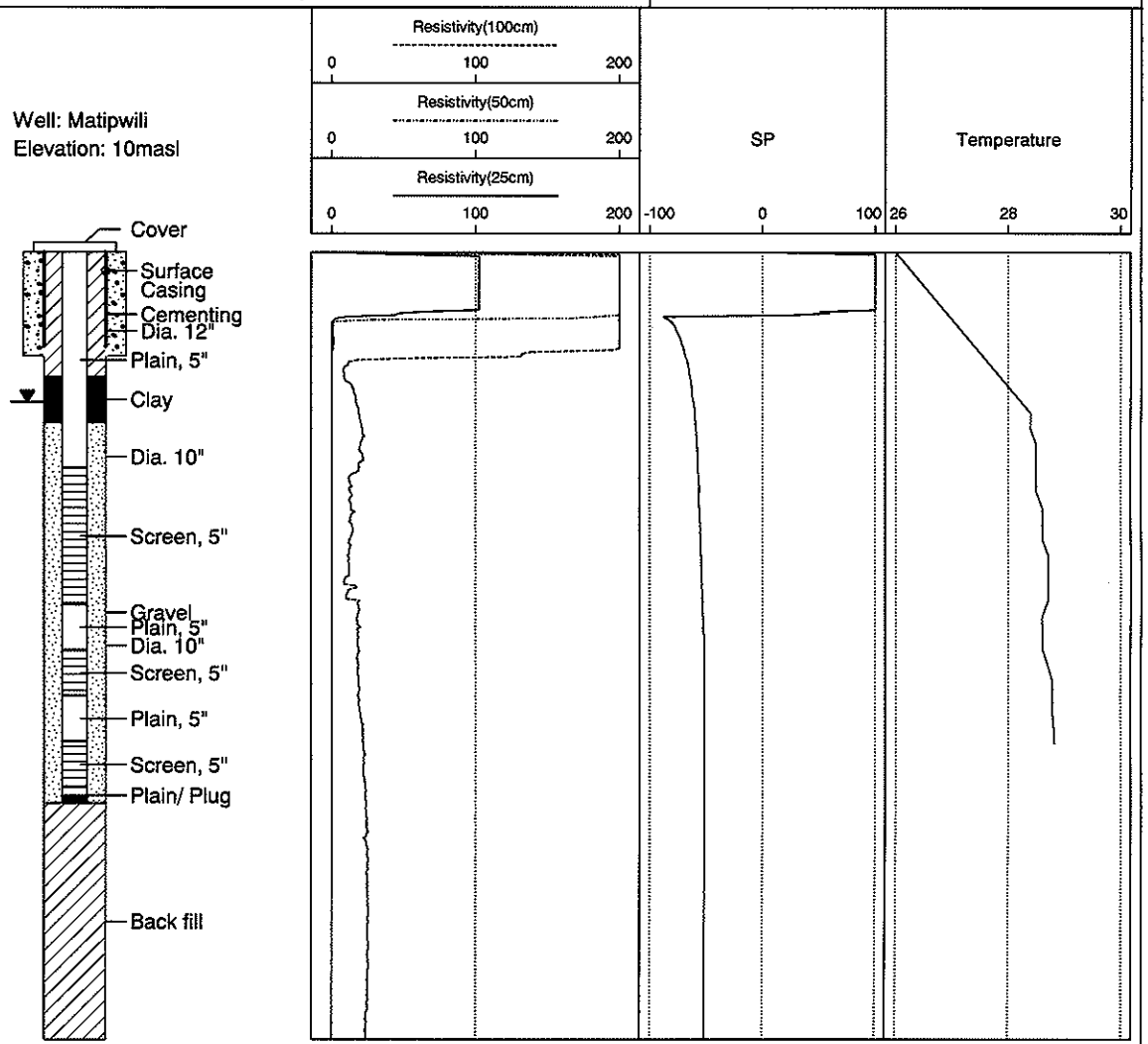
Borehole Log: J-5 BH No.CO 772/2004 Matipwili Village

Longitude	: 38.68917	Commenced date	: 16,December,2004
Latitude	: 6.23222	Completed date	: 22,December,2004
Elevation	: 10 masl	Pumping test date	: 9,January,2005
SWL	: 9.5 mbgl	Yield	:
Drillling depth	: 70m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	Formation	GRAPHIC	DESCRIPTION
0	132			SAND, grey-reddish, fine to medium grained,
5	127			
10	122			SAND, grey, medium to coarse grained, traces of gravel, intercalated with limestone.
15	117			
20	112			
25	107			
30	102			
35	97			
40	92			
45	87			Dark-grey,medium to coarse sand
50				



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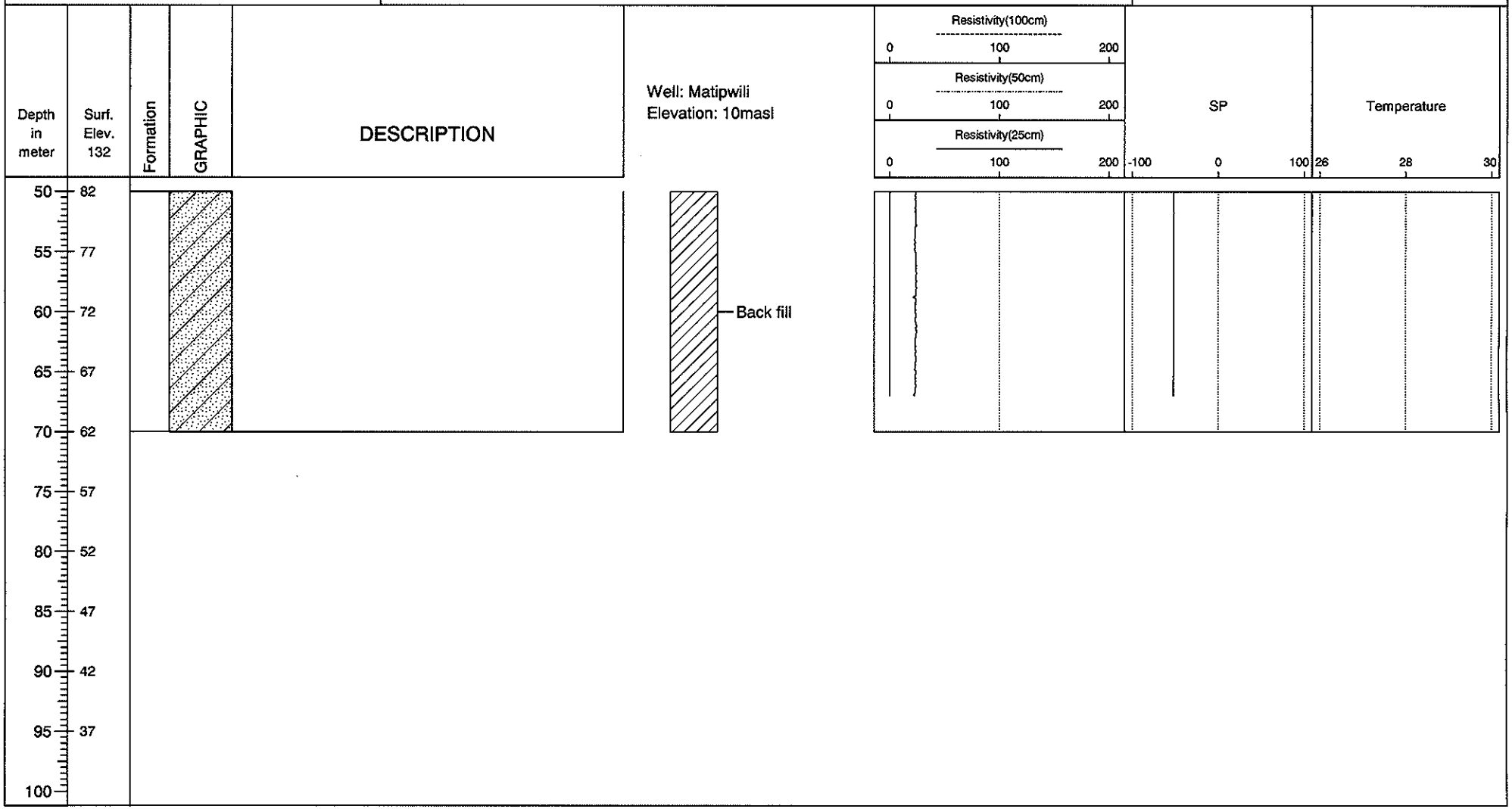
in the Republic of Tanzania

Borehole Log: J-5 BH No.CO 772/2004 Matipwili Village

(page 2 of 2)

Longitude	: 38.68917	Commenced date	: 16,December,2004
Latitude	: 6.23222	Completed date	: 22,December,2004
Elevation	: 10 masl	Pumping test date	: 9,January,2005
SWL	: 9.5 mbgl	Yield	:
Drillling depth	: 70m	Performed by	: DDCA



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on Water Supply Improvement
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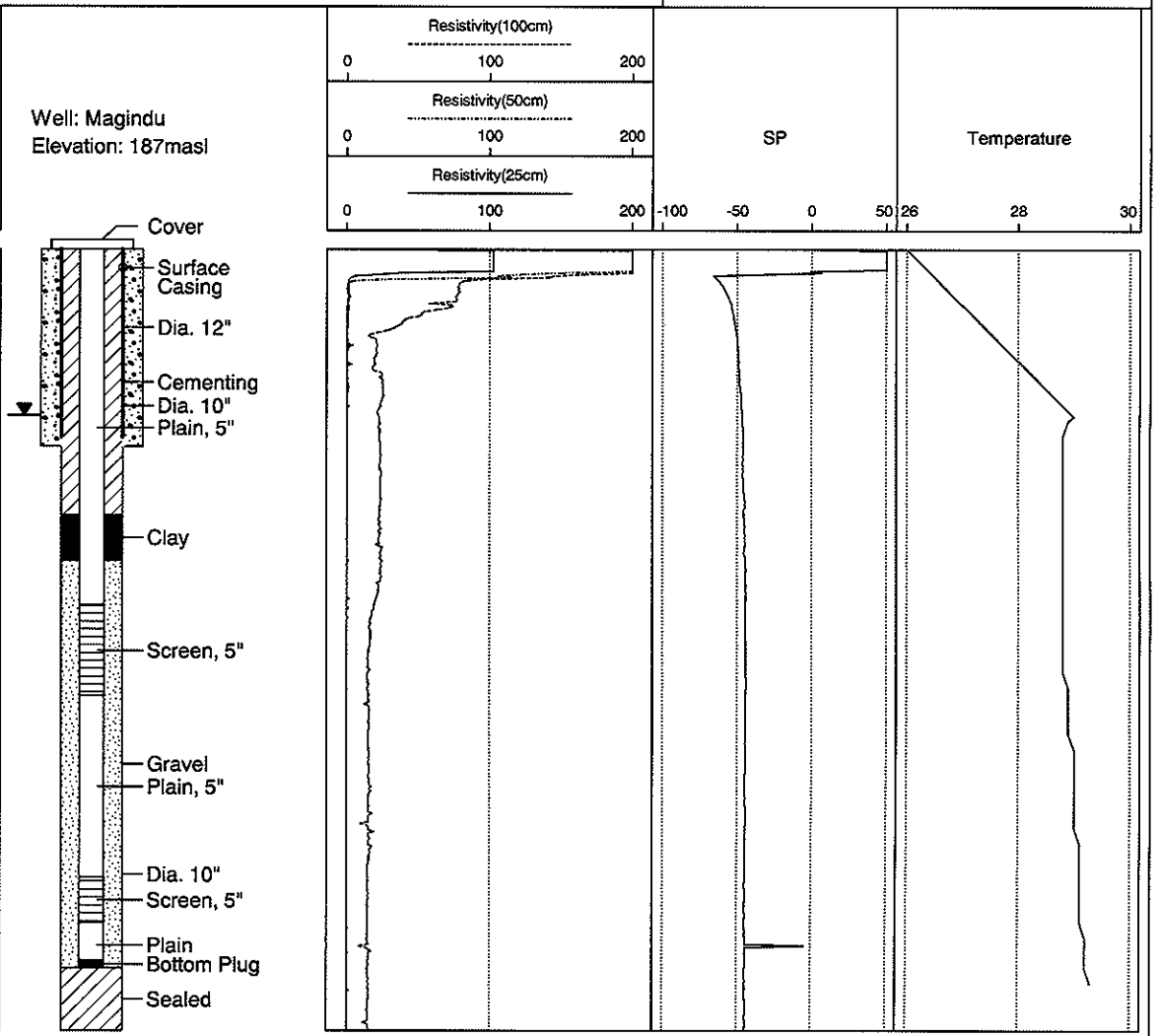
Borehole Log: J-6 BH No.CO 773/2004 Magindu Village

Longitude	: 38.31556	Commenced date	: 16, November,2004
Latitude	: 6.82111	Completed date	: 23, November, 2004
Elevation	: 187 masl	Pumping test date	: 06, January,2004
SWL	: 10.6 mbgl	Yield	: 1.47 liter/min
Drillling depth	: 100m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	Formation	GRAPHIC	DESCRIPTION
0	132	F38		CLAYEY SAND, Yellowish-grey, fine to medium grained,
5	127			
10	122			
15	117			
20	112			
25	107	SP		SAND, Yellowish-grey, coarse grained,traces of gravel,
		F34		Greyish, fractured sandstone
30	102	SC		Grey,slightly to moderate weathered sandstone
35	97			
40	92			
45	87			
50				



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Borehole Log: J-6 BH No.CO 773/2004 Magindu Village

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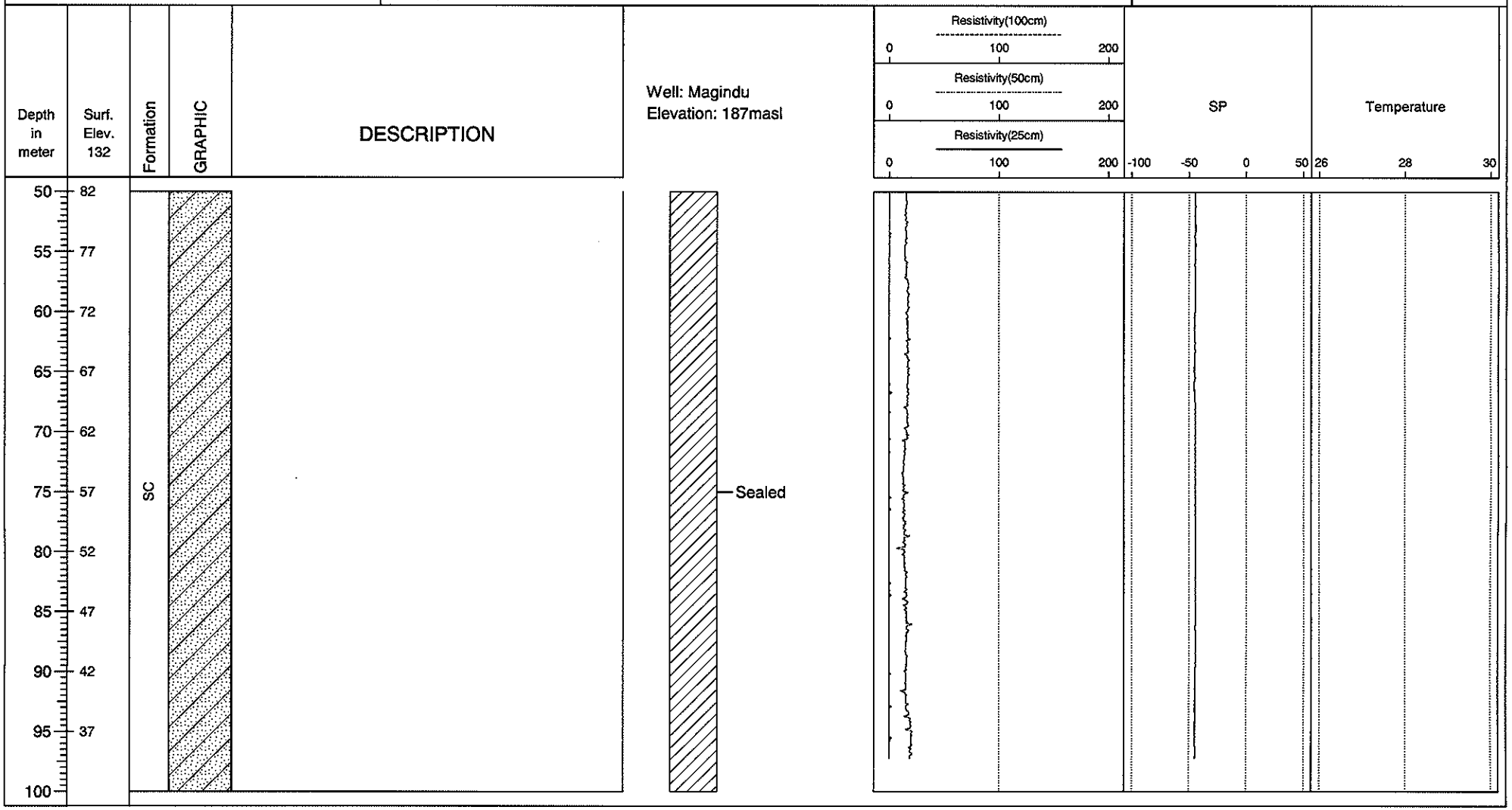
Longitude	: 38.31556	Commenced date	: 16, November,2004
Latitude	: 6.82111	Completed date	: 23, November, 2004
Elevation	: 187 masl	Pumping test date	: 06, January,2004
SWL	: 10.6 mbgl	Yield	: 1.47 liter/min
Drilling depth	: 100m	Performed by	: DDCA



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The Study
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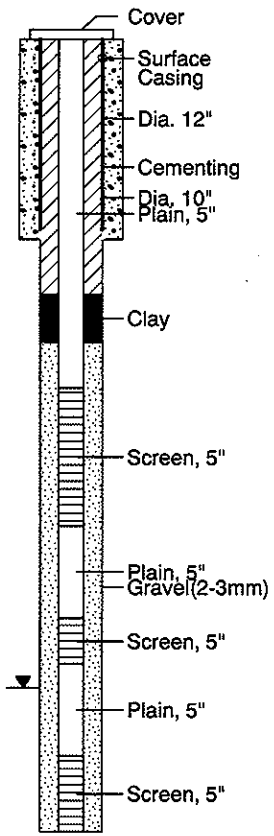
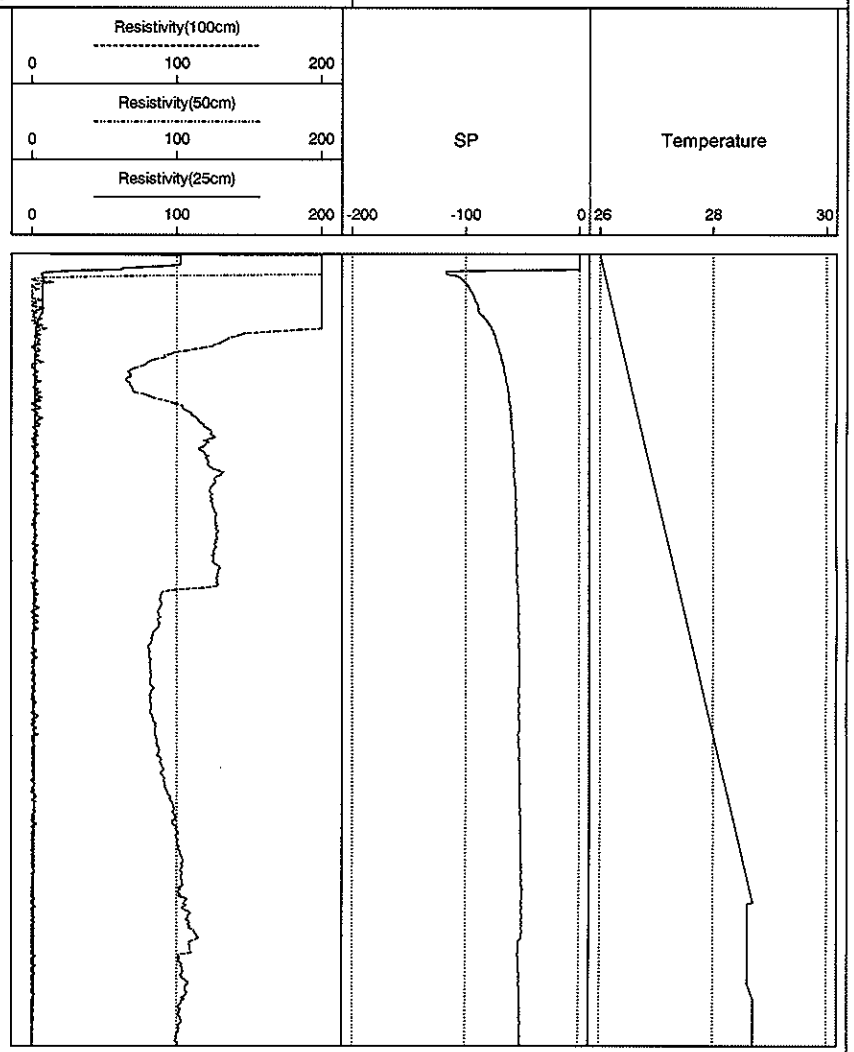
Borehole Log: J-7 BH No.CO 768/2004 Kipangege Village

(page 1 of 2)

Longitude	: 38.83833	Commenced date	: 26,December,2004
Latitude	: 6.86583	Completed date	: 3,January, 2004
Elevation	: 138masl	Pumping test date	: 20,December,2004
SWL	: 14.12mbgl	Yield	: 1.40 liter/min
Drillling depth	: 80m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	USCS	GRAPHIC	DESCRIPTION
0	132	BR		CLAYEY SAND, grey, medium to coarse grained,traces of gravel.
40	92	SP		SANDY CLAY, Whitish-grey,fine grained.
45	87	GW		Whitish-grey,medium to very coarse sand with traces of gravel,intercalated with limestone.
50				





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The Study
on Water Supply Improvement
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Borehole Log: J-7 BH No.CO 768/2004 Kipangege Village

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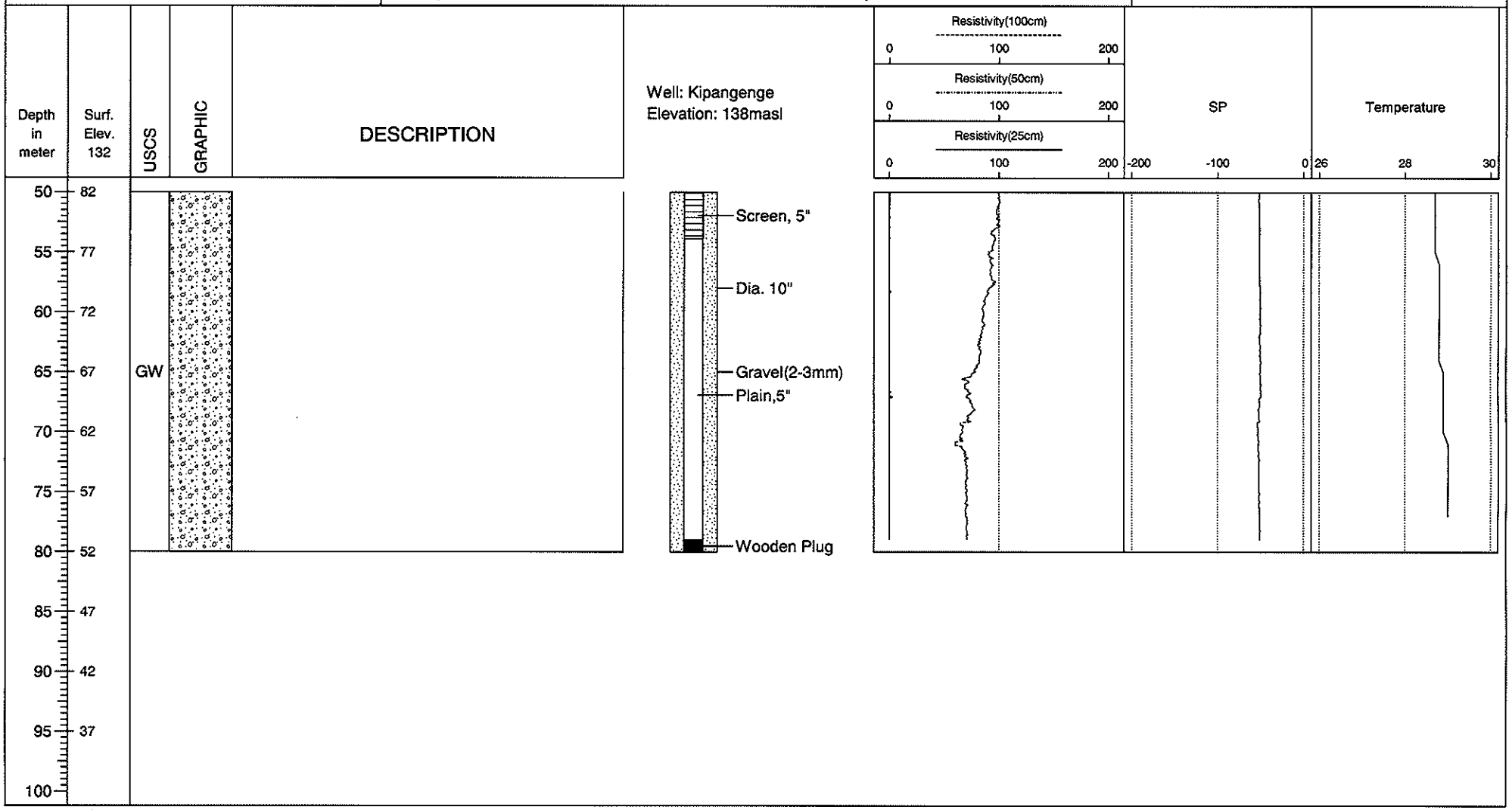
Longitude	: 38.83833	Commenced date	: 26,December,2004
Latitude	: 6.86583	Completed date	: 3,January, 2004
Elevation	: 138masl	Pumping test date	: 20,December,2004
SWL	: 14.12mbgl	Yield	: 1.40 liter/min
Drillling depth	: 80m	Performed by	: DDCA



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Borehole Log: BH No. J-8 CO 770/2004 Dundani Village

Longitude	: 39.22417	Commenced date	: 1,December,2004
Latitude	: 7.07139	Completed date	: 14,December,2004
Elevation	: 114 masl	Pumping test date	: 16,December,2004
SWL	: 46.35mbgl	Yield	: 38.84 Liter/min
Drillling depth	: 81mbgl	Performed by	: DDCA

Depth in meter	Surf. Elev. 114	USCS	GRAPHIC	DESCRIPTION
0	114	F38		Humus,dark soil
		SP		CLAYEY SAND, Reddish- grey, fine to medium grained,
30	84	CG		SAND,grey, medium to coarse grained, intercalated with limestone.
		GP		SAND, grey, fine to coarse grained,
50	69			

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Borehole Log: BH No. J-8 CO 770/2004 Dundani Village

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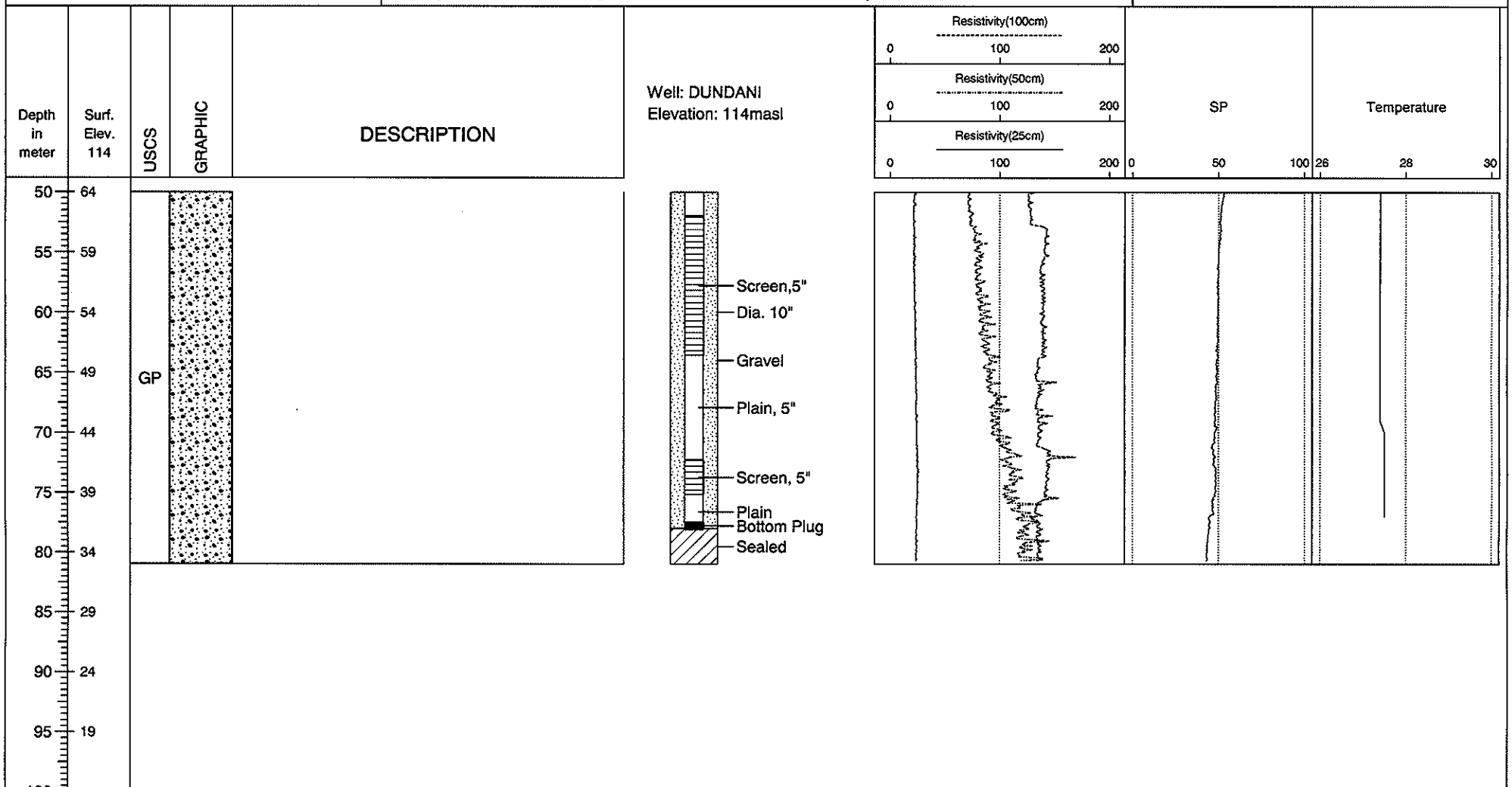
Longitude	: 39.22417	Commenced date	: 1,December,2004
Latitude	: 7.07139	Completed date	: 14,December,2004
Elevation	: 114 masl	Pumping test date	: 16,December,2004
SWL	: 46.35mbgl	Yield	: 38.84 Liter/min
Drillling depth	: 81mbgl	Performed by	: DDCA



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The Study
on Water Supply Improvement
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Borehole Log: J-9 BH No.CO 768/2004 Kise Village

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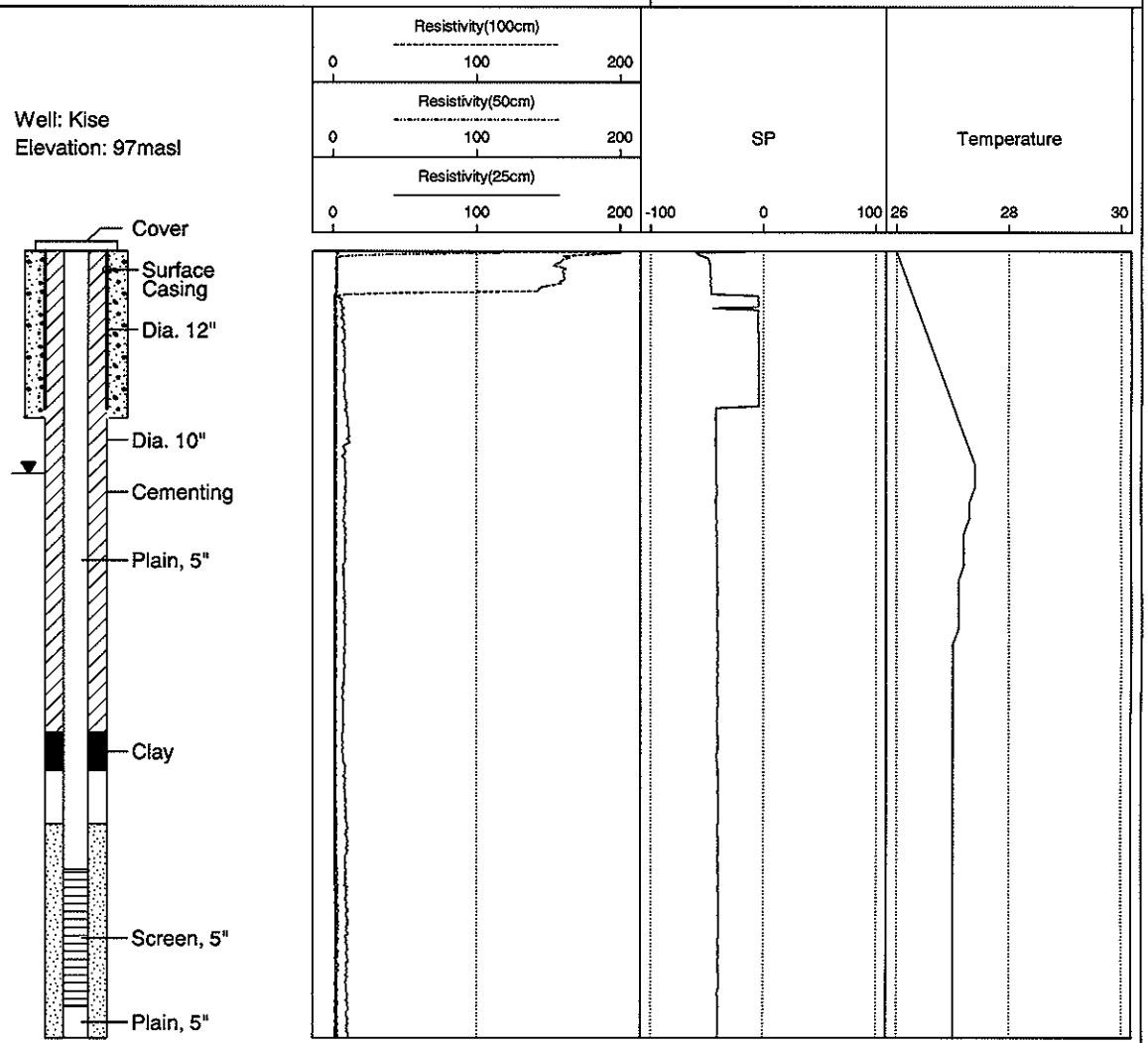
Longitude	: 39.116667	Commenced date	: 29,November,2004
Latitude	: 7.16028	Completed date	: 3,December, 2004
Elevation	: 97masl	Pumping test date	: 20,December,2004
SWL	: 14.12mbgl	Yield	: 6 liter/min
Drillling depth	: 84m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	Formation	GRAPHIC	DESCRIPTION
0	132	SP		Yellowish-grey,fine to medium sand
5	127			
10	122			
15	117			
20	112			
25	107			
30	102			
35	97	BR		SAND, yellowish -grey,with reddish patches,medium grained.
40	92	CG		Whitish-grey,coarse to very coarse sand with traces of gravel.
45	87			
50				



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The Study
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in Coast Region and Dar es Salaam Peri-Urban
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Borehole Log: J-9 BH No.CO 768/2004 Kise Village

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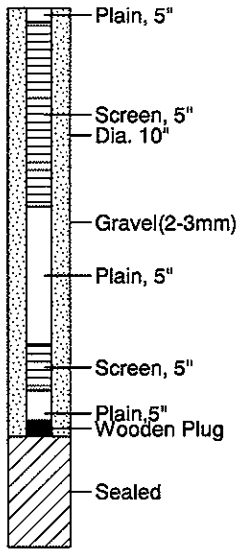
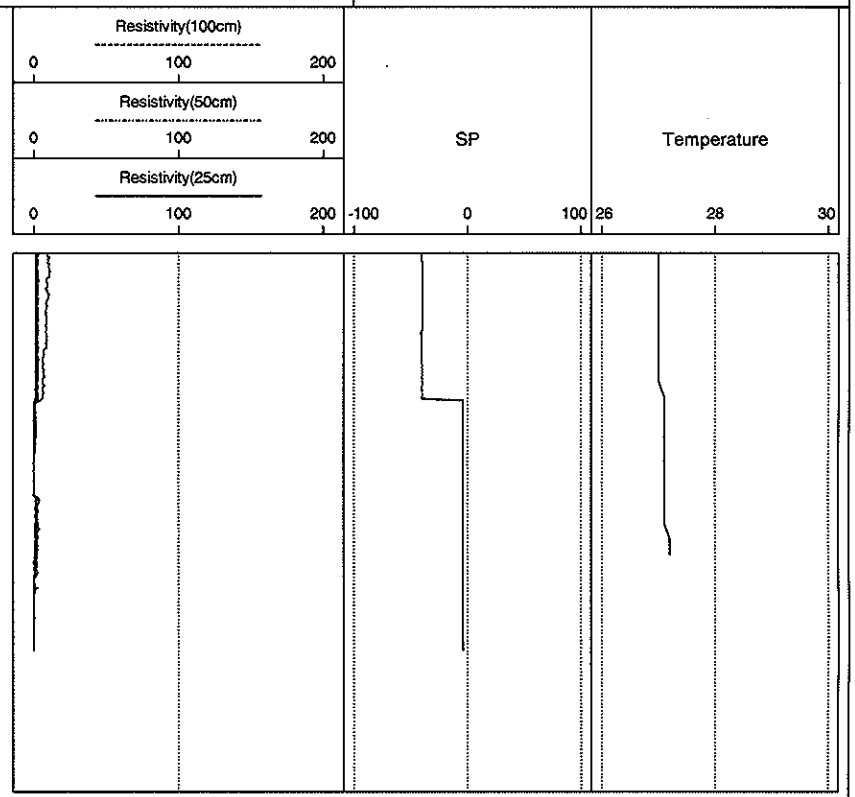
Longitude	: 39.116667	Commenced date	: 29,November,2004
Latitude	: 7.16028	Completed date	: 3,December, 2004
Elevation	: 97masl	Pumping test date	: 20,December,2004
SWL	: 14.12mbgl	Yield	: 6 liter/min
Drillling depth	: 84m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	Formation	GRAPHIC	DESCRIPTION
50	82	CG		
55	77			
60	72			
65	67	QU		SAND, Whitish-grey,fine to medium grained, with traces of limestone.
70	62			
75	57			
80	52			
85	47			
90	42			
95	37			
100				





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The Study
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Borehole Log: J-10 BH No.CO 769/2004 Titu Village

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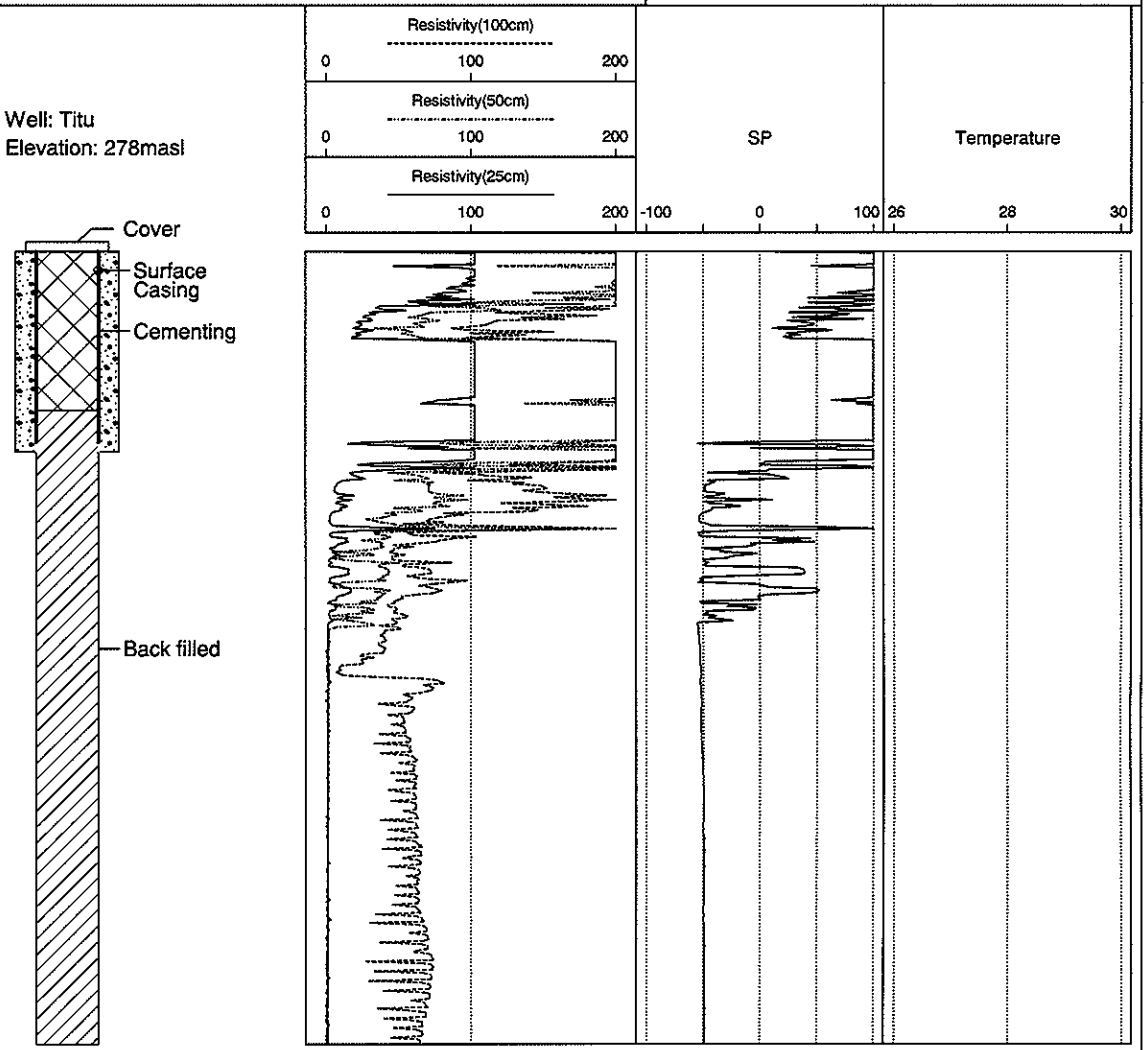
Longitude	: 38.67167	Commenced date	: 30,November,2004
Latitude	: 7.39389	Completed date	: 21,December, 2004
Elevation	: 278masl	Pumping test date	: was not conducted
SWL	: Dry	Yield	: Dry
Drillling depth	: 100m	Performed by	: DDCA

Depth in meter	Surf. Elev. 132	USCS	GRAPHIC	DESCRIPTION
0	132	SP		SAND, Greyish-brown,very fine grained.
5	127			
10	122			
15	117			
20	112			
25	107			
30	102			
35	97			
40	92			
45	87			
50		BR		SAND, Yellowish-grey,very fine grained, (Crushed sandstone).



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The Study
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Borehole Log: J-10 BH No.CO 769/2004 Titu Village

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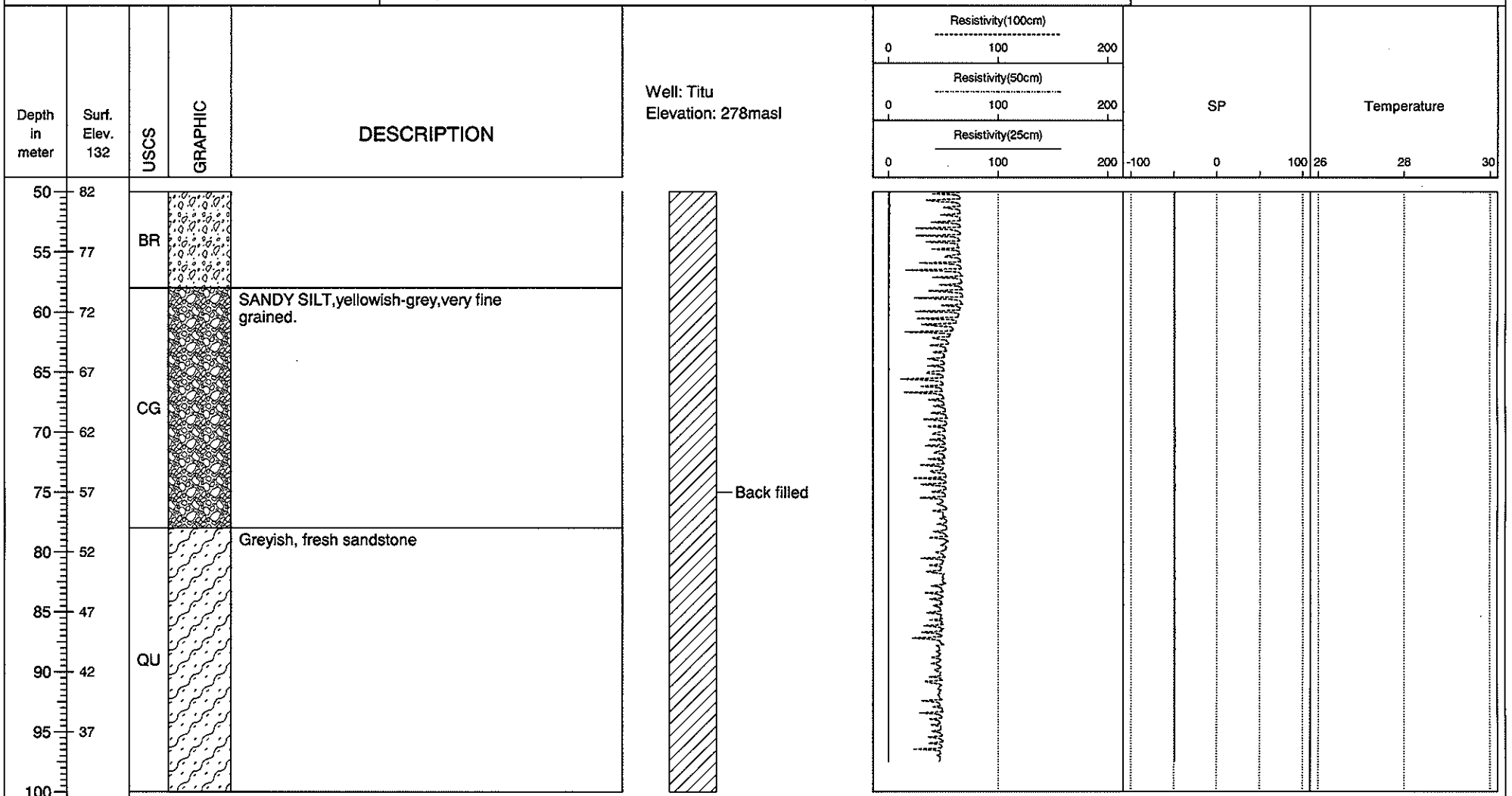
Longitude	: 38.67167	Commenced date	: 30,November,2004
Latitude	: 7.39389	Completed date	: 21,December, 2004
Elevation	: 278masl	Pumping test date	: was not conducted
SWL	: Dry	Yield	: Dry
Drillling depth	: 100m	Performed by	: DDCA



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