Mt. Meru drainage area and three sites, No.8, 9 and 10, are located in the Plateau Lava and No. 4 is located in Mt. Monduli drainage area(see Figure A-3-30, Location Map of Resistivity Prospecting in Engare Olmotoni).

Resistivity of major aquifers in the Mt. Meru drainage ranges from 14 to 32 Ω-m and these layers are underlain by volcanic rocks with resistivity ranging from 27 to 528 Ω-m (see Figure A-3-31, Resistivity Profile in Engare Olmotoni).

Although a VES curve of No. 4 in the Mt. Monduli drainage shows same as it of Mt. Meru, the curves in the Plateau Lava show different figure from both volcanic drainages.

Results of interpretation is summarized in the following table:

<Results of Interpretation in Mt. Meru and Monduli Drainage>

Layers	Resistivity (Ω-m)	Thickness (m)	Lithological correlation
Upper	13 -2200	5 - 27	volcanic sand and gravel
Middle	14 - 32	61 - 85	volcanic sand & gravel, saturated by groundwater
Lower	37 - 528	100 +	volcanic rocks

<Results of Interpretation in Plateau Lava>

Layers	Resistivity (Ω-m)	Thickness (m)	Lithological correlation
Upper	31 - 33	1 - 2	top soil
Middle	5 - 12	10 - 34	clayey material
Lower	24 - 631	145 +	tuff breccia and volcanic rocks

A-3-3 Results of PLMT Prospecting

(1) Procedure of Interpretation

The electromagnetic impedance calculates by measured ratio between induced electric and magnetic fields through FFT(fast fourier transform). An apparent resistivity at respective frequencies can be represented following equation:

$$AR = \frac{1}{5 \times f}\left(\frac{Ex}{Hy}\right)^2$$

where AR : apparent resistivity(Ω-m)
f : frequency(Hz)
Ex : electric field(μ V/m)
Hy : magnetic field(nT)

Final apparent resistivity of respective frequencies determines by steady data which is selected from data among repeated measurement.

Measured resistivity model can be calibrated based on initial theoretical model which was constructed by actual geological data. The theoretical model can be modified and reconstructed by computing iteration until it match with measured apparent resistivity model.

(2) Results of Prospecting

Interpreted resistivity model is composed of three different resistivity layers; low resistivity with less than 50 Ω-m, middle resistivity with 50 to 500 Ω-m and high resistivity more than 500 Ω-m.

The results are shown in two profiles and resistivity distribution contour maps at 50 and 100 meters below ground surface as shown in Figure A-3-26, A-3-27, A-3-32 and A-3-33.

a) Resistivity Profiles (A - A') in Figure A-3-26.

The profile trends east-westerly direction from upper part of the Eluanata Basin to east end of the Ardai Basin along the northern edge of the escarpment of Plateau Lava.

As shown in Profile, two resistivity structure is interpreted in the Eluanata Basin that is low resistivity layer in the upper and high resistivity layer in the lower. Resistivity of the upper layer ranges from 4 to 12 Ω-m with less than 100 meters thick and the lower layer ranges from 730 to 850 Ω-m with 100 to 450 meters thick. The lower layer probably corresponds to basalt in Plateau Lava. Only the site P12 indicates 150 Ω-m in the lower layer. It appears to be of fractured zone in the Plateau Lava due to north-south fault.

The upper layer thins in P30 where a divide is located between two basins. The divide is occupied by Plateau Lava.

Three resistivity structure is interpreted in the Ardai Basin as shown in the eastern part of profile. The upper layer indicates 8 to 44 Ω-m resistivity with less than 80 meters thick and it probably corresponds to colluvial beds and tufferceous beds in the Plateau Lava.

Resistivity of the middle layer ranges from 19 to 150 Ω-m and thickness attains a maximum of more than 350 meters. The layer corresponds to pyroclastic beds and fractured volcanic rocks(see Figure A-4.10, Exploratory Well Log of EX-10).

The lower layer were detected at P37, P54 and P71. Resistivity ranges from 13 to 17 Ω-m. Although no drilling were tried more than 200 m depth in the southern part of the Ardai Basin, there is a large possibility that it corresponds to heavily weathered Basement rocks.

b) Resistivity Profiles (B - B') in Figure A-3-27.

The profile trends north-southerly direction from Tarosero Estate, northwest of Monduli Town, to Arkatan village.

As easily visualized from the figure, three major resistivity layers underlie in this profile. Resistivity of the Upper layer ranges from 10 to 84 Ω-m with a maximum thickness of 100 meters. The middle layer have a resistivity ranging from 100 to 150 Ω-m with exception in P50 and P87, and thickness indicates more than 250 meters. The lower layer shows resistivity less than 21 Ω-m.

The upper layer is correlative with the colluvial beds, pyroclastic rocks and fractured volcanic rocks, and the middle layer is chiefly correlative with fractured volcanic rocks. The lower layer may be equivalent to the heavily weathered basement. The resistivity of these layers indicate that there are no thick massive hard volcanic rock in this profile except at site P68.

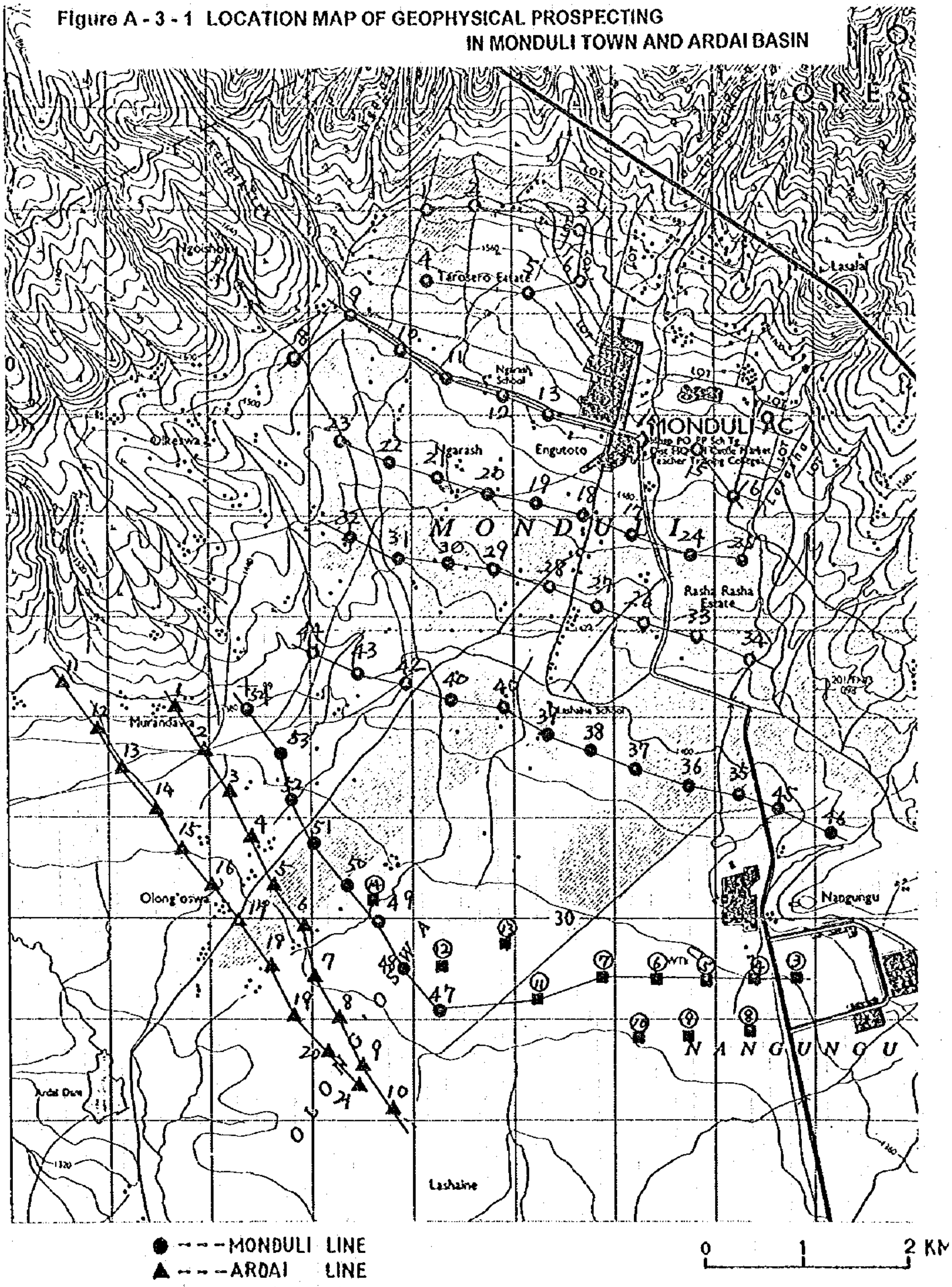
c) Resistivity Distribution at 100 meters Depth (Figure A-3-33)

An iso-resistivity contour lines map at 100 meters below ground surface is presented in Figure A-3-33. A contour lines of more than 500 Ω-m which is probably indicated solid volcanic rock, distributes in accord with mountain slope from north of Monduli to Kosiki Mountain via Lendikinya. Another 500 Ω-m contour line draws on Plateau Lava along Arusha-Dodoma Highway. It is the most striking feature that 500 Ω-m contour line is underlain on the divide between the Eluanata and Arkatan Basins.

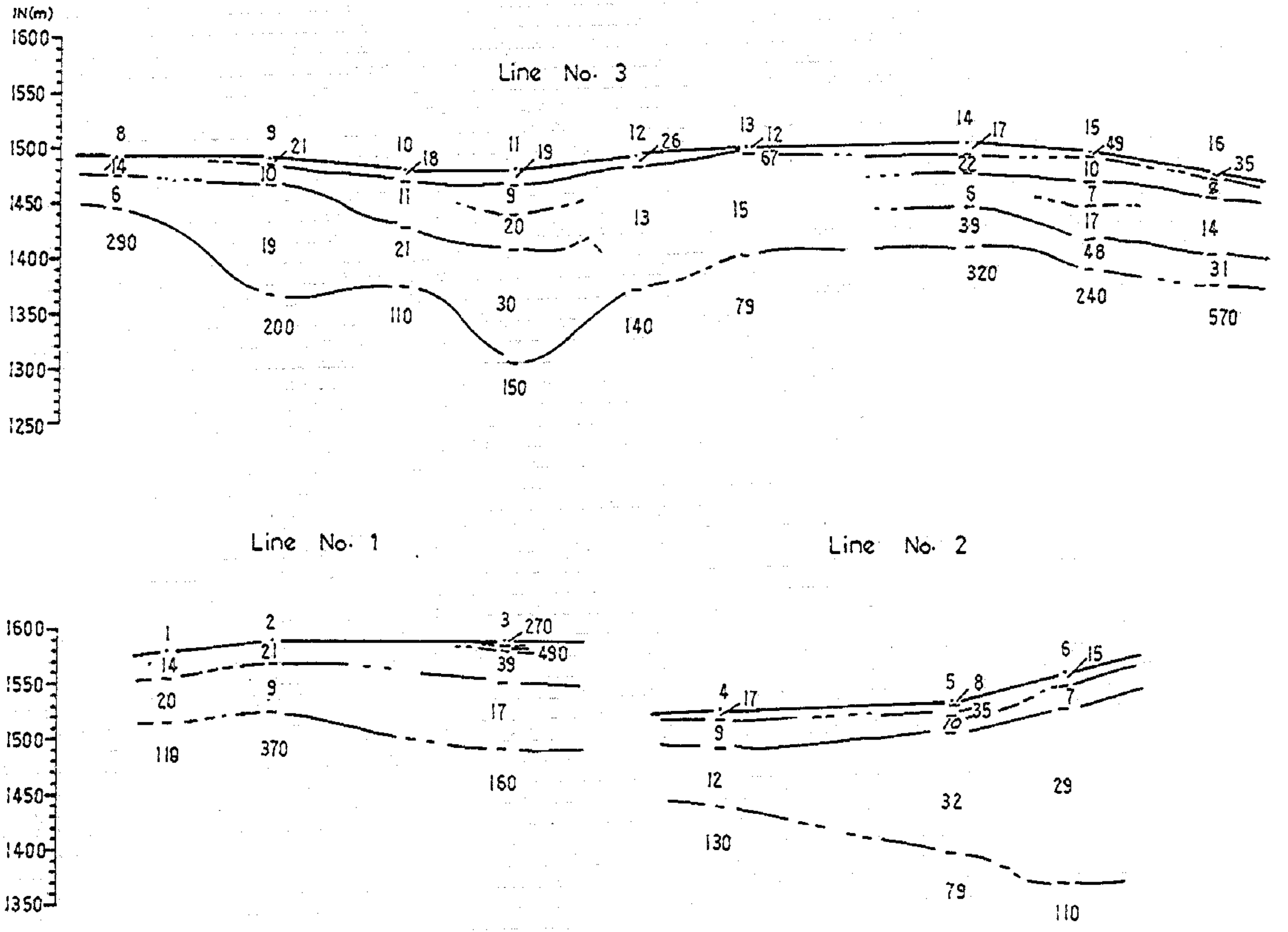
Table A-3-1 INTERPRETATION OF VES CURVE IN ARDAI-ELUANATA

Site No.	1st layer		2nd layer		3rd layer		4th layer		5th layer	
	Resis. (Ω-m)	Depth (m-m)	Resis. (Ω-m)	Depth (m-m)	Resis. (Ω-m)	Depth (m-m)	Resis. (Ω-m)	Depth (m-m)	Resis. (Ω-m)	Depth (m-m)
1	43	-10	12	10- 48	54	48-				
2	19	- 2	10	2- 7	16	7- 49	120	49-		
3	25	- 4	12	4- 34	100	34-				
4	8	- 1	84	1- 29	53	29- 83	152	83-269	13	269-
5	22	- 3	9	3- 38	57	38-				
6	4	-72	852	72-						
7	20	- 7	12	7- 96	727	96-				

Figure A - 3 - 1 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN MONDULI TOWN AND ARDAI BASIN



● - - - MONDULI LINE
▲ - - - ARDAI LINE
■ - - - MAJI LINE



MONDULI TOWN 1:5000

Figure A-3-2 RESISTIVITY PROFILE OF LINE NO.1, NO.2 AND NO.3 IN MONDULI TOWN

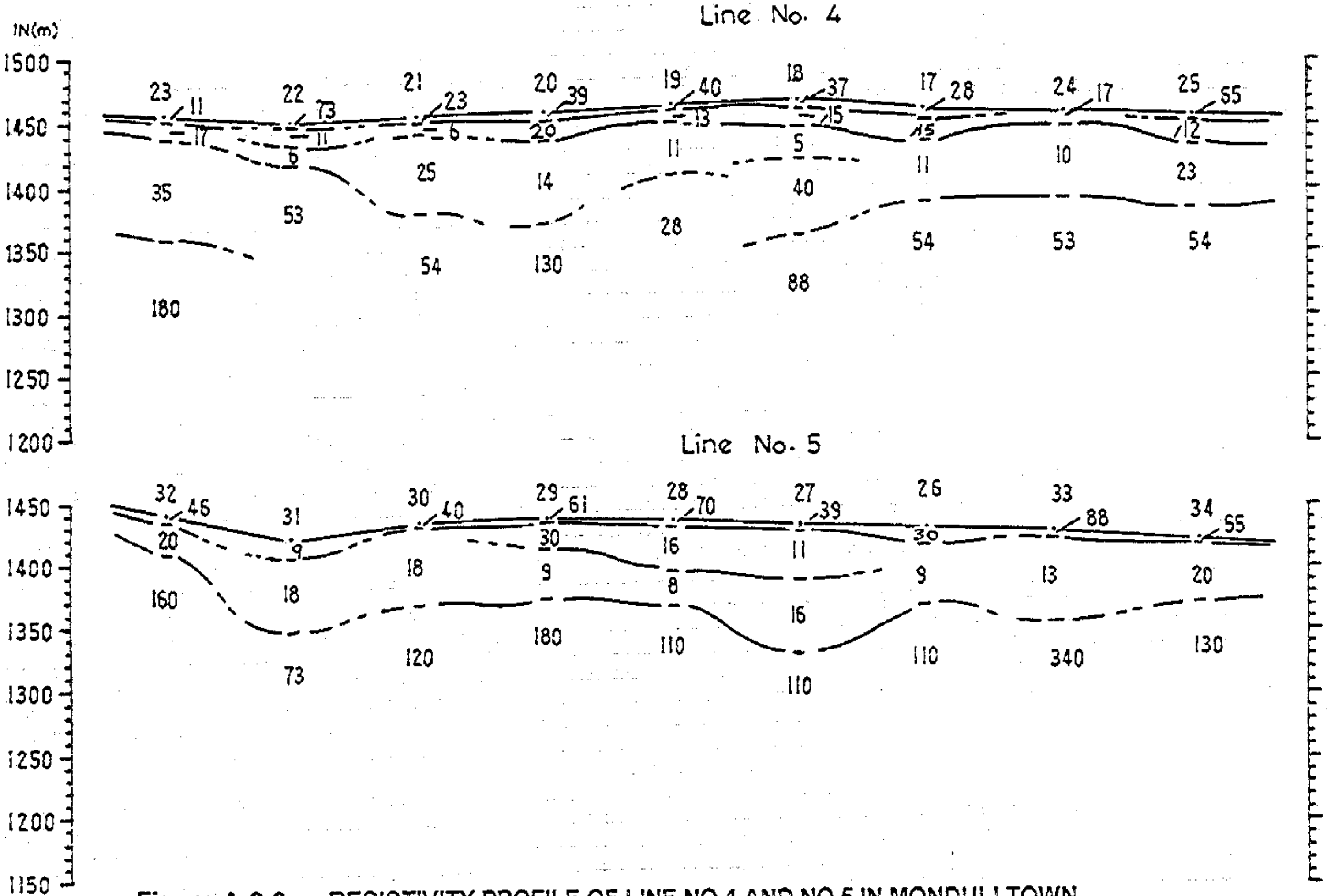


Figure A-3-3 RESISTIVITY PROFILE OF LINE NO.4 AND NO.5 IN MONDULI TOWN

MONDULI TOWN 1:5000

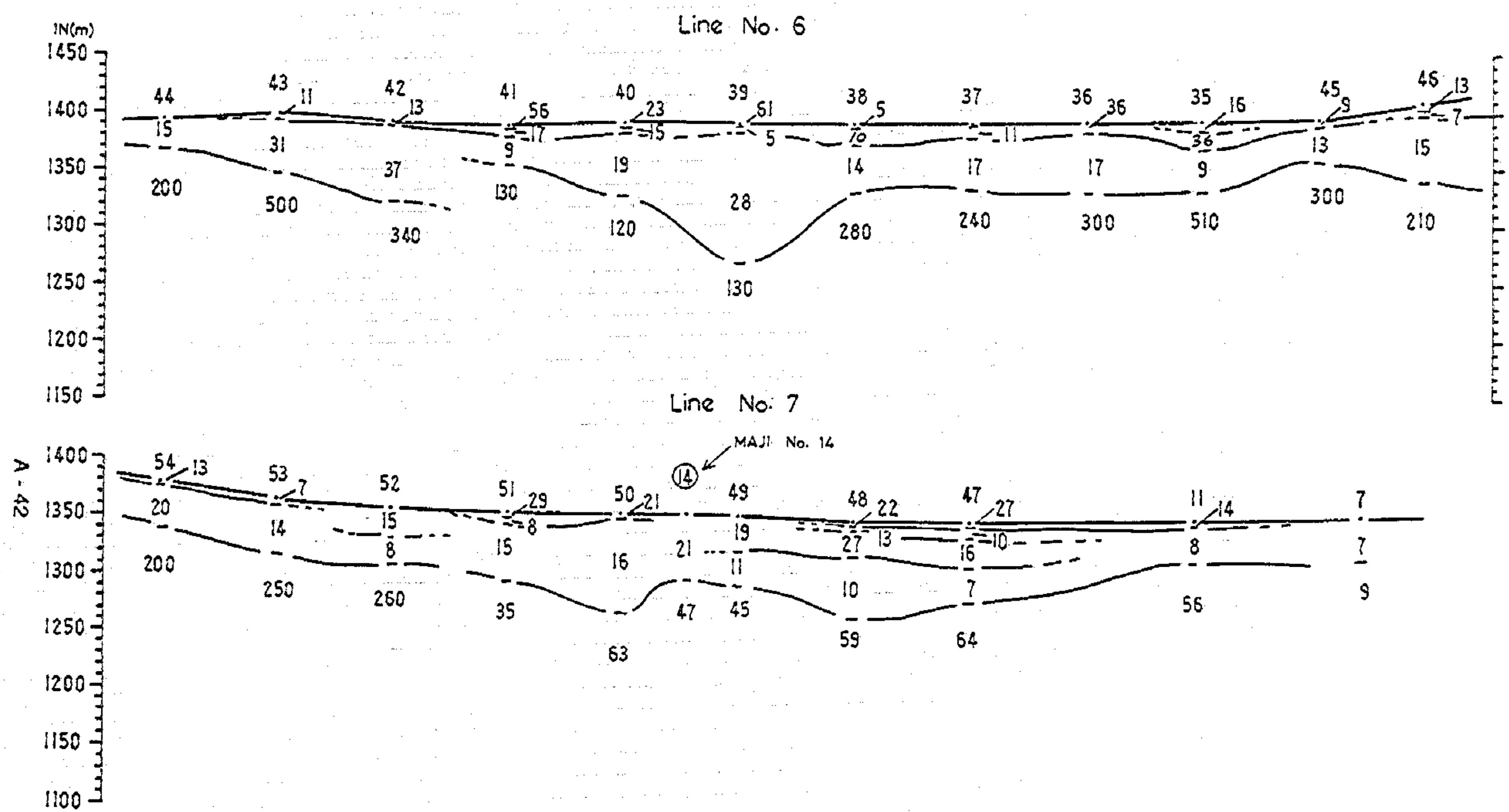


Figure A-3-4 RESISTIVITY PROFILE OF LINE NO.6 AND NO.7 IN MONDULI TOWN

MONDULI 1:5000

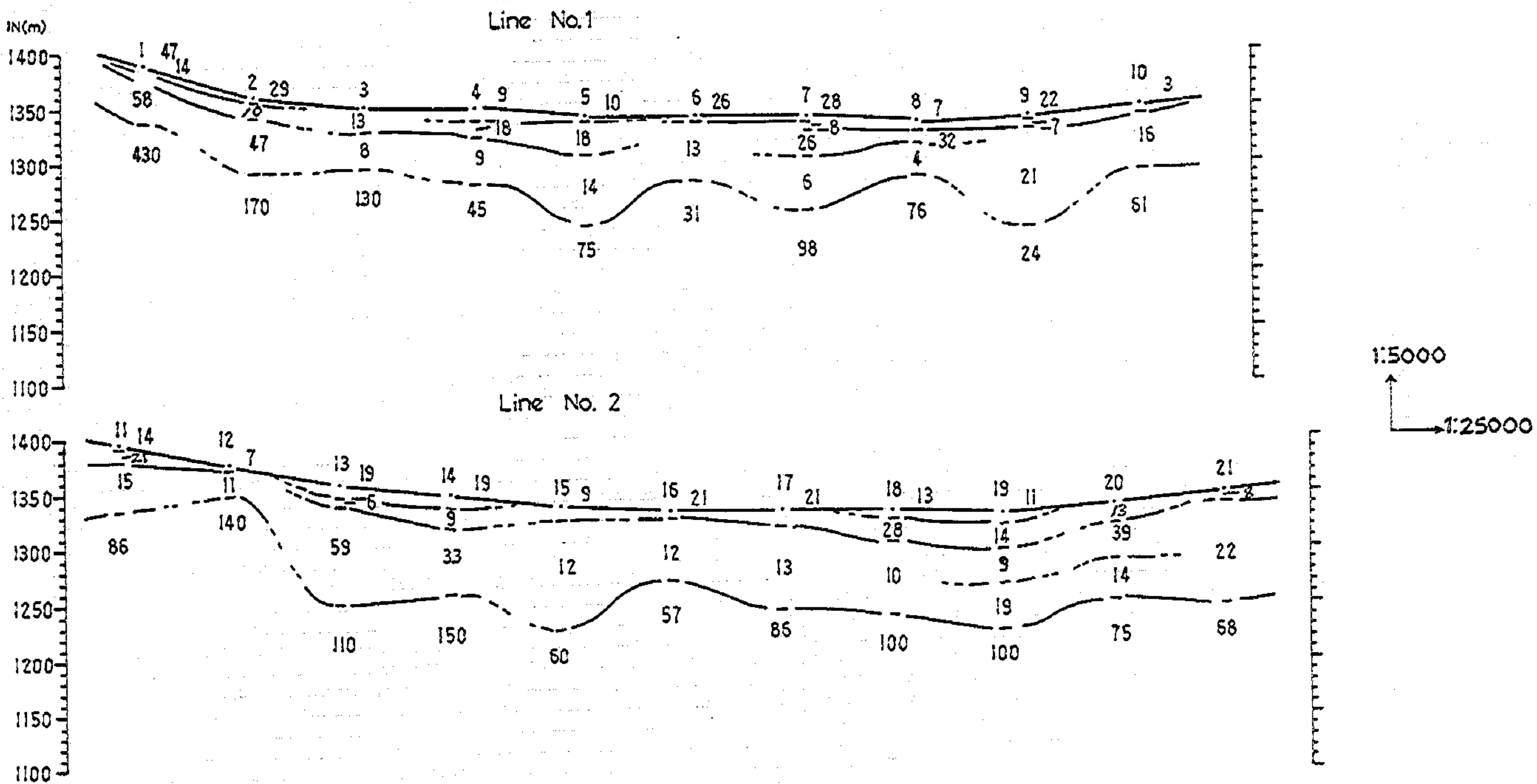
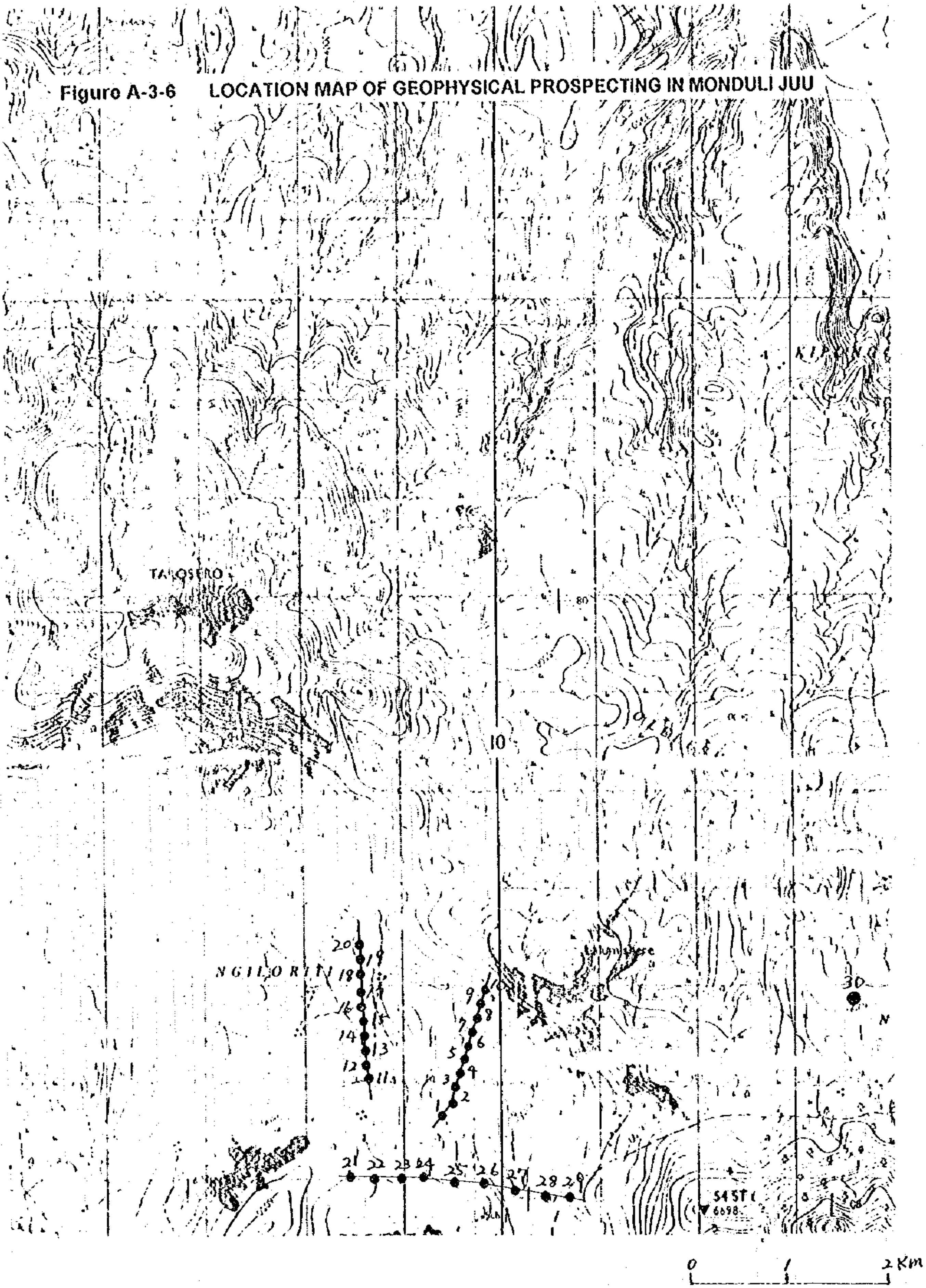


Figure A-3-5 RESISTIVITY PROFILE OF LINE NO.1 AND NO.2 IN ARDAI BASIN

Figure A-3-6 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN MONDULI JUU



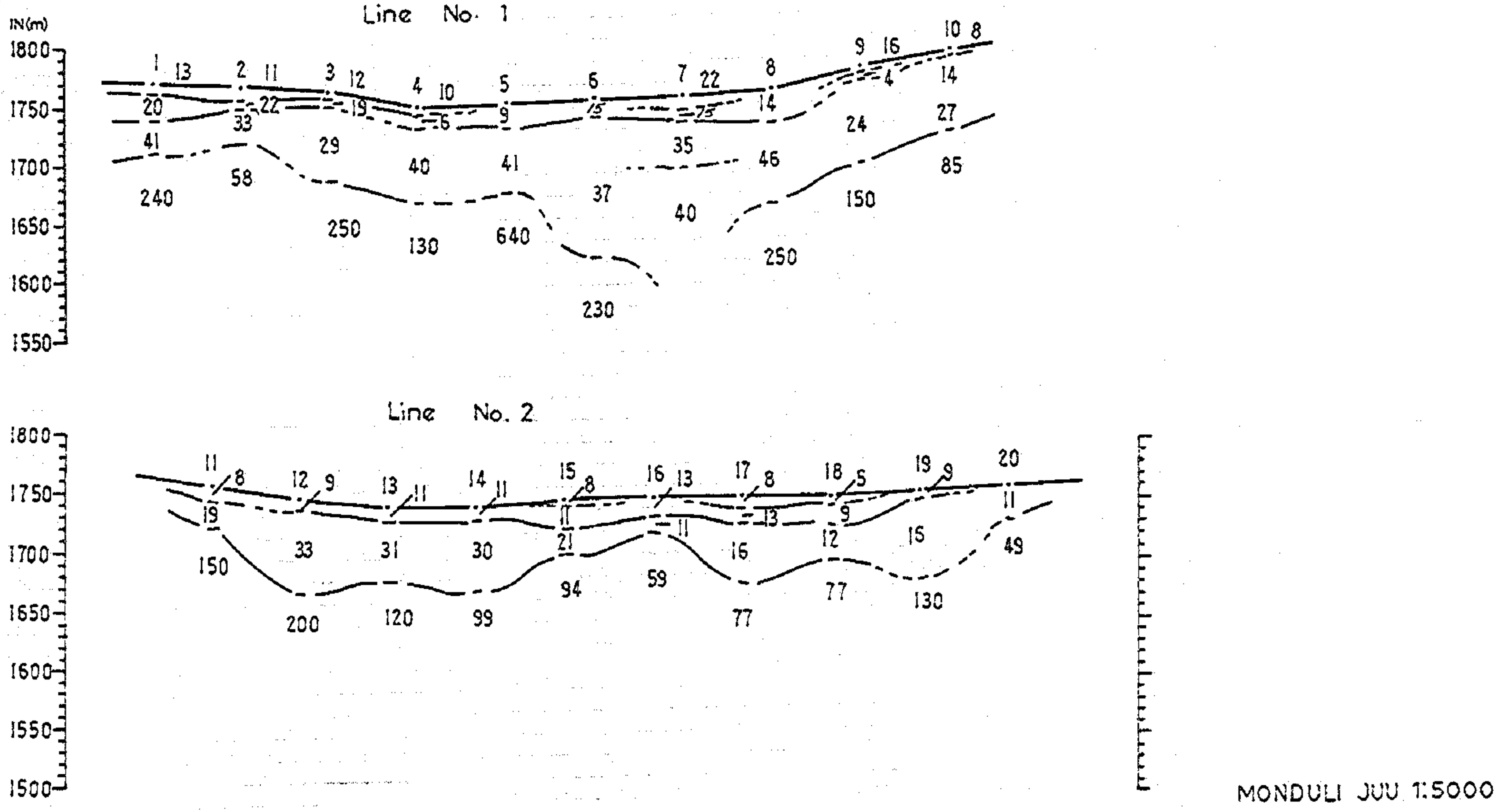


Figure A-3-7 RESISTIVITY PROFILE OF LINE NO.1 AND NO.2 IN MONDULI JUU

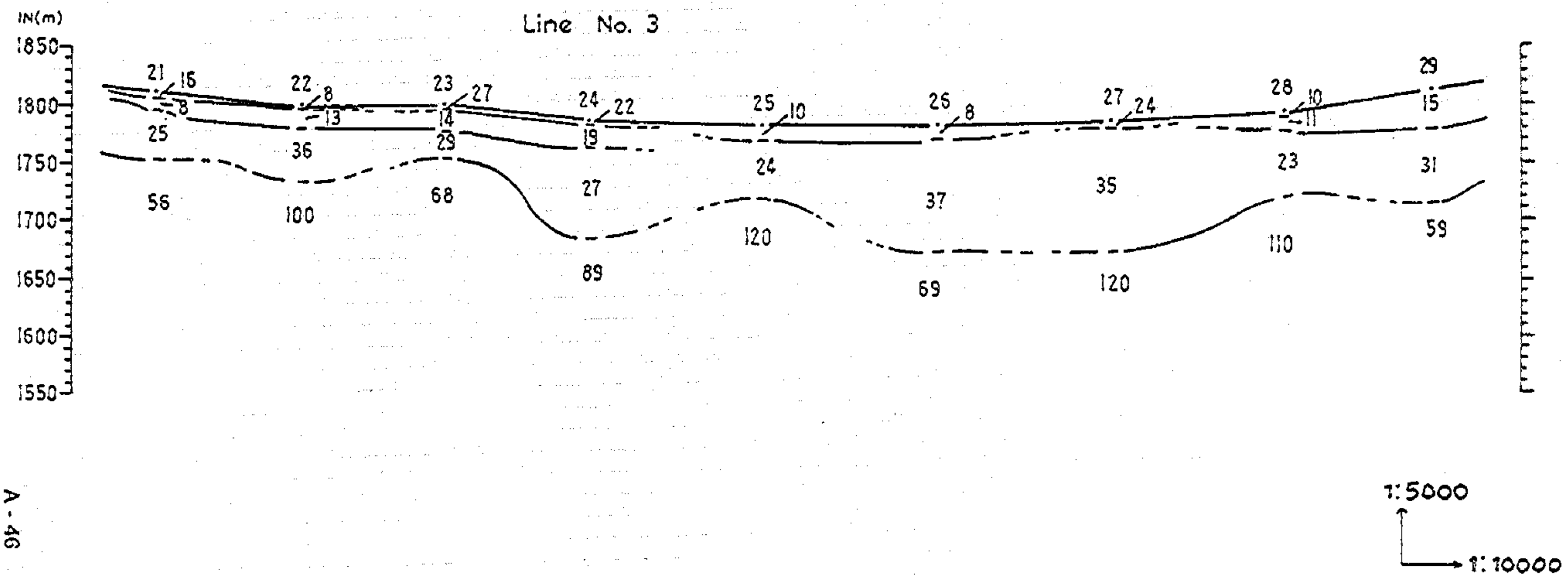
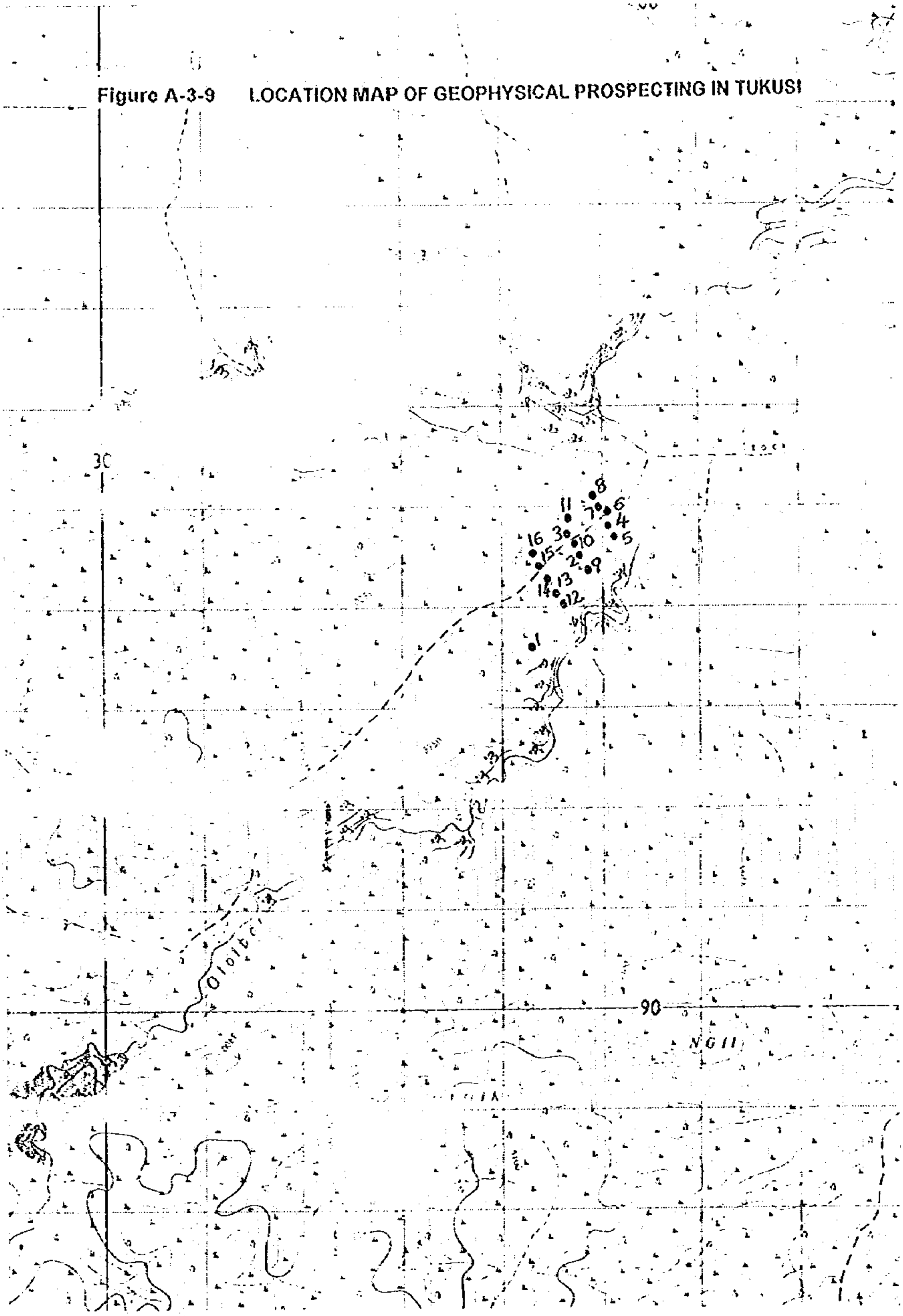


Figure A-3-8 RESISTIVITY PROFILE OF LINE NO.3 IN MONDULI JUU

MONDULI JUU

TUKUSI

Figure A-3-9 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN TUKUSI



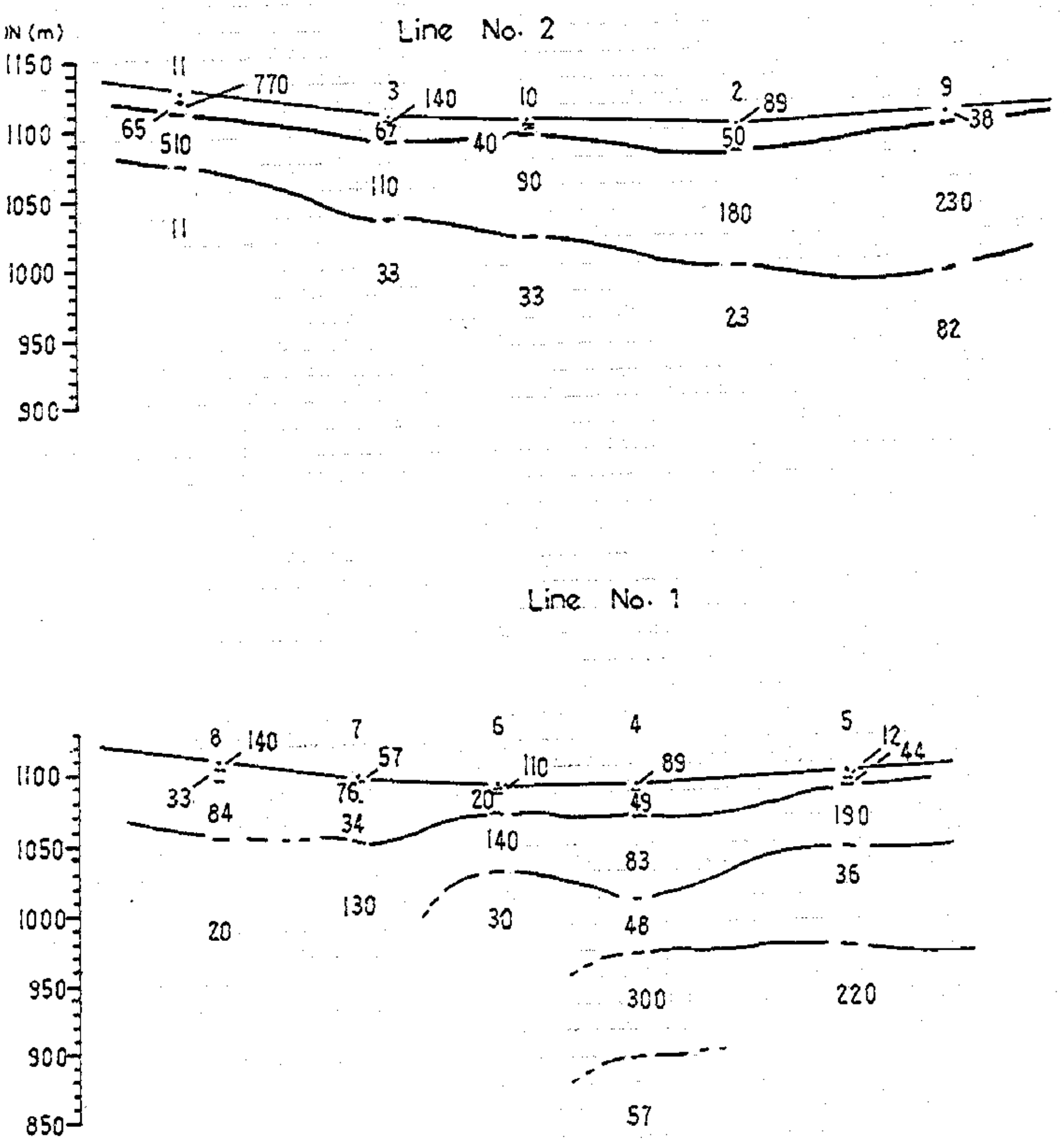


Figure A-3-10 RESISTIVITY PROFILE OF LINE NO.1 AND NO.2 IN TUKUSI

TUKUSI 1:5000

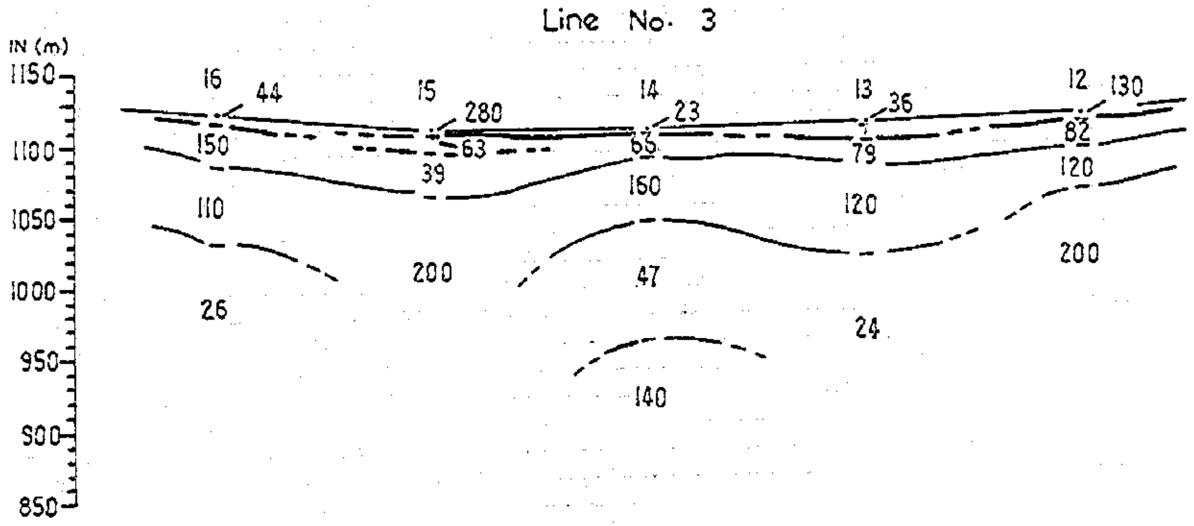
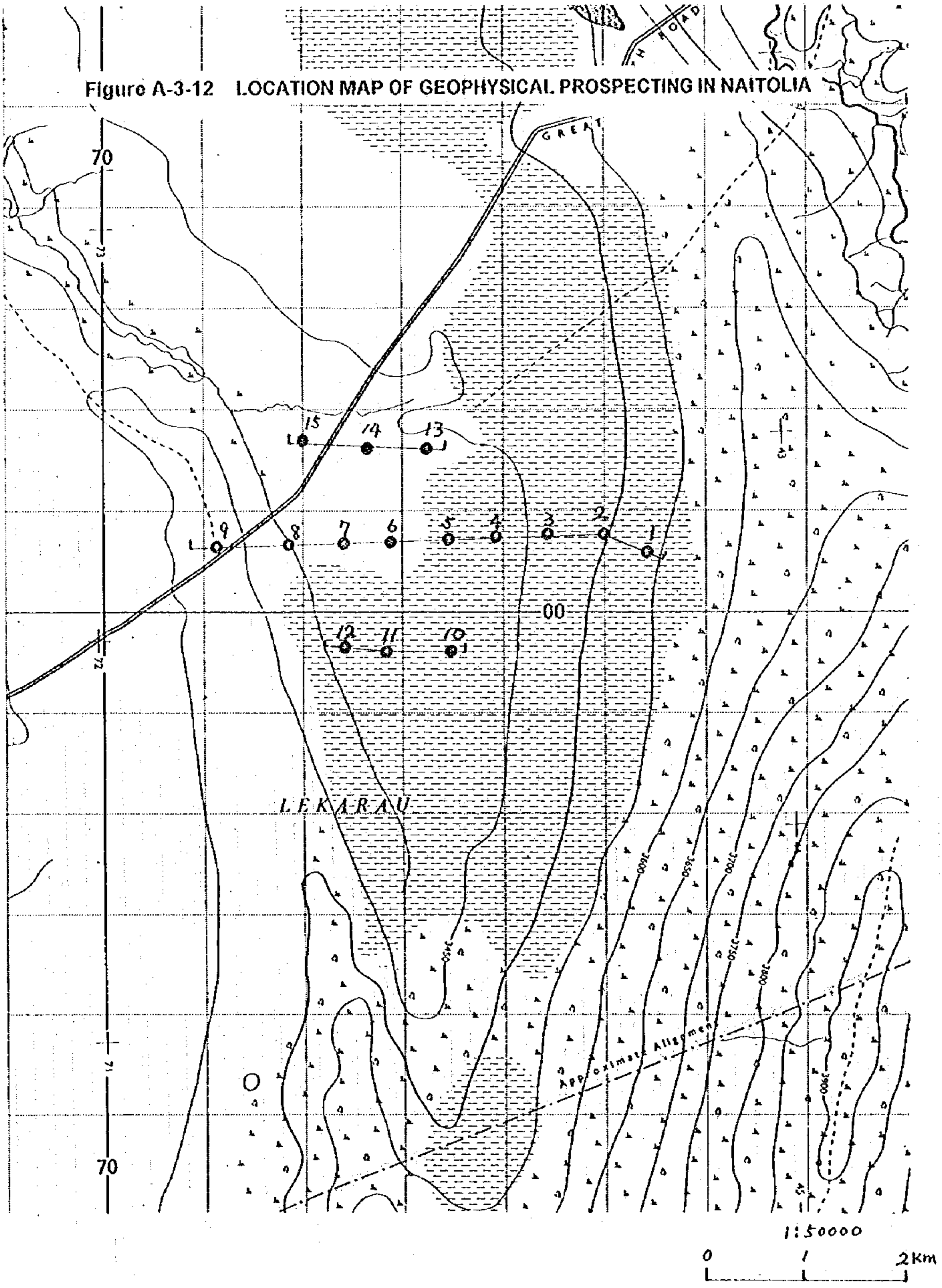


Figure A-3-11 RESISTIVITY PROFILE OF LINE NO.3 IN TUKUSI

TUKUSI 1:5000

Figure A-3-12 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN NAITOLIA



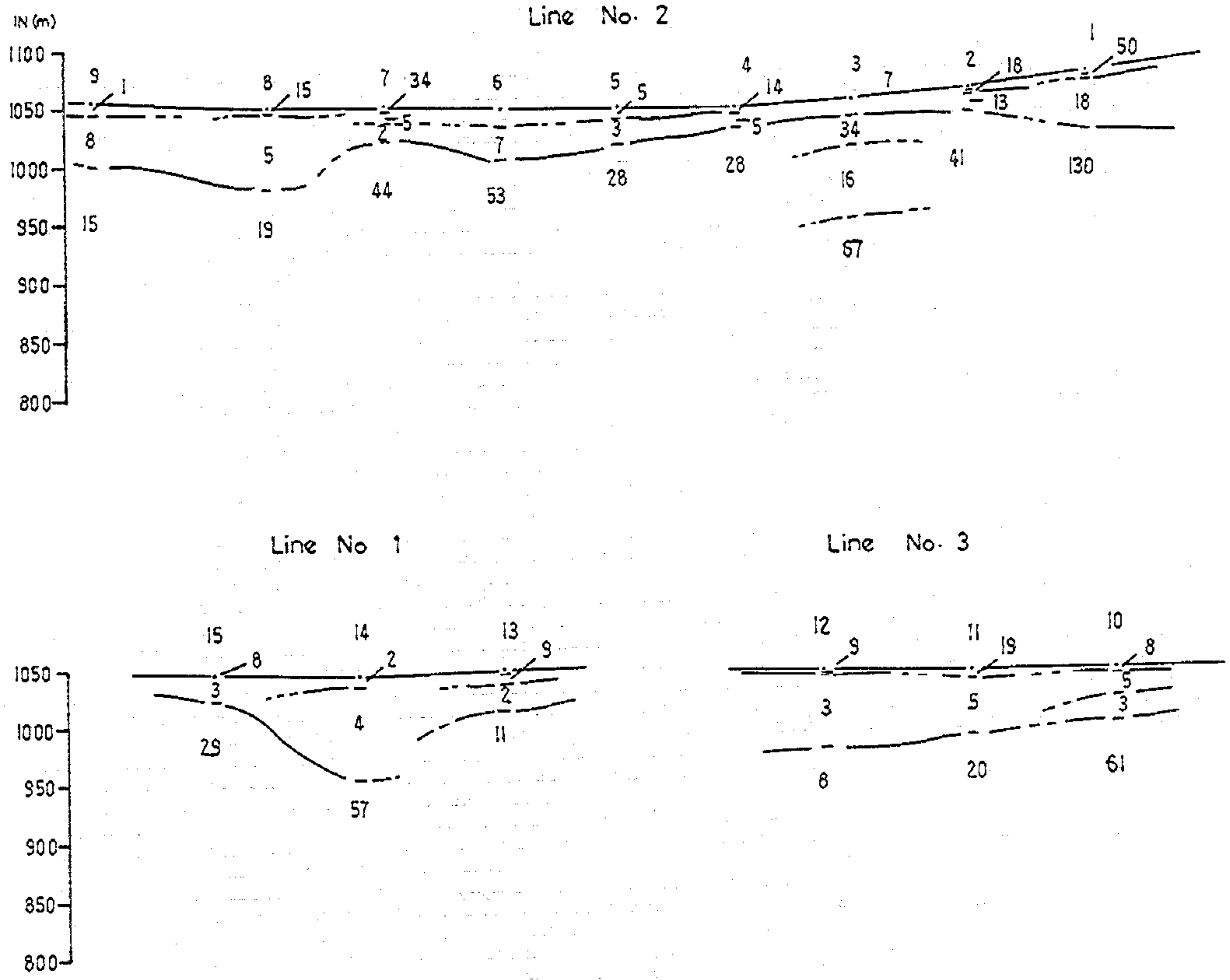
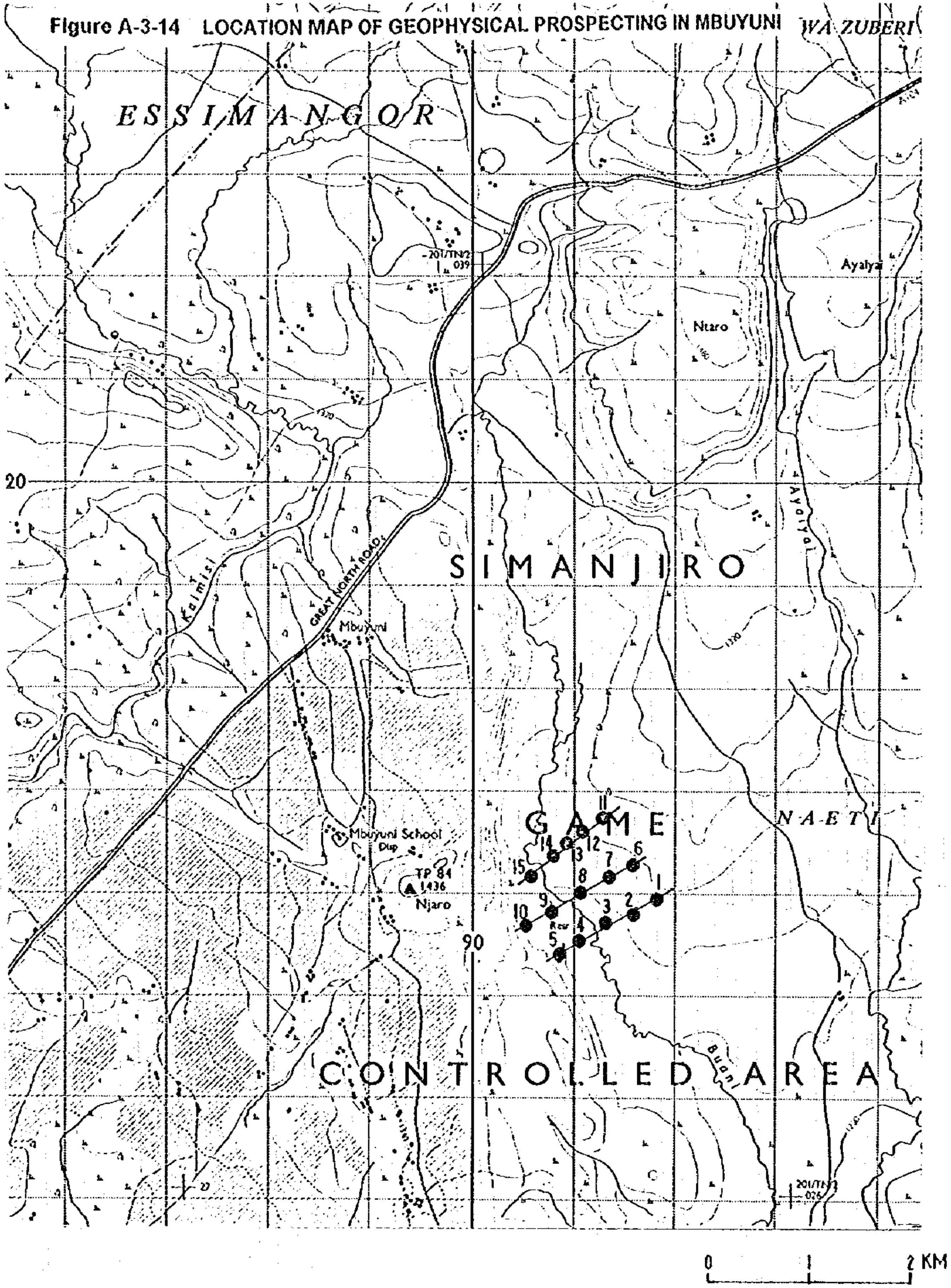


Figure A-3-13 RESISTIVITY PROFILE OF LINE NO.1, NO.2 AND NO.3 IN NAITOLIA

NAITOLIA 1:5000

Figure A-3-14 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN MBUYUNI



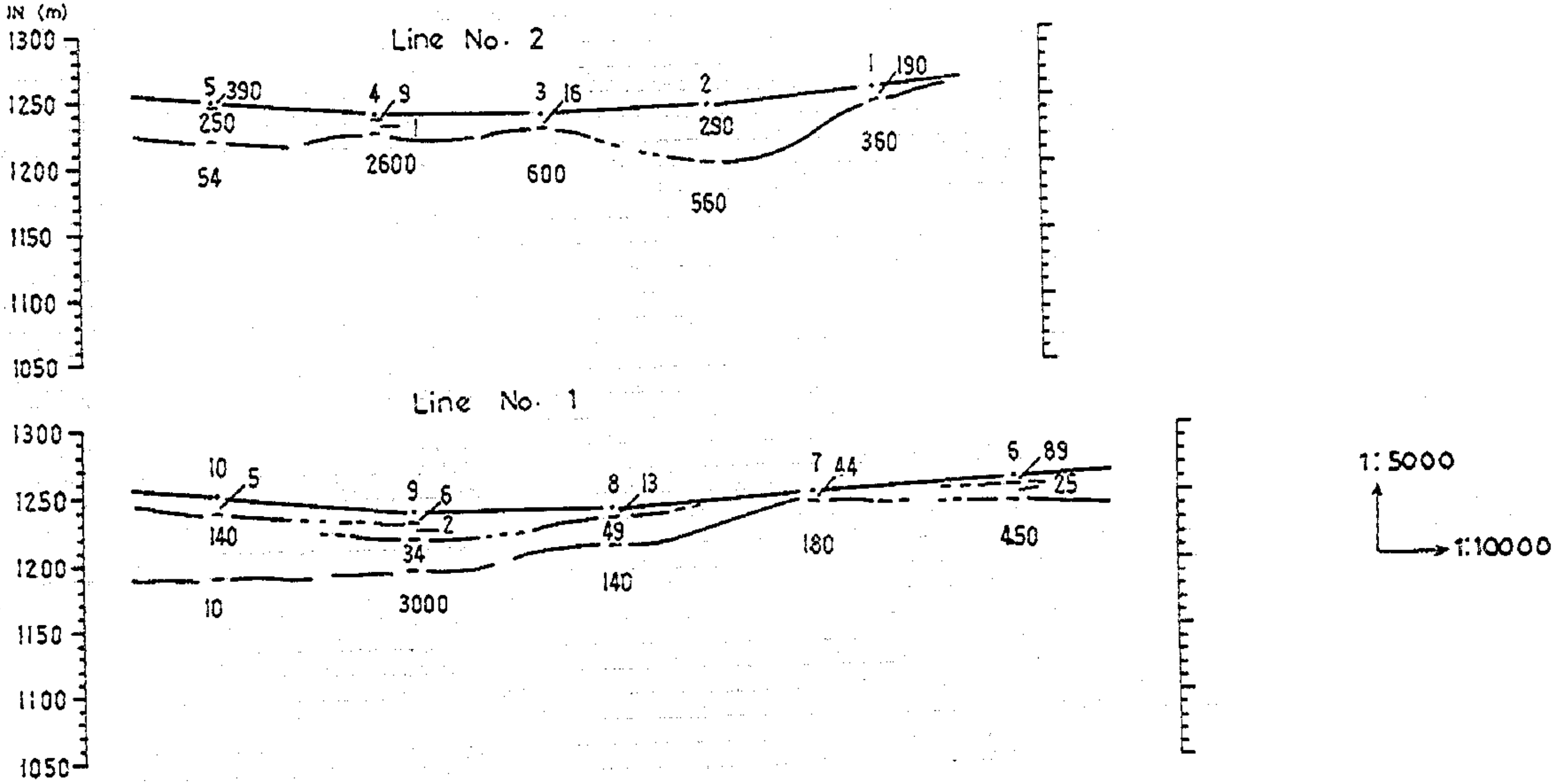


Figure A-3-15 RESISTIVITY PROFILE OF LINE NO.1 AND NO.2 IN MBUYUNI

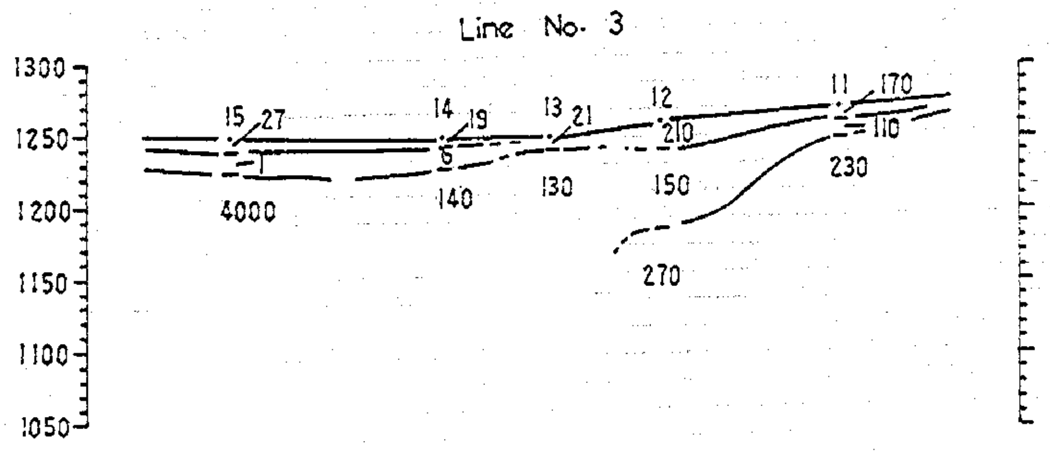
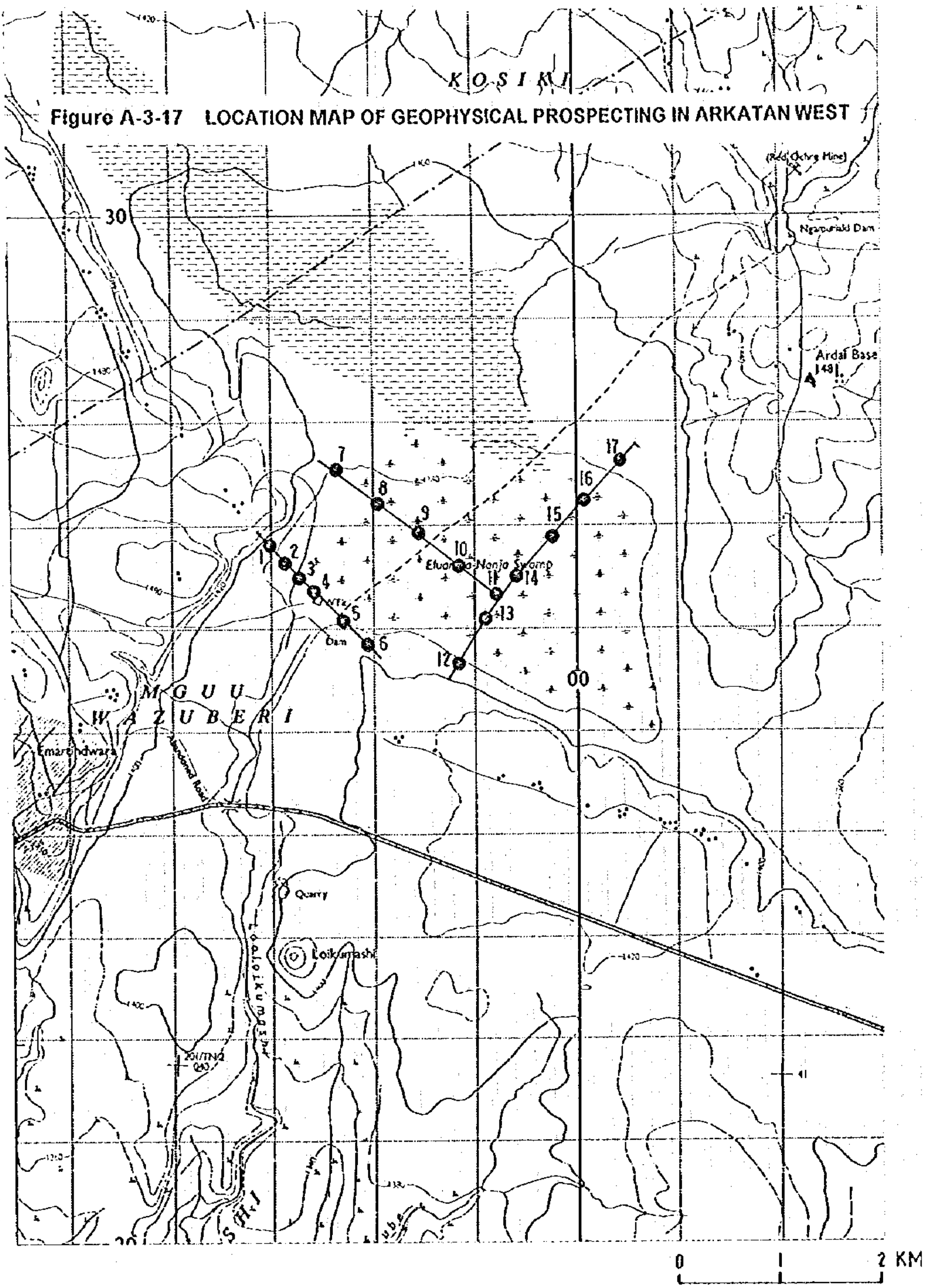


Figure A-3-16 RESISTIVITY PROFILE OF LINE NO.3 IN MBUYUNI

Figure A-3-17 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN ARKATAN WEST



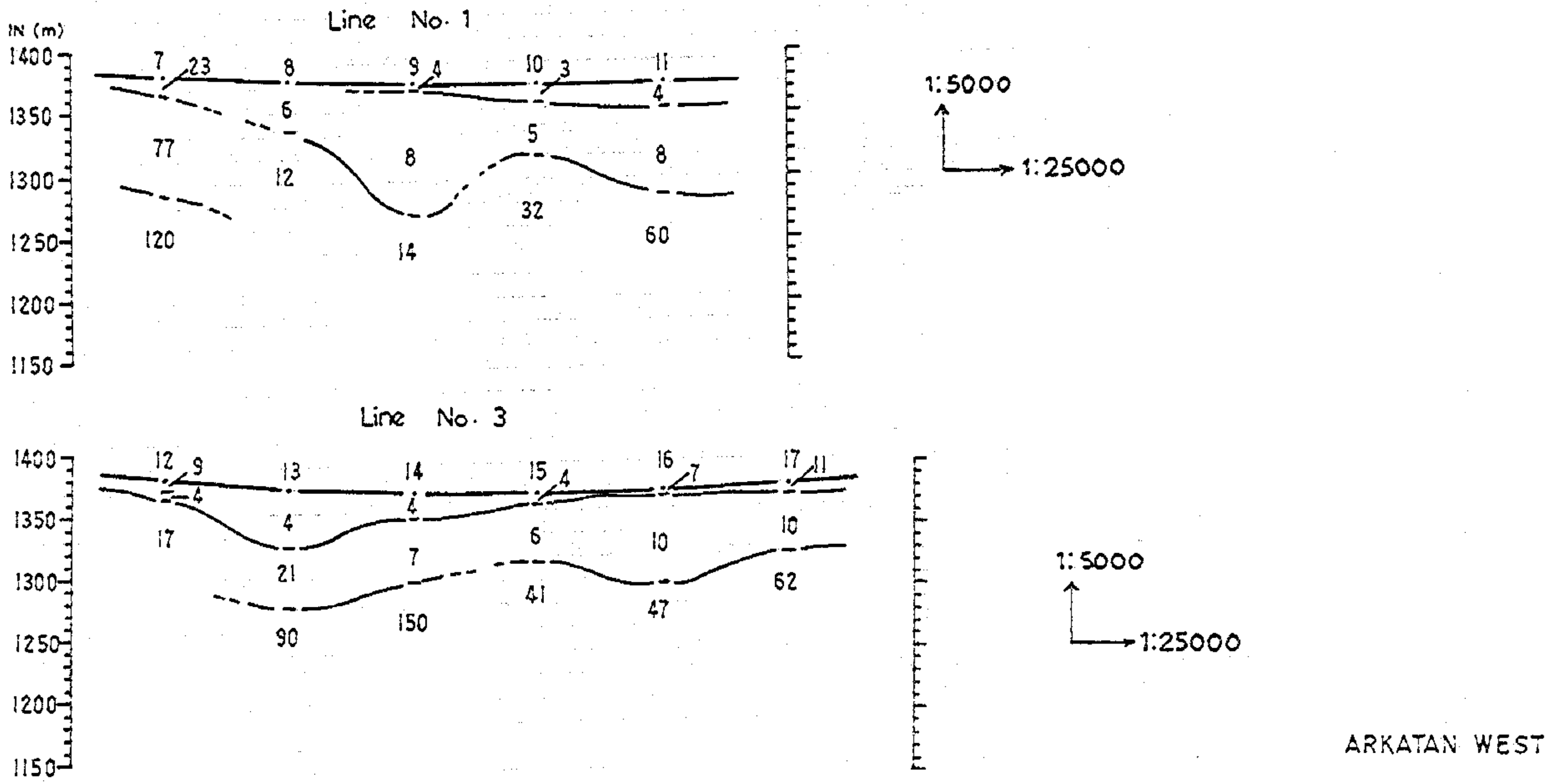


Figure A-3-18 RESISTIVITY PROFILE OF LINE NO.1 AND NO.3 IN ARKATAN WEST

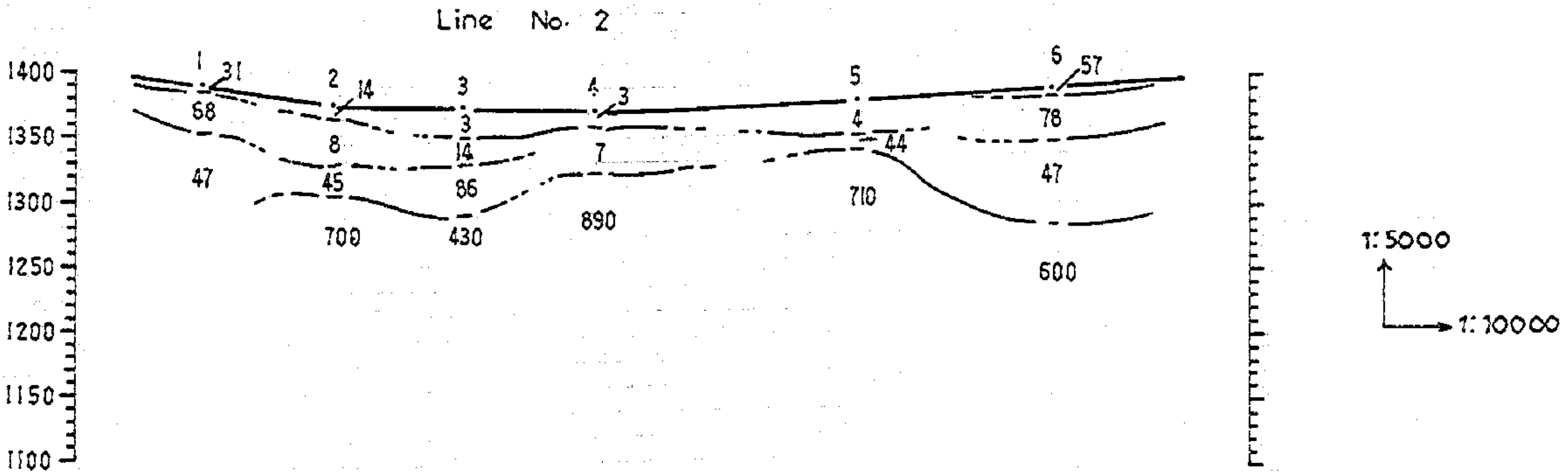
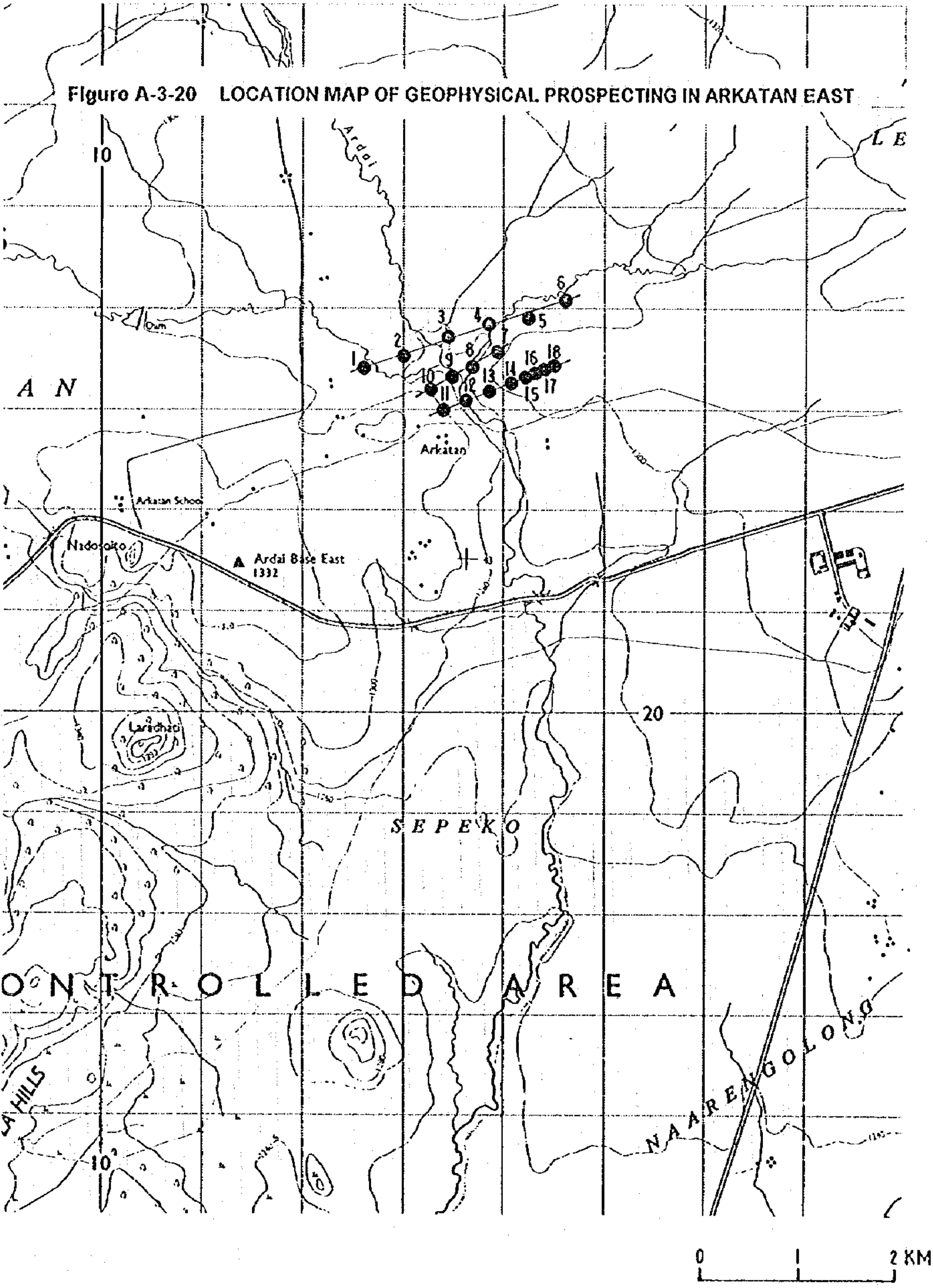


Figure A-3-19 RESISTIVITY PROFILE OF LINE NO.2 IN ARKATAN WEST

Figuro A-3-20 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN ARKATAN EAST



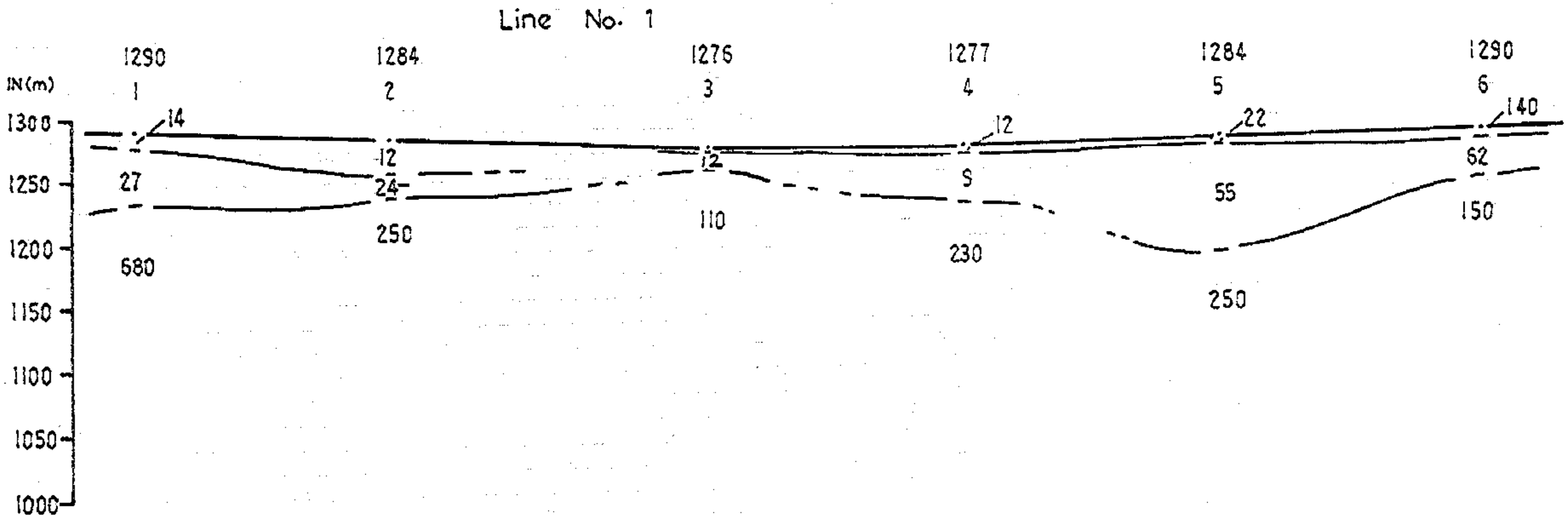


Figure A-3-21 RESISTIVITY PROFILE OF LINE NO.1 IN ARKATAN EAST

ARKATAN EAST 1:5000

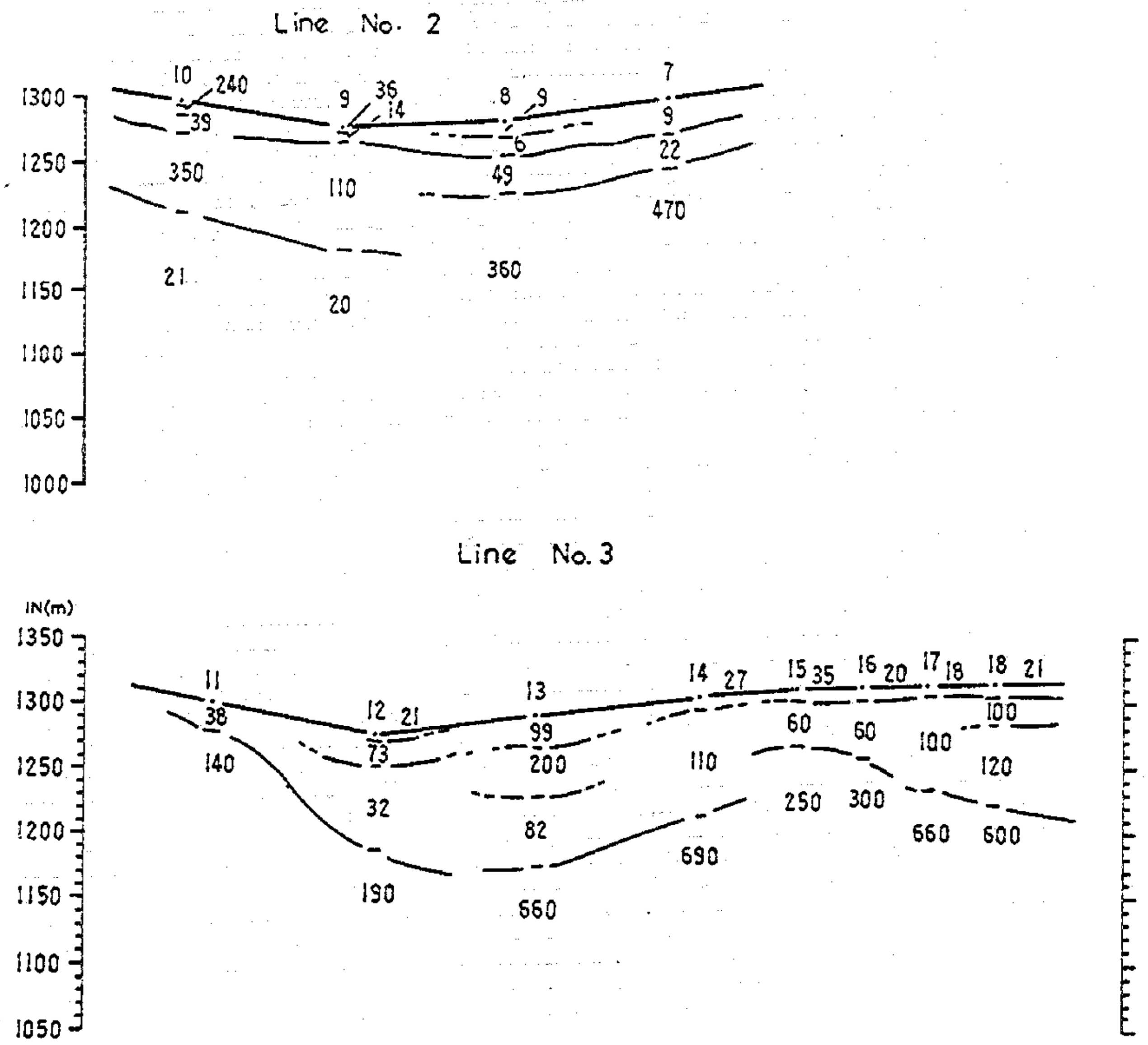


Figure A-3-22 RESISTIVITY PROFILE OF LINE NO.2 AND NO.3 IN ARKATAN EAST

Figure A-3-23 LOCATION MAP OF GEOPHYSICAL PROSPECTING IN OLTUKAI

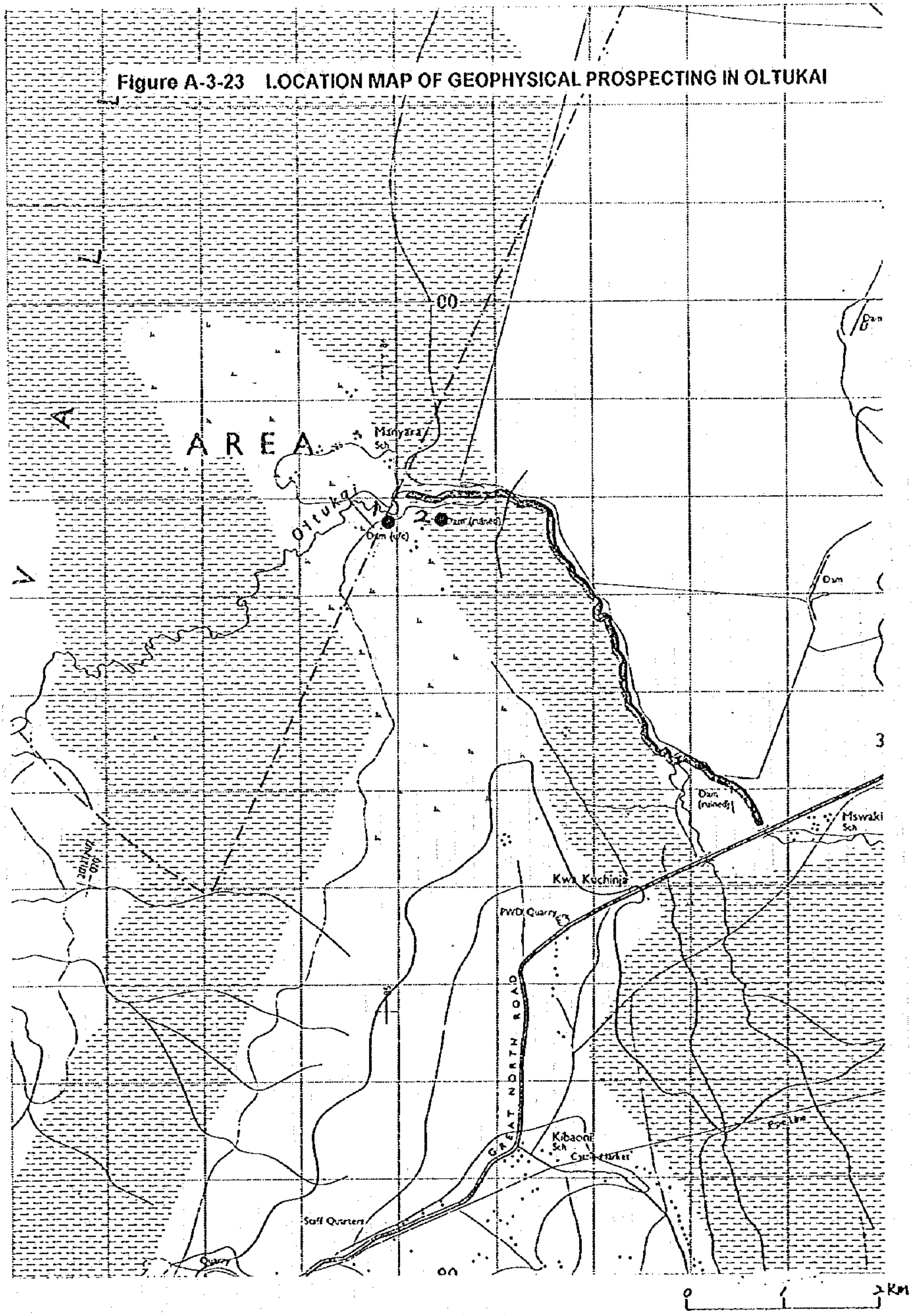
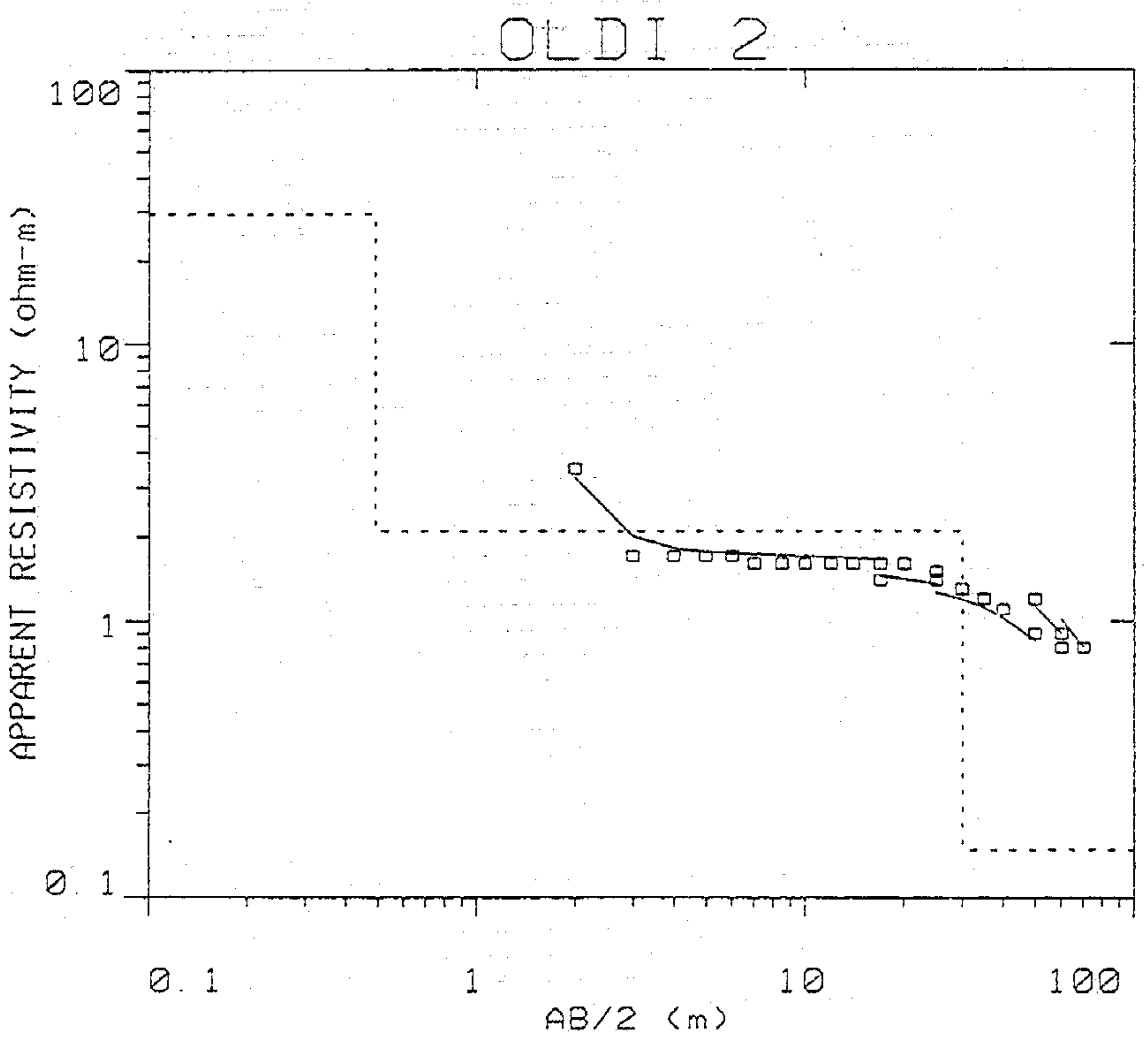


Figure A-3-24 VES CURVE IN OLTUKAI



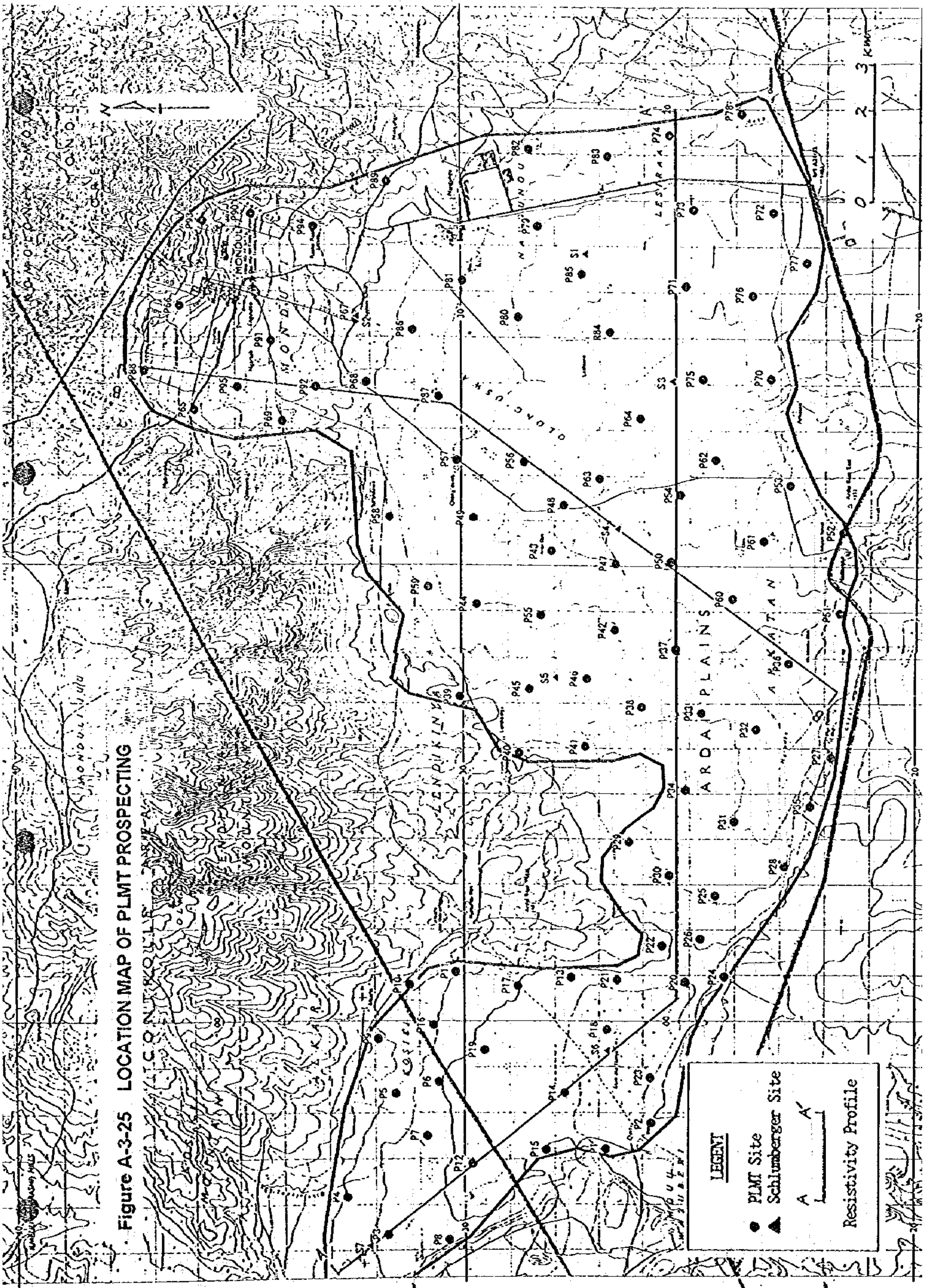


Figure A-3-25 LOCATION MAP OF PLMT PROSPECTING

LEGENT

● PLMT Site

▲ Schlumberger Site

A ——— A' Resistivity Profile

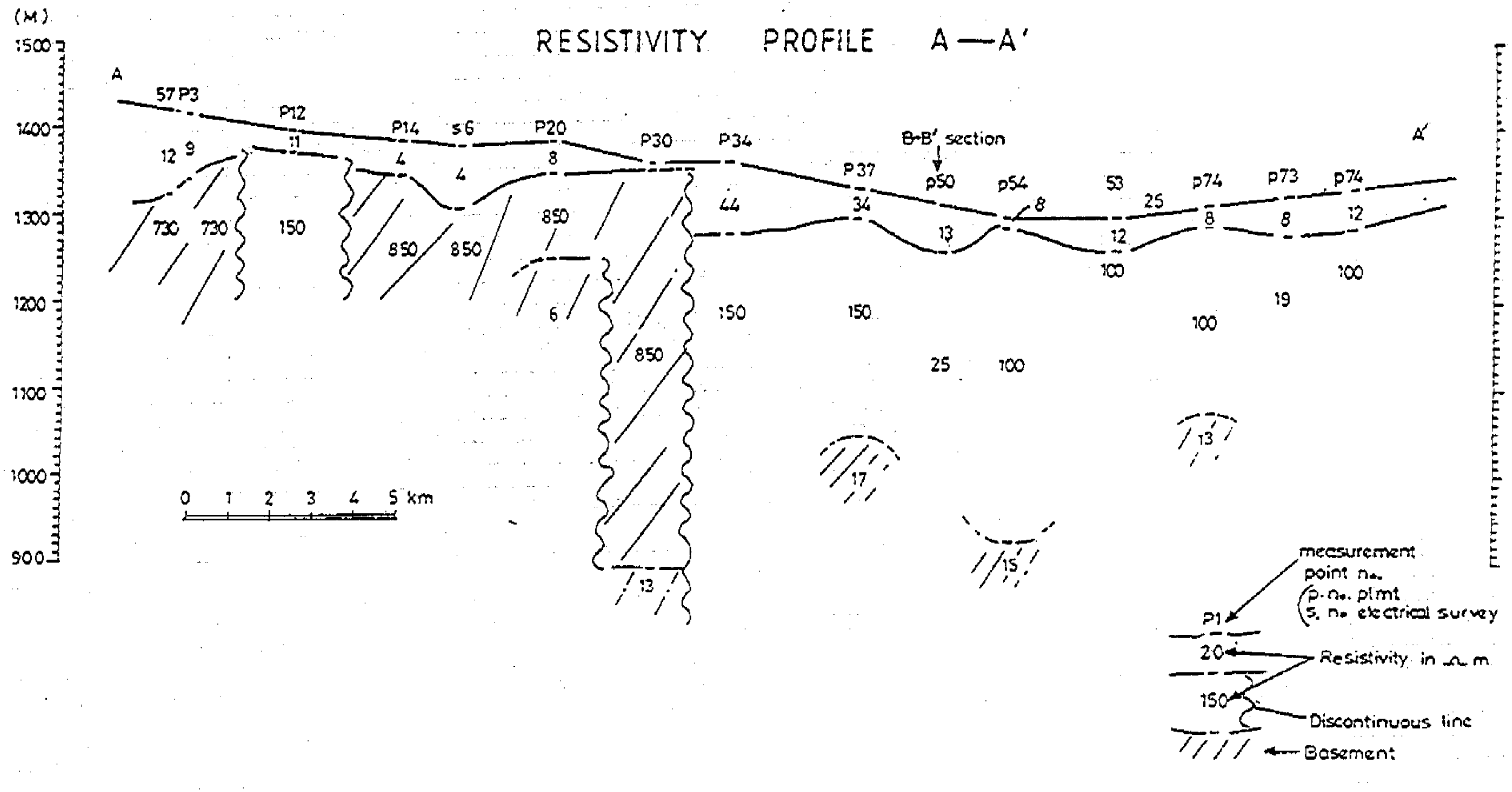
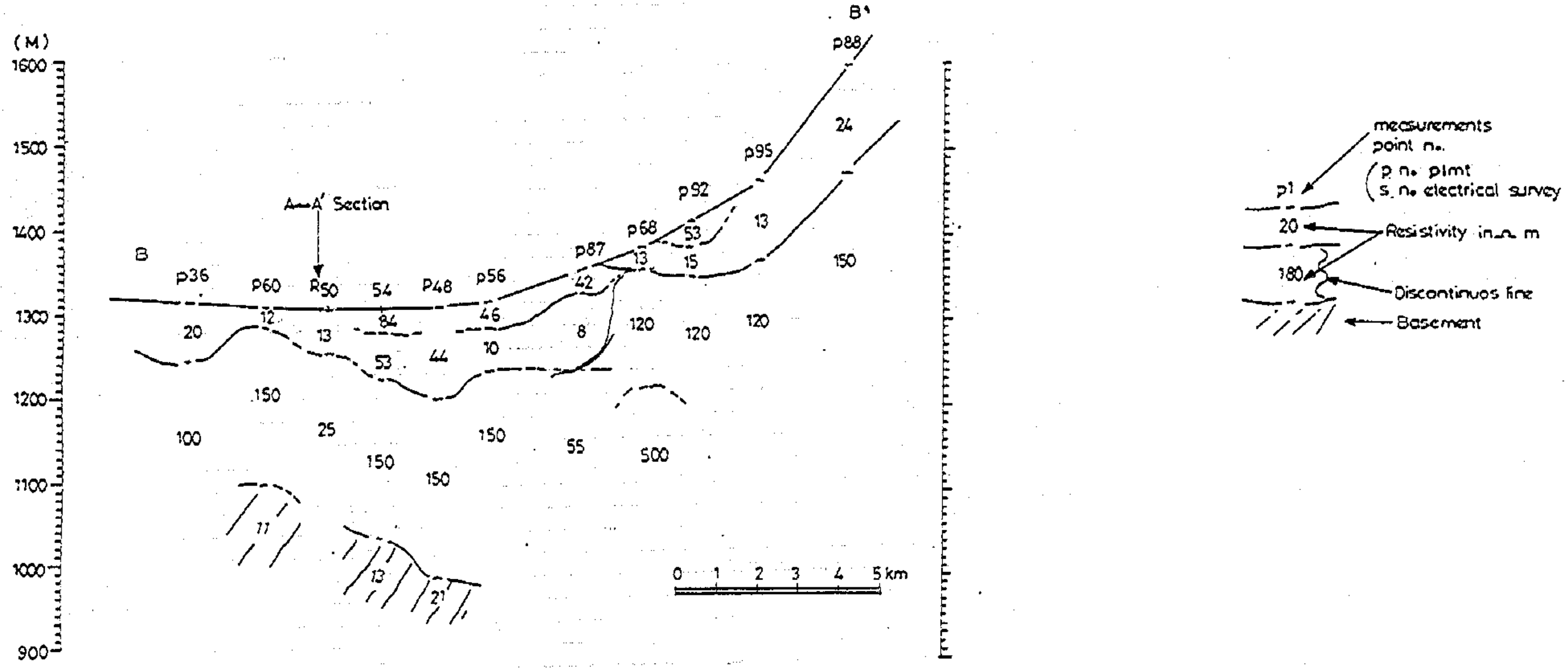


Figure A-3-26 RESISTIVITY PROFILE OF PLMT PROSPECTING A-A'



RESISTIVITY PROFILE B—B'

Figure A-3-27 RESISTIVITY PROFILE OF PLMT PROSPECTING B-B'

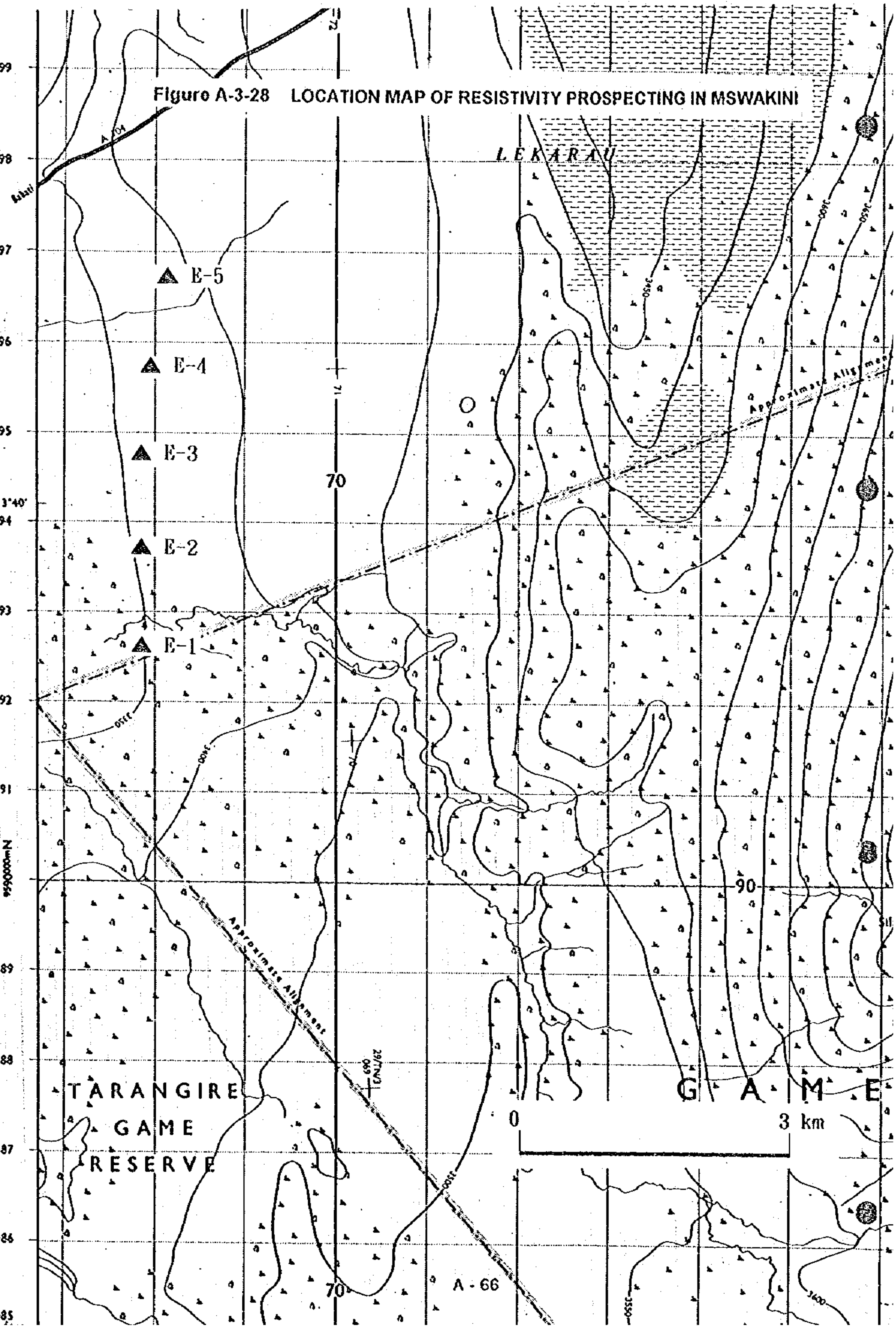


Figure A-3-28 LOCATION MAP OF RESISTIVITY PROSPECTING IN MSWAKINI

Figure A-3-29 LOCATION MAP OF RESISTIVITY PROSPECTING IN MAKUYUNI

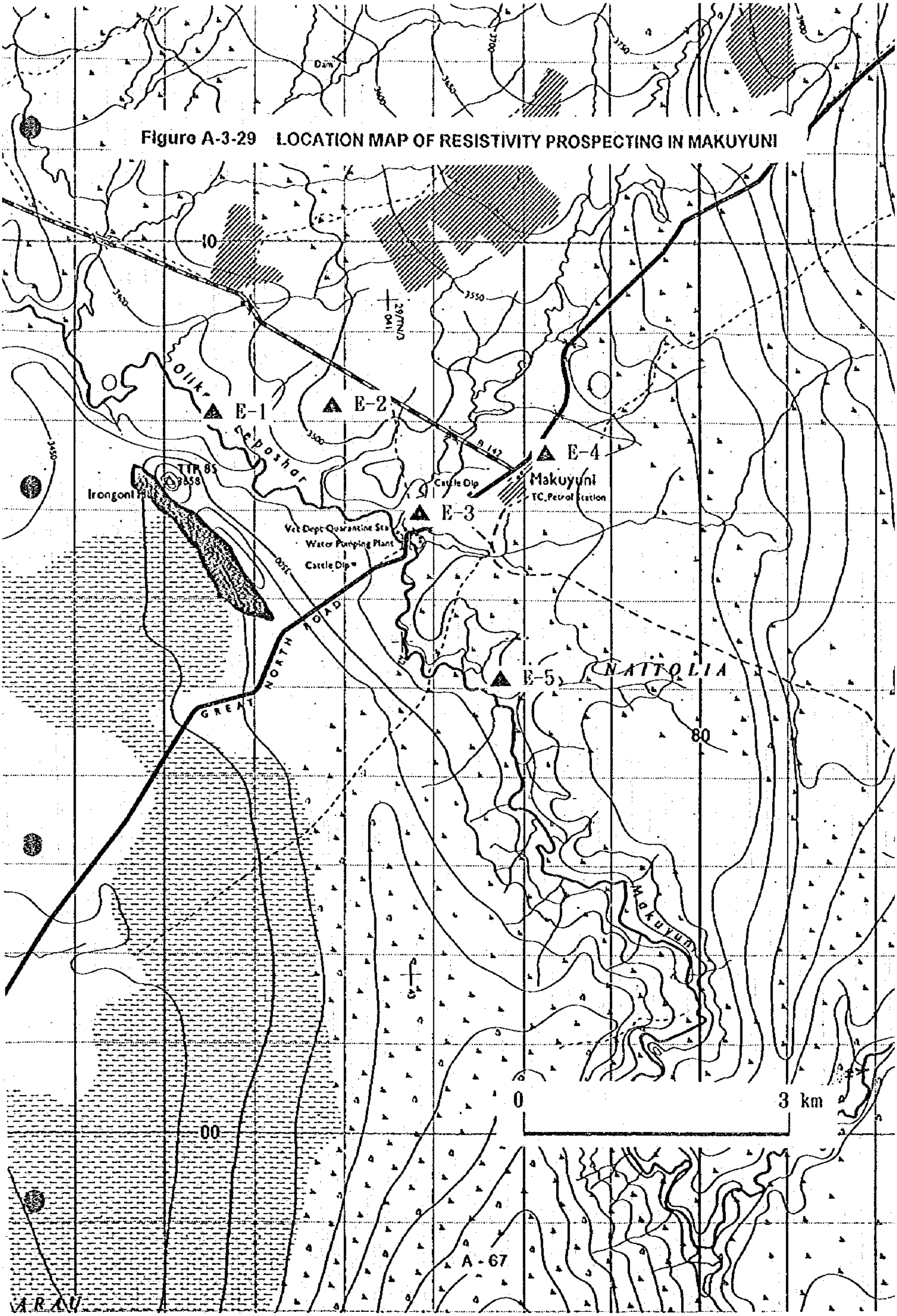


Figure A-3-30 LOCATION MAP OF RESISTIVITY PROSPECTING IN ENGARE OLMOTONI

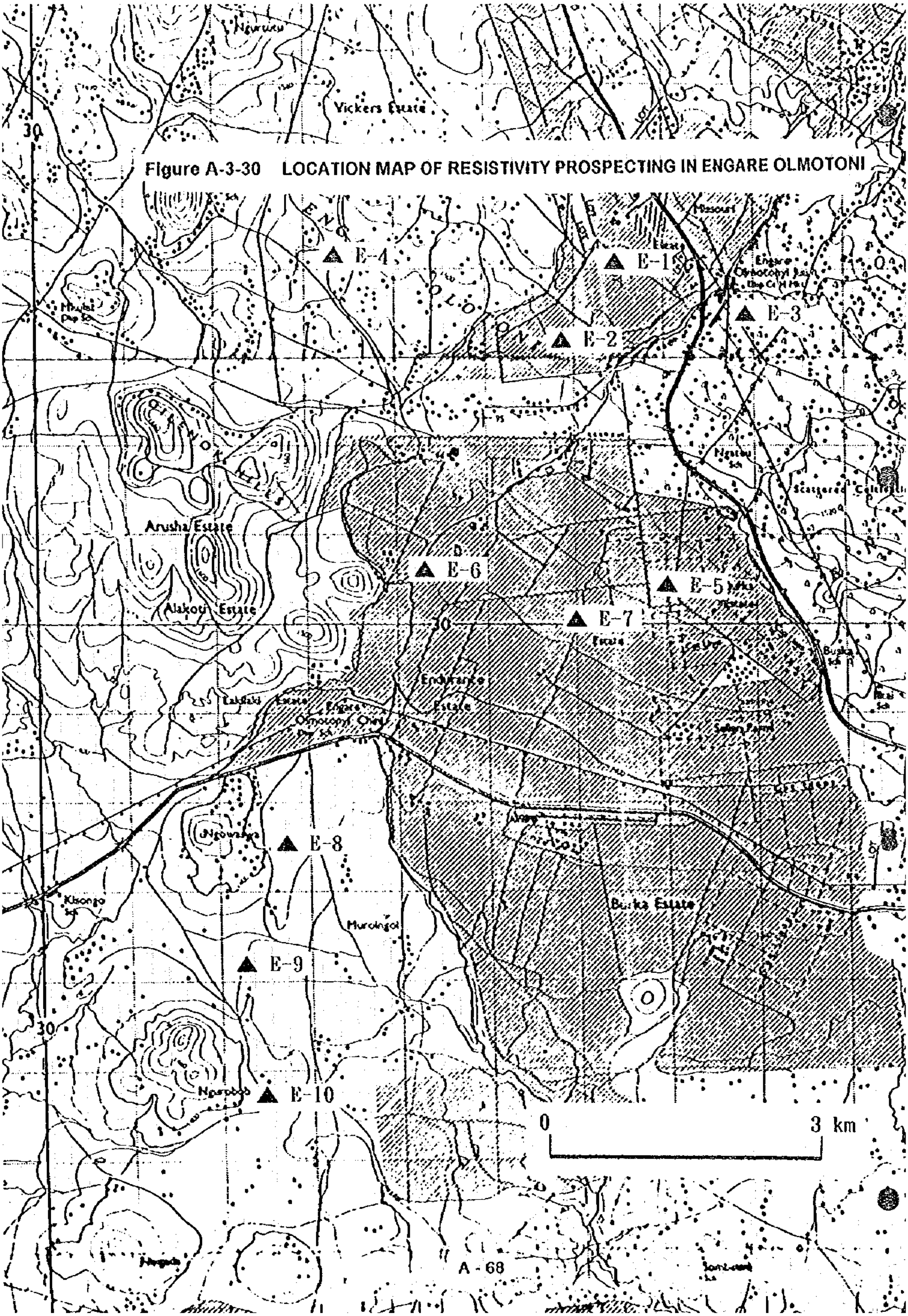


Figure A-3-31 RESISTIVITY PROFILE IN ENGARE OLMOTONI

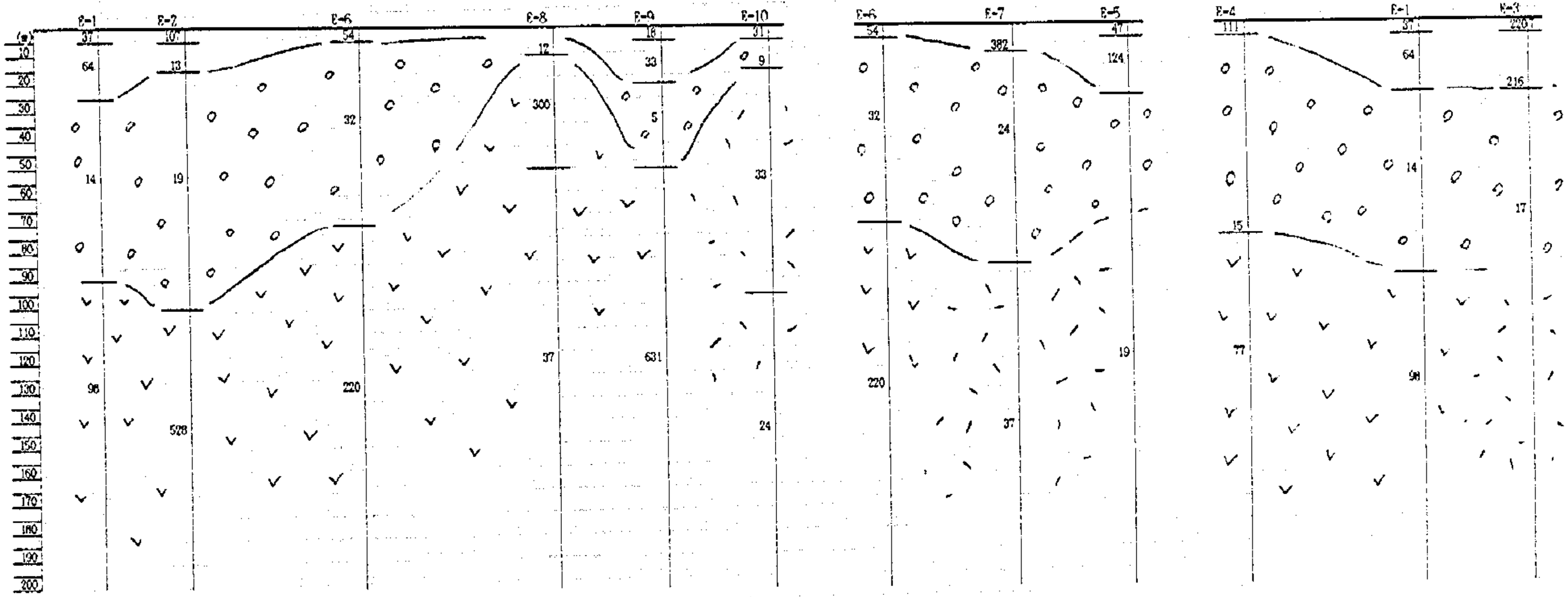


Figure A-3-32 RESISTIVITY DISTRIBUTION CONTOUR MAP AT 50 MBGS

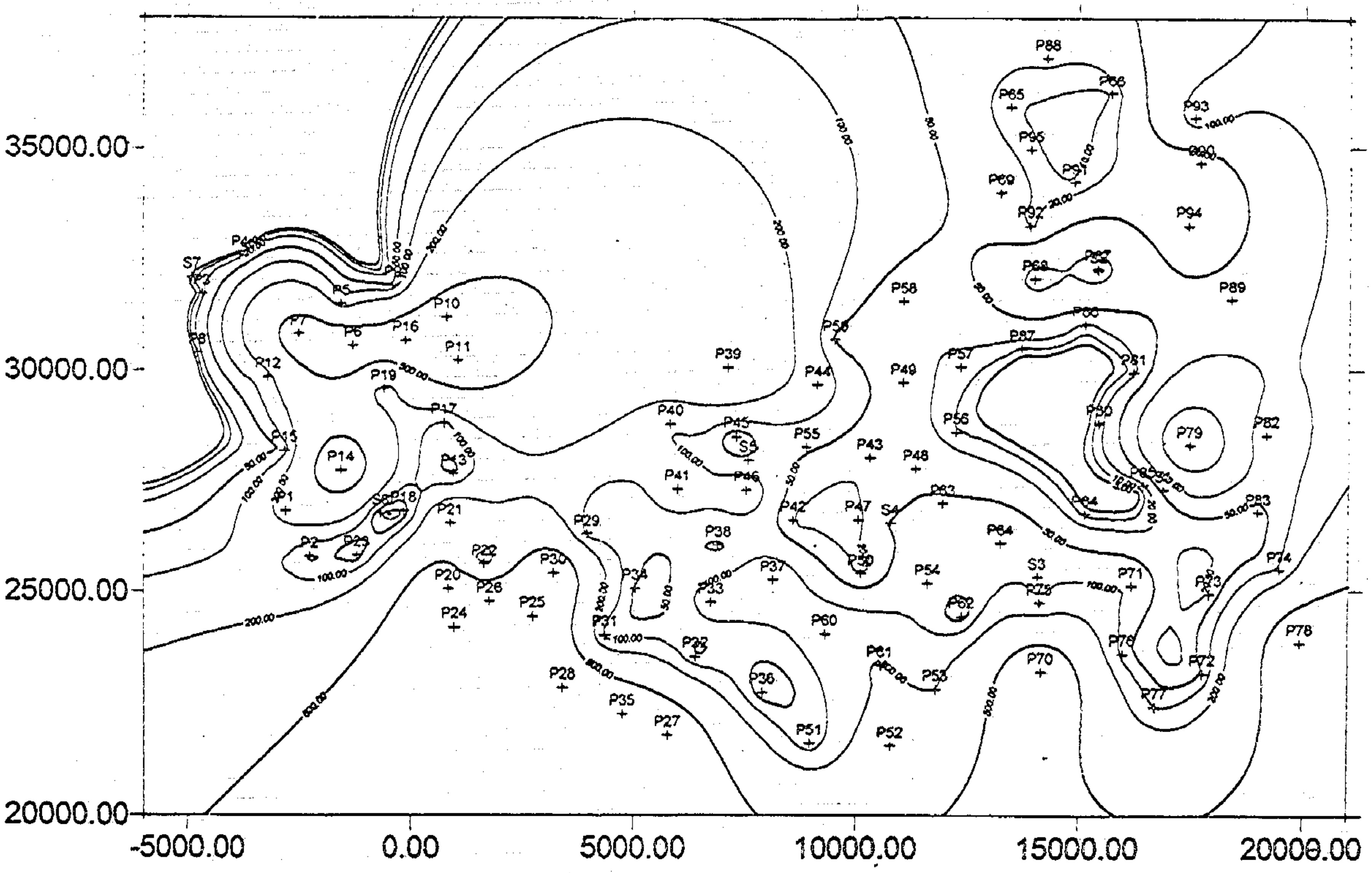
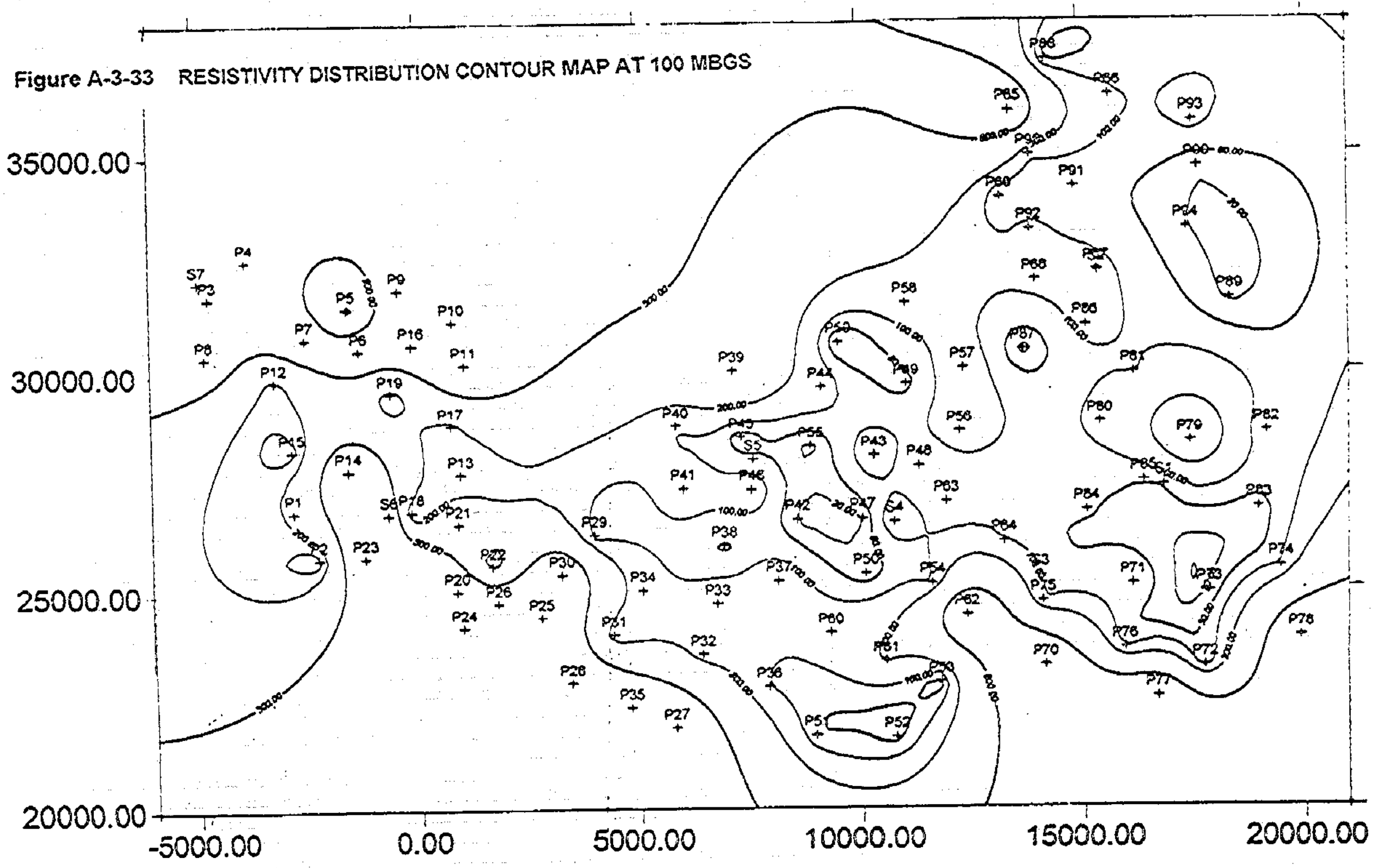


Figure A-3-33 RESISTIVITY DISTRIBUTION CONTOUR MAP AT 100 MBGS



A-4 EXPLORATORY WELL DRILLING

A-4-1 Outline of the Work

The objectives of the work are to obtain the hydrogeological conditions of the Study Area, including,

- to set up hydrogeological units
- to obtain vertical/horizontal extent of the aquifers,
- to obtain aquifer characteristics and potential and
- to obtain groundwater quality

Eleven (11) exploratory wells are located in selected five (5) villages and Monduli Town (see Figure A-2-1, Location Map of Hydrogeological Study). Well site and depth are decided based on results of hydrogeological survey and resistivity prospecting. Drilling depth of the exploratory wells is ranging from 100 m to 250 m.

Three type of truck mounted rotary drilling rigs, T-64HB and T-985 of Schramm, and Super Rock-1994 are used for the drilling, and water-based drilling fluids with bentonite and CMC, and air percussion are applied during the drilling procedure.

Although full column of borehole logging are not conducted due to heavy circulation loss, results of resistivity logging are created to locate aquifers and aquicludes after the drilling is completed. An interpretation of the lithologic logs assists in determination the location of the screens with the above borehole loggings.

After completion of the drilling, fiberglass reinforced pipe (FRP) casings of 150 mm diameter and horizontal slotted screens of FRP with twelve (12) percent openings are installed in the borehole.

The standard well structure of the exploratory well is shown in Annex.

A-4-2 Results of Drilling

(1) EX-1 in Naitolia

Drilling aims to obtain aquifer potential in the Lake Manyara Beds. First drilling work was commenced on January, 1995 and stopped it at depth of 84 mbgs due to heavy mud loss. Casing installation was failed by hole collapse. Drilling activities was ceased on March 24 due to time limitation of the Study Team.

Drilling work in Phase II starts on August, 1995 and it was completed at 76 meters depth. Casing was installed up to 74 meters with screen interval from 52 to 72 mbgs (see Figure A-4-1, Exploratory Well Log, EX-1).

Drilled cuttings indicate that lithology of well log up to 58 meters is composed of alternative beds of clay and, sand and gravel with calcareous fragments which is correlative with Lake Manyara Beds. The hole is underlain by weathered granite from 58 to the bottom.

Preliminary test is tried by air lift pumping at static water level of 65 mbgs, but very little amount of water is confirmed by it.

(2) EX-2 in Mbuyuni

Drilling aims to obtain groundwater potential of the Plateau Lava. It was commenced on February, 1995 and was stopped at depth of 64 mbgs due to heavy mud loss. Screen was located on fractured volcanic rock after the borehole logging. Exploratory well log is shown in Figure A-4-2.

Well was developed by a jetting and static water level was obtained at 58 mbgs. Pumping was preliminarily tried by air lift pumping, but no enough quantity of water was extracted due to low groundwater potential.

(3) EX-3 in Tukusi

Drilling aims to investigate aquifer potential in the Basement Rocks. It was commenced on March, 1995 and stopped at depth of 98 mbgs on the weathered gneiss of the Basement. Casing was installed after the borehole logging. Exploratory well log is shown in Figure A-4-3.

Well was developed by a jetting and static water level was obtained at 54.56 mbgs. Pumping was preliminarily tried by an air lifting and yield was 1 ℓ/min. but drawdown was not recorded.

(4) EX-4 in Ngarasi, Southwest of Monduli Town

Drilling aims to investigate aquifer potential in the pyroclastic rocks and fractured volcanic rocks. Drilling was commenced on July, 1995 and completed at 154 meters depth. Casing was installed up to 144 mbgs with 40 meters screen from 100 to 140 mbgs after the borehole logging (see Figure A-4-4, Exploratory Well Log, EX-4).

Static water lever attains 122 mbgs. Preliminary test was tried by air lift pumping, but no enough quantity of water was extracted due to low groundwater potential.

(5) EX-5 in Lashaine, South of Monduli Town

Drilling aims to investigate aquifer potential in the pyroclastic rocks and fractured volcanic rocks. The site is located the northern edge of Ardai Basin. Drilling was commenced on August, 1995 and it was completed at 192 meters depth.

A heavy circulation loss was encountered at depth of 67 mbgs in fractured volcanic rock. The loss causes in a dry cave with gas, and it was finally plugged by cement. The hole was drilled by air drilling method up to 198 meters, but no sign of water during drilling procedure.

The hole is finally backfilled without casing (see Figure A-4-5, Exploratory Well Log of EX-5, Lashaine).

(6) EX-6 in Ardai Basin for Lendikinya

Drilling aims to investigate aquifer potential in the pyroclastic rocks and fractured volcanic rocks. The site is located the middle course of Ardai Basin. Drilling was commenced on September, 1995 and it was completed at 250 meters depth.

A heavy circulation loss was encountered at depth from 128 to 138 mbgs where formation changes from thick clayey bed to fractured volcanic rock. The loss causes in a dry cave with gas, and it was finally plugged by cement.

Drilling was stopped at 250 meters depth, but no sign of water until the bottom. The hole was backfilled without casing (see Figure A-4-6, Exploratory Well Log, EX-6).

(7) EX-7 in Emairete, Monduli Juu

Drilling aims to investigate aquifer potential in the colluvial beds in Monduli Juu Caldera. Drilling was commenced on August, 1995 and it was completed at 102 meters depth.

Casing was installed up to 100 mbgs with 20 meters total length of screen from 72 to 76 and 80 to 96 mbgs in a location of volcanic sand (see Figure A-4-7, Exploratory Well Log, EX-7).

Static water lever attains 72.25 mbgs. Constant yield test was conducted to evaluate well potential. Tested yield and maximum drowdown by 24 hours continuous pumping are 20.7 ℓ/min. and 3.26 respectively, and calculated specific capacity and transmissivity are 6.34 ℓ/min./m and 8 m^2/day respectively.

(8) EX-8 in Sinon, Monduli Town

Drilling aims to investigate aquifer potential in the pyroclastic rocks and fractured volcanic rocks. Drilling was commenced on August, 1995 and it was completed at 126 meters depth.

A heavy circulation loss was encountered at depth of 126 mbgs where formation changes from thick scoriatic breccia to fractured volcanic rock. The loss causes in a dry cave with gas, and it was finally plugged by cement.

Casing was installed up to 100 mbgs with 18 meters total length of screen from 72 to 90 mbgs in a location of fractured volcanic rock (see Figure A-4-8, Exploratory Well Log, EX-8).

Preliminary test was tried by air lift pumping, but the hole was dry.

(9) EX-9 in Arkatan-west

Drilling aims to investigate aquifer potential in the fractured volcanic rocks in the Plateau Lava. The site is located the southern part of the Eluanata Basin. Drilling was commenced on July, 1995 and it was completed at 48 meters depth.

A heavy circulation loss was encountered at depth of 48 mbgs in fractured volcanic rock. The loss causes in a dry cave with pressure gas.

Drilling was stopped at 48 meters depth and casing was not installed. Well geologic log shows in Figure A-4-9, Exploratory Well Log, EX-9.

(10) EX-10 in Arkatan-east

Drilling aims to investigate aquifer potential in the pyroclastic and fractured volcanic rocks in the Plateau Lava. The site is located the southern part of the Ardai Basin. Drilling was commenced on July, 1995 and it was completed at 152 meters depth.

A heavy circulation loss was encountered at depth of 85 mbgs in tufferceous pyroclastic rocks. The loss causes in a dry cave with pressure gas, and it was finally plugged by cement.

Drilling was stopped at 152 meters depth and casing was installed up to 140 mbgs with 40 meters screen from 88 to 96 and from 104 to 136 mbgs (see Figure A-4-10, Exploratory Well Log, EX-10).

After development, water level was measured but no water in the well.

Results of exploratory well drilling is summarized in Table A-4-1.

(11) EX-11 in Tarosero, Monduli Town

Drilling aims to investigate aquifer potential in the fractured volcanic rock of Younger Extrusive. The site is located in the northeast of Monduli township. Drilling was commenced in October. A heavy circulation loss was encountered at depth of 150 mbgs in the pyroclastic rocks. The loss causes in a dry cave, and it was finally plugged by cement.

Results of exploratory well drilling is summarized in Table A-4-1.

A-4-3 Results of Pumping Test

(1) Methodology

Aquifer are tested by three kind of pumping tests: preliminary test, constant yield testand recovery test. Tested well include one exploratory well and one existing well of RDD.

The discharge rate for the constant discharge test is usually decided by the results of maximum discharge in the preliminary test. Water is continuously pumped for 24 hours, and when pumping stops, recovery of the water level is measured until it attains a static water level.

Submersible pump was used for testing. The capacity of the pump is 15 kw and 300 ℓ/min. at 150 m of TDH respectively.

(2) Results of Test

Drawdown data is plotted versus the time to obtain the transmissivity, and the results are analyzed by Jacob's and recovery methods. Results of the test are summarized in Table A-4-2.

Transmissivity from each formation is consistent with the lithologic characteristics of the formations as shown below.

Name of formation	Transmissivity(m^2/d)	Name of tested wells
Colluvial Beds	8	EX-7
Lake Manyara Beds	11	10/52

The Lake Manyara Beds indicates comparatively good transmissivity where aquifers are subject to recharge by surface river and rainfall from wide alluvial plain. The colluvial beds in Monduli Juu shows 8 m^2/day of transmissivity in volcanic sand.

Table A - 4 - 1 SUMMARY OF EXPLORATORY WELLS

Well No.	Location	Coordinate Lat-S Lon-E	Alt. (masl)	Depth		Well Structure		Tested Data					Litology of Aquifer	Remark
				Drilled (m)	Cased (m)	Dia. (mm)	Screen (m-m)	S.W.L. (mbgs)	Yield (l/min)	D/d (m)	S.C. (1/min/m)	T (m^2/day)		
EX-1	Naitolia	3° 36.48' 36° 04.77'	1.100	76	73	150	52-72 =20	65.00					calcareous sand	
EX-2	Mbuyuni	3° 28.03' 36° 13.16'	1.270	64	60	150	44-56 =12	57.00	dry	—			fructured basalt	
EX-3	Tukusi	3° 39.79' 36° 36.92'	1.100	98	79	150	59-75 =16	54.56	1.00	—			weathered basement	
EX-4	Ngarasi Monduli Town	3° 18.09' 36° 25.35'	1,390	154	144	150	100-140 =40	122.65					vocanic sand	
EX-5	Lashaine	3° 19.65' 36° 26.25'	1,375	198	not cased	—								Air in cave at 67 mbgs
EX-6	Lendikinya	3° 20.52' 36° 24.72'	1,340	250	not cased	—			dry					
EX-7	Emairete Monduli Juu	3° 15.01' 36° 23.37'	1,800	102	100	150	72-76,80-96 =20	72.25	20.66	3.26	6.34	8	valcanic sand	
EX-8	Sinon Monduli	3° 18.96' 36° 26.52'	1,420	126	100	150	72-96 =24		dry				fractured basalt	Air in cave at 126 mbgs
EX-9	Arkatan -West	3° 21.89' 36° 16.79'	1,400	48	not cased	—			dry abandoned					Air in cave at 44 mbgs
EX-10	Arkatan -East	3° 24.20' 36° 25.26'	1,275	152	140	150	88-96,104-136 =40	135.91	dry				scoriatic vol. rocks	Air in cave at 85 mbgs
EX-11	Tarosero Moduli Town	3° 16.82' 36° 26.31'	1,540	150										

Table A - 4 - 2 SUMMARY OF PUMPING TEST

Name of Well	Location (m)	Well Depth	Static W.L. (mbgs)	Yield (m^3/hr) (l/min)	Drawdown (m)	S.C. (m^3/hr/m) (l/min/m)	Transmissivity (m^2/day)	
							Jacob	Recovery
10/52	Makuyuni	36	19.33	4.7 78.2	7.53	0.62 10.39	11	7
EX-7	Emaireti	100	72.25	1.2 20.7	3.26	0.37 6.34	8	10

Remark : S.C. = Specific capacity

Figure A-4-1 EXPLORATORY WELL LOG OF EX-1, NAITOLIA

WELL No.	Ex-1	LOCATION	Naitolia, Monduli			SITE ALT.	1,100 masl
DEPTH	78 m	DRILL. DIA.	265 mm	CASING DIA.	150 mm	RIG TYPE	Mud drill
S. W. L.	65 mbgs	Y I E L D	— l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	52-72 = 20 m		m-m	D A T E	oct. 1995

Depth (m)	Thick (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity
4.0			Top Soil		
10.0			m~c. sand, drk gry		
20					
24.0			volcanic pebbles		
32.0			c.Sand w/clay		
38.0			w/Quartz grains volcanic pebbles		
40					
			c.sand w/limestone frag-		
			c.sand w/pebble, Q3 grai		
58.0					
60					
			64~84m mud loss		
			sample not collected		
80					
82			weathered granite		
84			Granite		

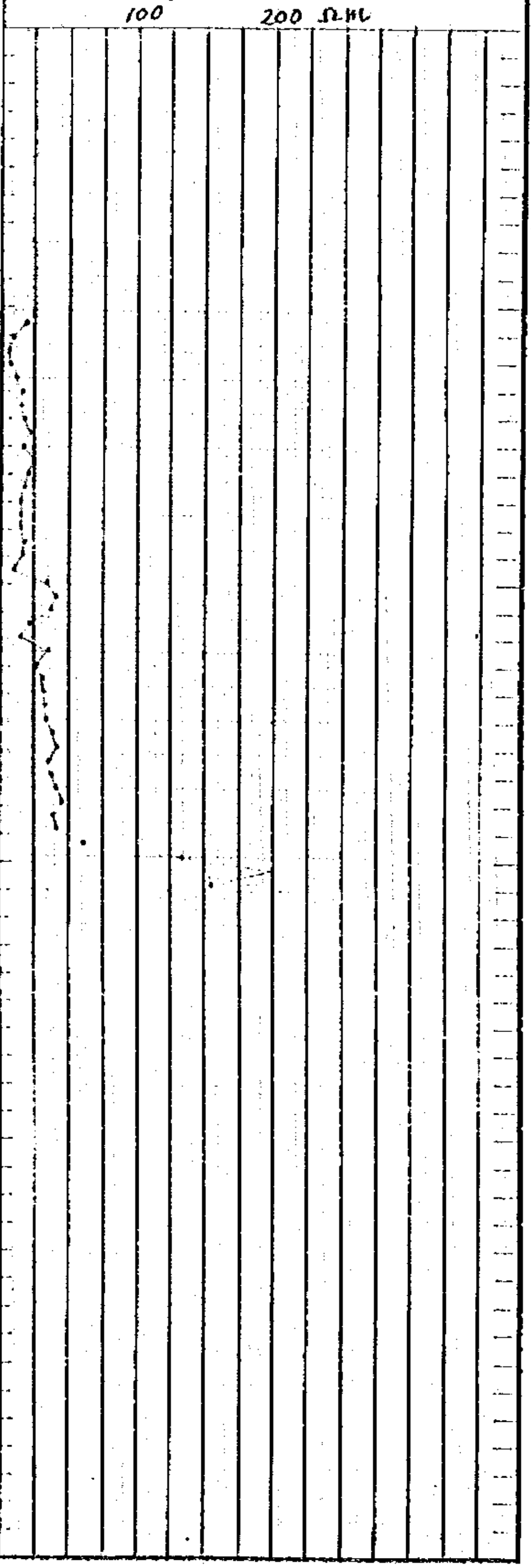
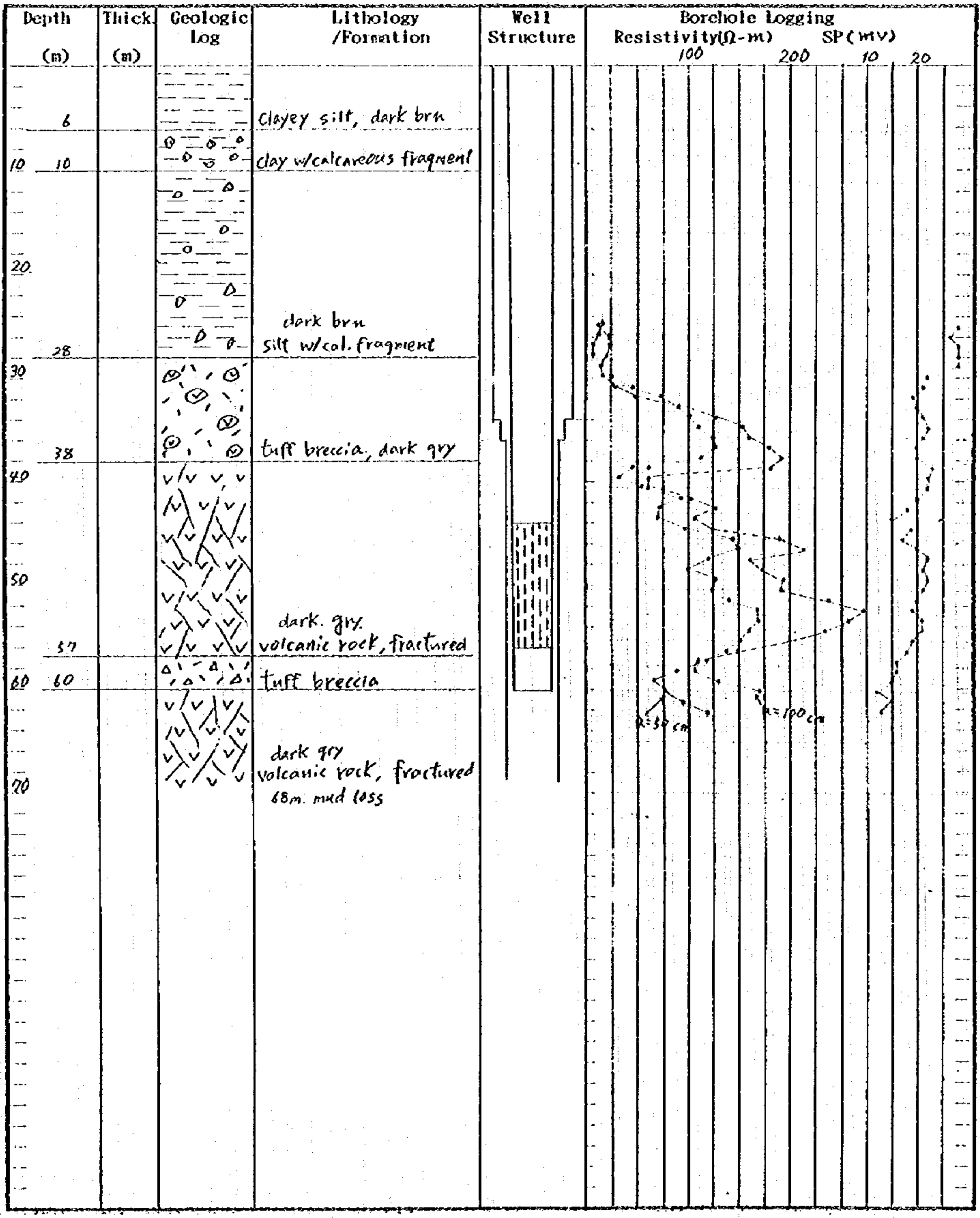


Figure A-4-2 EXPLORATORY WELL LOG OF EX-2, MBUYUNI

WELL No.	EX-2	LOCATION	Mbuyuni, Monduli			SITE ALT.	1,270 masl
DEPTH	70 m	DRILL. DIA	206~281~215 mm	CASING DIA	150 mm	RIG TYPE	Mud drill
S. W. L.	57 mbgs	YIELD	Dry l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	44 ~ 56 m = 12 m		m-m	DATE	Mar., 1995

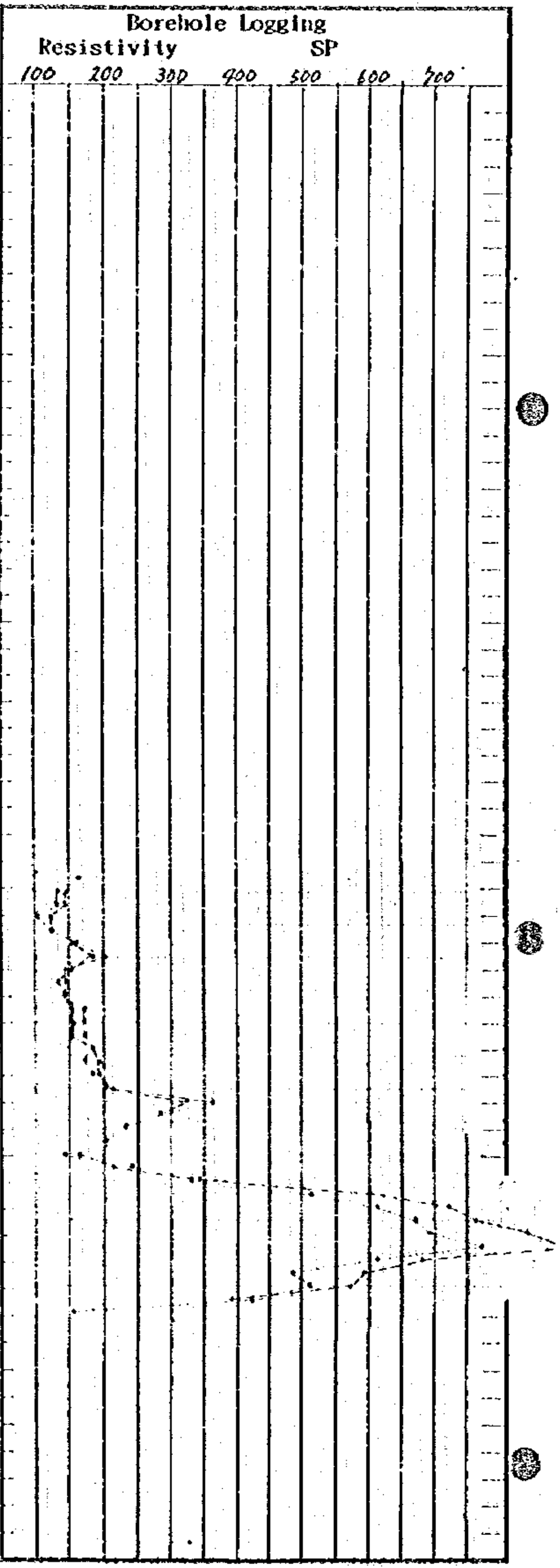


Depth (m)	Thick (m)	Lithology /Formation
6		clayey silt, dark brn
10		clay w/calcareous fragment
28		dark brn silt w/cal. fragment
38		tuff breccia, dark gry
57		dark. gry. volcanic rock, fractured
60		tuff breccia
		dark gry volcanic rock, fractured 68m. mud loss

Figure A-4-3 EXPLORATORY WELL LOG OF EX-3, TUKUSI

WELL No.	EX-3	LOCATION	Tukusi, Monduli			SITE ALT.	1,100 masl
DEPTH	79 m	DRILL. DIA	265 mm	CASING DIA	150 mm	RIG TYPE	Air drill
S. W. L.	54 mbgs	Y I E L D	— l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	m-m			D A T E	Mar., 1995

Depth (m)	Thick (m)	Geologic Log	Lithology /Formation	Well Structure
6			m.sand, brn	
12			Quartz grains sand & gravel, drk brn	
20 22			m~c sand w/ pebble	
38			dark gry c.sand w/gravel	
40 60 60			m~c. sand, brn	
80 80			heavily weathered gneiss	
84			weathered gneiss	
100			fractured basic rock clayey sand	



Figuro A-4-4 EXPLORATORY WELL LOG OF EX-4, NGARASI

WELL No.	EX-4	LOCATION	Ngarash, Monduli			SITE ALT.	1,390 masl
DEPTH	144 m	DRILL. DIA.	265 mm	CASING DIA.	FRP 150 mm	RIG TYPE	Mud drill
S.W.L.	129 mbgs	Y I E L D	--- l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	FRP slot op.=12% 100~140 m-m			D A T E	Jul. 1995

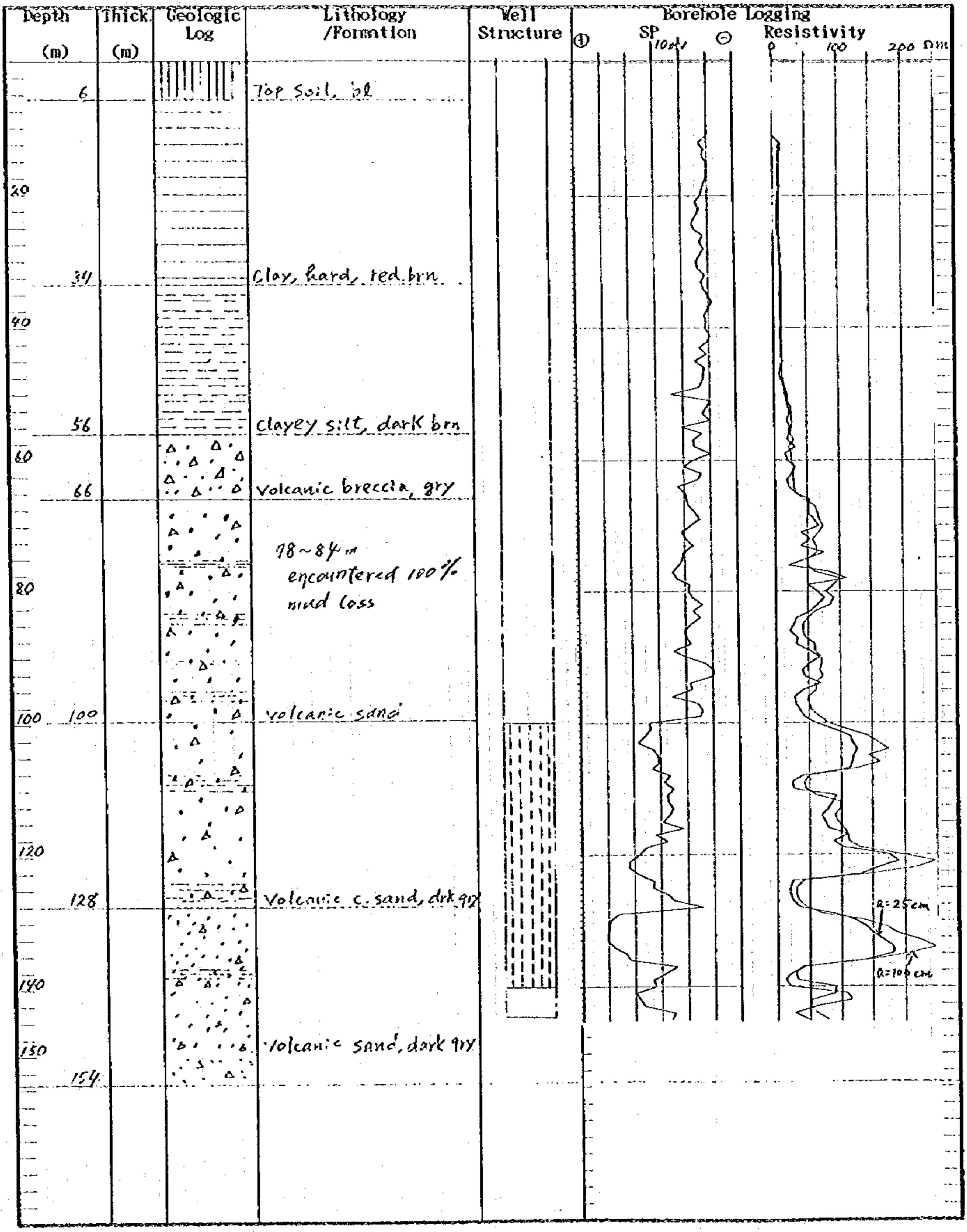
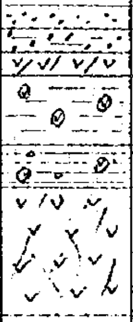


Figure A-4-5 EXPLORATORY WELL LOG OF EX-5, LASHAINE

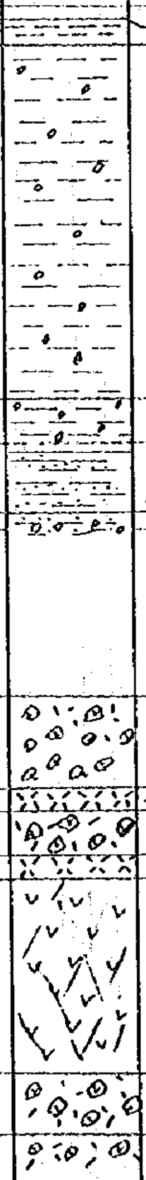
WELL No.	EX-5	LOCATION	Lashaine, Monduli Town			SITE ALT.	1,375 masl
DEPTH	192 m	DRILL. DIA	mm	CASING DIA.	not cased mm	RIG TYPE	Air drill
S.W.L.	mbgs	Y I E L D	dry l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN			m-m	D A T E	oct., 1995



Depth (m)	Thick (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity SP
4			f. sand		
10			c. sand w/clay		
16			vol. rock fractured, gry		
30			silt w/f. breccia, brn		
38			clay w/vol. fragment		
50					
67			vol rock, gry		
			→67m pressure gas. from cavern rock		
100			67 to 192m. cuttings not obtained due to cavern pyroclastic rocks		
150					
192					

Figure A-4-6 EXPLORATORY WELL LOG OF EX-6, LENDIKINYA

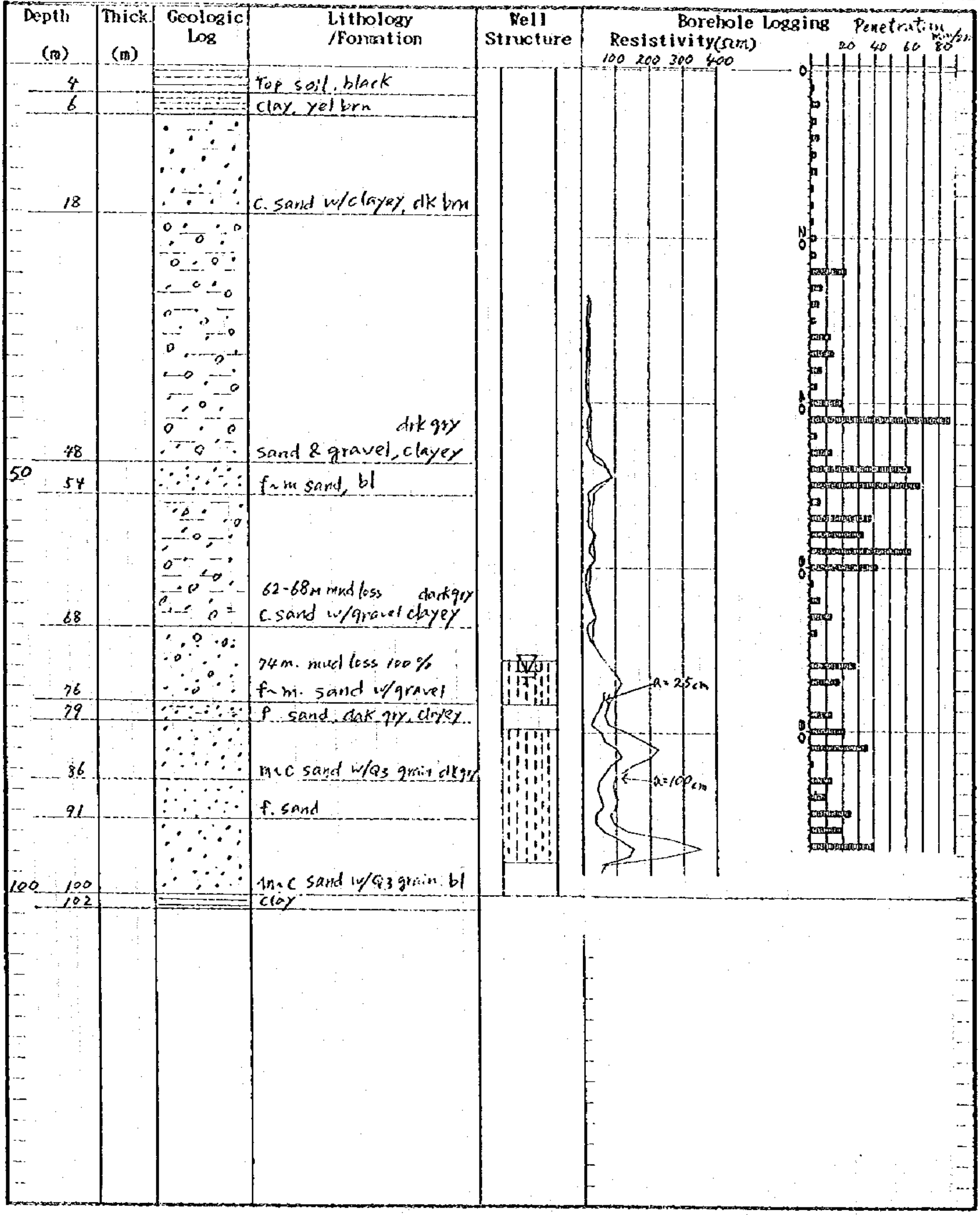
WELL No.	EX-6	LOCATION	Lendikinya, Monduli			SITE ALT.	1,340 masl
DEPTH	250 m	DRILL. DIA.	200 mm	CASING DIA.	not cased mm	RIG TYPE	Mud/Air drill
S. W. L.	mbgs	Y I E L D	dry l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN			m-m	D A T E	sep.-oct. 1995



Depth (m)	Thick. (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity SP
2			top soil		
8			loam, brn		
50					
86			reddish brn loamy silt. w/little pebble		
94			loam, w/pebble, brn		
100					
104			clay ~ v.f. sand	air drill ↓	
112			vol.ash w/c.s. gravel		
150 150			128m. air lakage 138m caving No samples cement seal 102-129m	mud drill	
170			tuff breccia	↓ Air drill	
175			tuff ~ tuff. s.s		
185			tuff breccia		
190			tuff ~ tuffac. s.s		
200					
232			fractured vol. rock		
248			tuff breccia		
250					

Figure A-4-7 EXPLORATORY WELL LOG OF EX-7, EMAIRETE

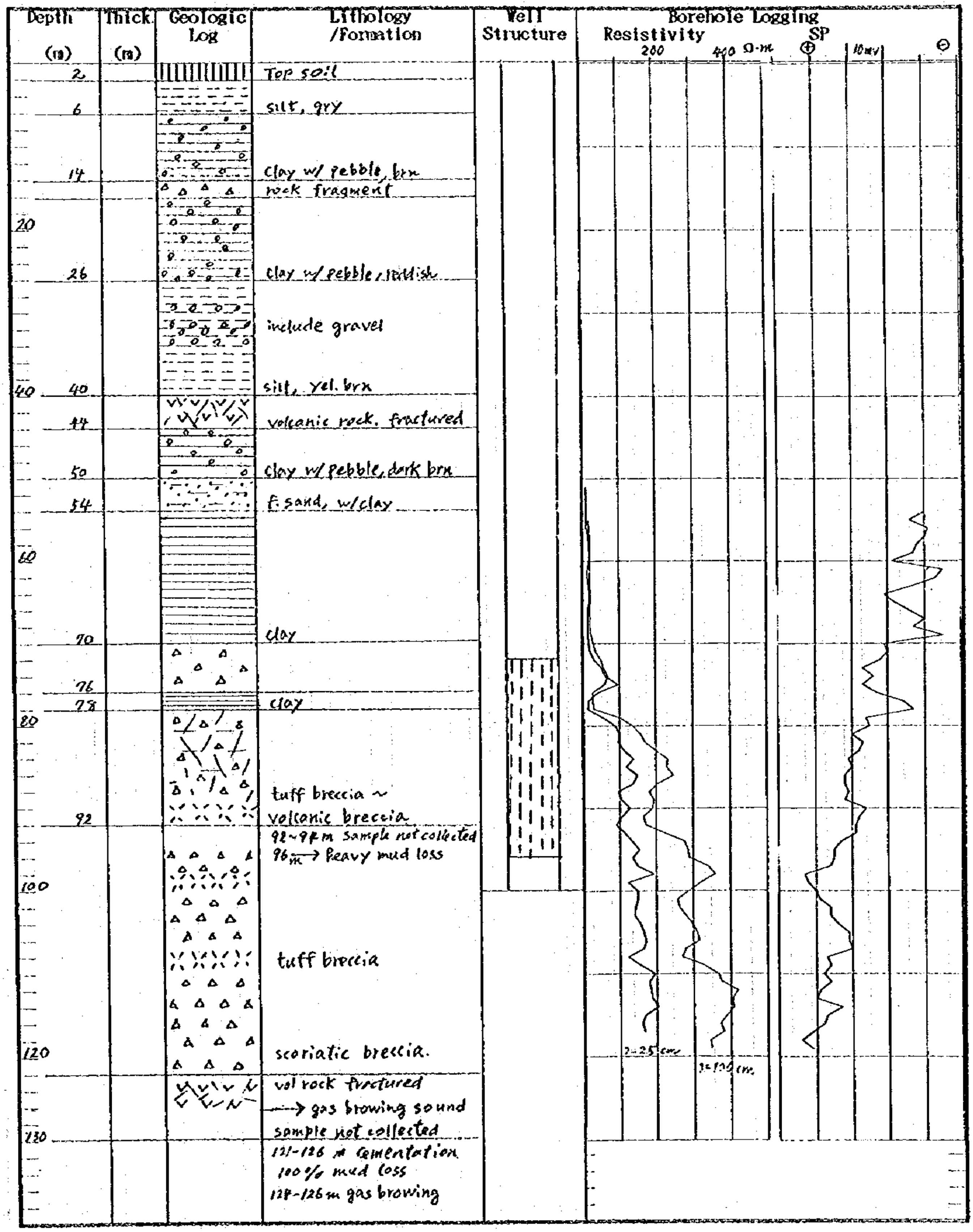
WELL No.	EX-7	LOCATION	Emairete, Monduli			SITE ALT.	1,800 msl
DEPTH	102 m	DRILL DIA.	265 mm	CASING DIA.	150 mm	RIG TYPE	Mud drill
S.W.L.	72.25 mbgs	YIELD	0.34 l/s	DRAWDOWN	3.26 m	SPEC. CAP.	0.106 l/s/m
TRANS.	8 sqm/d	SCREEN	72~76, 80~96 Total 20m m-m			DATE	Sep., 1995



Depth (m)	Thick. (m)	Lithology /Formation
4		Top soil, black
6		clay, yel brn
18		c. sand w/clayey, dk brn
48		drk gry sand & gravel, clayey
54		f~m sand, bl
68		62-68m mud loss dark gry c. sand w/gravel clayey
76		74m. mud loss 100% f~m. sand w/gravel
79		f. sand, dak gry, clyey
86		m~c sand w/Q3 grain dkgry
91		f. sand
100		m~c sand w/Q3 grain. bl
102		clay

Figure A-4-8 EXPLORATORY WELL LOG OF EX-8, SINON

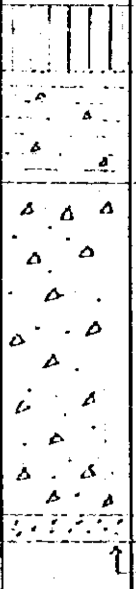
WELL No.	EX-8	LOCATION	Sinon, Monduli Town			SITE ALT.	1,420 msl
DEPTH	130 m	DRILL. DIA.	mm	CASING DIA.	150 mm	RIG TYPE	64 HB Mud drill
S. W. L.	mbgs	Y I E L D	Dry l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	72 ~ 96 m = 24 m		m-m	D A T E	Sep., 1995



Depth (m)	Thick. (m)	Lithology /Formation
2		Top soil
6		silt, gry
14		clay w/ pebble, brn
		rock fragment
26		clay w/ pebble, reddish
		include gravel
40		silt, yel. brn
44		volcanic rock, fractured
50		clay w/ pebble, dark brn
54		f. sand, w/clay
70		clay
76		
78		clay
92		tuff breccia ~ volcanic breccia
		92~94m sample not collected 96m → heavy mud loss
		tuff breccia
		scoriatic breccia.
		vol rock fractured → gas browing sound sample not collected
130		121-126 m cementation 100% mud loss 124-126m gas browing

Figure A-4-9 EXPLORATORY WELL LOG OF EX-9, ARKATAN-WEST

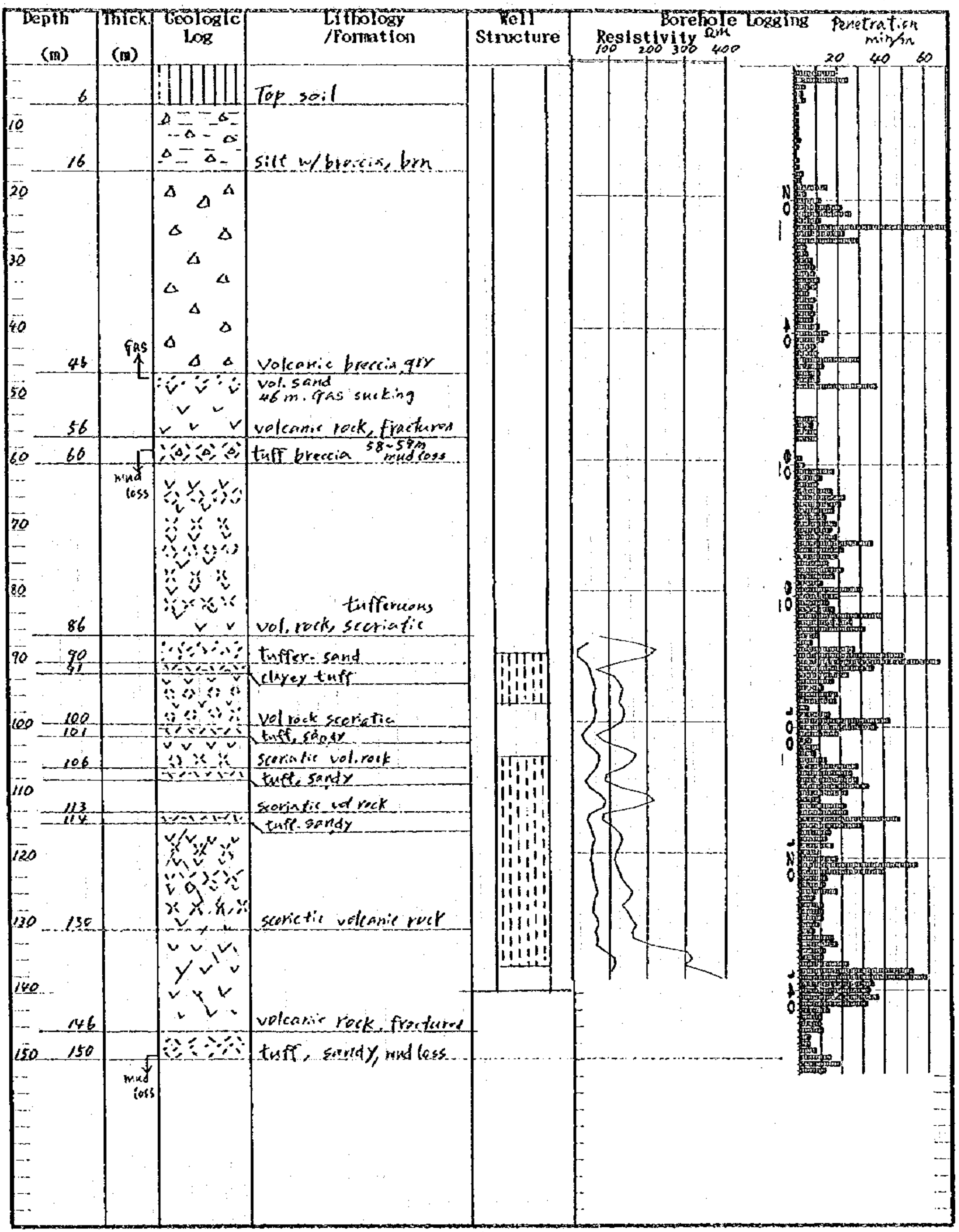
WELL No.	EX-9	LOCATION	Arkatan-West, Monduli			SITE ALT.	1,400 msl
DEPTH	48 m	DRILL. DIA.	mm	CASING DIA.	None mm	RIG TYPE	Air drill
S. W. L.	mbgs	Y I E L D	Dry l/s	DRAWDOWN	m	SPEC. CAP.	- l/s/m
TRANS.	sqm/d	SCREEN	m-m			D A T E	Jul 17,'95



Depth (m)	Thick (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity SP
6			Top soil		
10					
16			silt w/ vol breccia brn		
20					
30					
40					
46			volcanic breccia gry		
48			volcanic sand dark gry		
50		↑	Pressure Gas		

Figure A-4-10 EXPLORATORY WELL LOG OF EX-10, ARKATAN-EAST

WELL No.	EX-10	LOCATION	Arkatan east, Monduli			SITE ALT.	1,275 msl
DEPTH	151.5 m	DRILL. DIA.	265 mm	CASING DIA.	150 mm	RIG TYPE	Air drill
S.W.L.	mbgs	YIELD	Dry l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	88~96, 104~136 m-m			DATE	Jul., 1995



Depth (m)	Lithology /Formation
6	Top soil
16	silt w/breccia, brn
46	Volcanic breccia gry
	vol. sand 46 m. GAS sucking
56	volcanic rock, fractured
60 / 60	tuff breccia 58~59m mud loss
86	tufferuous vol. rock, scoriatic
90 / 90	tuffer. sand
91	clayey tuff
100 / 100	vol rock scoriatic
101	tuff, sandy
106	scoriatic vol. rock
	tuff, sandy
113	scoriatic vol rock
114	tuff. sandy
130 / 130	scorictic volcanic rock
146	volcanic rock, fractured
150 / 150	tuff, sandy, mud loss

Figure A-4-11 EXPLORATORY WELL LOG OF EX-11, TAROSERO

WELL No.	EX-11	LOCATION	Tarosero, Monduli Town			SITE ALT.	1,540 masl
DEPTH	m	DRILL. DIA.	200 mm	CASING DIA.	mm	RIG TYPE	Air drill
S. W. L.	mbgs	Y I E L D	l/s	DRAWDOWN	m	SPEC. CAP.	l/s/m
TRANS.	sqm/d	SCREEN	m-m			D A T E	

Depth (m)	Thick. (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity	SP
2			TOP SOIL			
40			clay, compact, brn gry			
50 48			pebble~cobbles w/clay			
52			c. gravels, Agg-tic			
90			Agglomeratic tuff breccia,			
100 100			tuff breccia, gry			
108			volcanic rock, gry			
122			Agglomeratic tuff breccia			
			volcanic rock			
150	gas		blowing pressure gas 155m			
200						

A - 5 WATER QUALITY ANALYSIS

A-5-1 Objectives of Water Quality Analysis

Water quality analyses were carried out for the Study Area by means of an in-situ test and a laboratory analysis. Analyses were done following objectives:

- to interpret hydrochemical evolution of groundwater, and
- to evaluate surface and groundwater sources for water supply planning.

The in-situ test is composed of following parameters:

- electrical conductance,
- pH,
- water temperature, and
- bacteriological examination.

The physical and chemical parameters of laboratory test includes the following:

- Color, Turbidity, Taste, Odor, Bacteria, pH, EC, TDS, NO_2, NO_3, Cl, Fe, Mn, NH_3, $CaCO_3$, Cu, Cr_6, Ca, Mg, SO4, Na, HCO_3, K, Ps, F

Sampling sites are located in Figure A-2-1 in Location Map of Hydrogeological Study.

A-5-2 In-situ Test

The tests were conducted for water samples from lake, reservoir, spring, dug pit and boreholes. Tested results is tabulated in Table A-5-1.

(1) Electrical Conductance

Electrical conductance ranges from 75 to 8,750 μ S/cm and the highest one was taken from Lake Manyara and the lowest was from a spring at the northern slope of Monduli Mountain. The groundwater samples from Lake Manyara Beds which are from boreholes in Mswakini and Makuyuni, indicate 1,406 and 1,032 μ S/cm respectively. From this, it may be inferred that Lake Manyara was subjected to heavy evaporation conditions in it's expanding time.

Electrical conductance of surface rivers and reservoirs range from 119 to 669 μ S/cm with an average of 410 μ S/cm and it is represented by rainfall in the proceeding days. A sample of surface river in Oltukai shows 423 μ S/cm nevertheless it flows in the depositional area of the Lake Manyara Beds. Spring sources in the northern volcanic mountains show low electrical conductance ranging from 75 to 802 μ S/cm with an average of 260 μ S/cm.

(2) pH

The value of pH indicates rather high in the Study Area ranging from 7.4 to 10. The samples from reservoirs and surface rivers show higher value which ranges from 7.8 to 9.1 with an average of 8.5. The samples from springs show rather low ranging from 7.4 to 8.5 with 7.9 in an average. It shows almost same as pH from boreholes.

A-5-3 Laboratory Test

(1) General

The laboratory test was conducted for water samples from lake, reservoir, spring and borehole. These samples were analyzed by Hach Test Kit Spectrophotometer DR 2000, digital titrator and in some instances drop pipette. The results is tabulated in Table A-5-2.

Water samples are initially assessed for the drinking purpose based on a maximum permissible level of WHO Drinking Standard (see Table A-5-3, WHO Standards). Some of the more important physical and chemical drinking water quality criteria are given in Table A-5-4, Physical and Chemical Drinking Water Standard.

Results of the laboratory test are plotted on Trilinear Diagram (Piper Diagram), Pattern Diagram (Stiff Diagram) and Wilcox Diagram (see Figure A-5-1, A-5-2, and Volume 3, Data and Drawing). In Table A-5-5 is presented water quality type and, geology and aquifer of sampling sites.

(2) Water Quality Assessment for Drinking Purpose

Briefly discussed below are the results of assessment based on WHO drinking standard.

a) pH

Tested result less than or more than the standard was recorded a sample from Lake Manyara of 10.34.

b) Turbidity

High turbidity values were mostly recorded from surface rivers, reservoirs and lake. Samples from the Lashaine reservoir, the Makuyuni River and Manyara Lake show extremely high values of turbidity, however these values except for the Lake are highly variable in an intensity of rainfall. The most of springs and boreholes sources meet on the standard.

c) Colour

High level of colour were recorded from the same samples which exceeded turbidity. A sample of the Makuyuni River has a maximum values of 98,000 NTU and minimum value was recorded zero NTU in the Mto wa Mbu River. Samples from boreholes except EX-3 and Burko BH-14, are within the limitation of standard.

d) Total Solid

Only one sample from Lake Manyara exceed the standard.

e) Hardness

The collected samples were recorded within the value of the standard.

f) Calcium, Magnesium

The collected samples were recorded within the value of the standard.

g) Iron

Three samples from reservoirs, Nanja, Lendikinya and Mbuyuni, and one sample from Lake Manyara exceed the limitation. Samples from dug wells, Monduli

Juu and Oltukai, also exceed the limitation. The highest value is recorded in Oltukai dug pit that is 6.0 mg/ ℓ .

h) Nitrate

Four samples have a high concentration of nitrate. These are Lake Manyara with 364, Nanja Swamp with 299, Lashaine reservoir with 275 and the Makuyuni River with 114 mg/ ℓ .

i) Chloride, Sulphate

A concentration of chloride and sulphate in the Lake Manyara was recorded at 2,500 and 1,200 mg/ ℓ respectively and a sample from Lashaine Reservoir is slightly exceeded in Sulphate.

j) Fluoride

Three samples were recorded more than the standard. These are the Lake Manyara with 36.45, Moita Kirolete Reservoir with 14.12 mg/ ℓ and Mswakini borehole with 9.54 mg/ ℓ . Since high concentration of fluoride is a qualitative problem of drinking water supply in Arusha region, it may be caused groundwater in the Manyara Lake deposits.

(3) Hydrochemical Interpretation

Hydrochemistry has greatly contributed to the understanding of groundwater flow. In an interpretation of the water quality data, analyses must correlated with one another and related information. As the surface flow begins from shallow to deeper artesian groundwater, the water quality is altered by three modification:dissolution reduction, base exchange, and concentration. These changing processes of water quality is called the "hydrochemical evolution of groundwater".

Groundwater flow may be traced chemically in highly different scale ranging from a distance of a few meters to several hundred kilometers. Regardless of scale, chemistry is always a detective tool of research.

Generally speaking the subsurface water regardless of the material through which it moves,starts out as a bicarbonate water deposited by precipitation and changes through a sequence of bicarbonate plus chloride to chloride plus bicarbonate to chlorite plus sulphate or sulphate plus chloride finally to a predominantly chloride water approaching the composition of the seawater.

As groundwater flows down in aquifer over a long distance, so increase the ratio of HCO_3 to the total anion and Na^+K to the total cation due to an acceleration of dissolution and base exchange. Therefore, it is easy to understand the hydrochemical evolution of each samples when they are plotted on a graph of relation between two ratio.

The Piper Diagram is a useful representation to indicate differences or similarities among water, i.e., classification of water in terms of elapsed time after it has been recharged by the surface water system.The Diagram can be divided into following five hydrochemical area:

1)Carbonate hardness
2)Carbonate alkali
3)Non-carbonate hardness
4)Non-carbonate alkali
5)Intermediate

The carbonate alkali zone is generally represented by water quality of surface river and shallow groundwater and the carbonate alkali zone is represented by it of deep groundwater.

In general, the hydrochemical evolution of groundwater is directed from 1) to 2), except for salt-contained and mineralized groundwater.

Following interpretation may be worked out based on graphical plotting in Figure A-5-1, A-5-2 and A-5-3.

Groupe 1: Area of the carbonate hardness.
<Surface river, Spring and Reservoir>
Lolkisale Spring, Tukusi Spring, Kiliman Spring, Lossimingor Spring, Mto Wa Mbu River, Kirurumo River and Ingulpani River.

<Borehole>

Mswakini 10/29, Tukusi EX-3, Makuyuni 23/68 and Monduli Juu EX-7.

Groupe 2: Area of the carbonate hardness, but close to th car bonate alkali zone.

<Surface river, Spring and Reservoir>

Monduli Juu Spring, Mbuyuni Dam, Lendikinya Dam, Meserani Bwawani, Lepurko Dam, Enguik Spring and Oltukai Dug well.

<Borehole>

Selian BH and Burka BH-14.

Groupe 3: Area of the carbonate alkali zone.

<Surface river, Spring and Reservoir>

Meru Spring(Emaoi Spring), Makuyuni River and Moita Kiloreti Dam.

<Borehole>

Makuyuni 10/52 and Burko BH-2.

Groupe 4: Area of the noncarbonate alkali zone.

<Surface river and Reservoir>

Nanja Swamp and Lashaine Dam.

Table A-5-1 RESULTS OF IN-SITU WATER QUALITY TEST

No.	Location		Altitude	Type of	Date	EC	pH	Temp	Bacteria	Coliform	Color	Turbid'y
	Village	Log./Lat.	(mamsl)	Sources		(μS/cm)		(℃)				
1	Lake Manyara	3° 38.714' 35° 52.285'	985	Lake	Dec.22,94	8,750	10.0	28.4	3	-	+	++
2	Arkatan Ardai Dam	3° 21.760' 36° 24.054'	1,315	Reservoir	Jan.17,95	558	8.8	30.9	-	-	+++	+++
3	Emairete Monduli Juu	3° 14.066' 36° 22.921'	1,780	Reservoir	Feb.16,95	274	8.1	24.2	5	5	+++	+++
4	Lepurko	3° 20.146' 36° 13.369'	1,520	Reservoir	Dec.15,94	311	8.2	26.5	-	+++	+	+++
5	Monita Bwawani	3° 33.470' 36° 35.829'	1,170	Reservoir	Dec.26,94	347	8.7	29.2	30+	20	+	++
6	Monita Kileriti	3° 28.736' 36° 32.014'	1,290	Reservoir	Dec.26,94	426	8.8	25.8	20+	0	+	++
7	Naitolia	3° 36.210' 36° 04.981'	1,100	Reservoir	Dec.14,94	150	8.7	28.7	0	0	+++	+++
8	Essimingor	3° 25.320' 36° 10.722'	1,325	Surface river	Dec.15,94	669	8.7	28.8	10	20+	+	++
9	Mbuyuni	3° 28.179' 36° 12.774'	1,320	Surface river	Dec.13,94	381	8.3	30.0	0	0	+	++
10	Meserani Bwawani	3° 29.425' 36° 26.541'	1,240	Surface river	Dec.23,94	559	9.1	30.7	+++	+++	++	++
11	Oltukai	3° 37.853' 35° 55.581'	1,020	Surface river	Dec.14,94	423	7.8	29.1	-	-	-	+++
12	Ardai River	3° 25.345' 35° 25.791'	1,440	Surface river	Mar.14,95	119	8.7	20.4		+++	+++	+++
13	Makuyuni River	3° 33.532' 36° 05.538'		Surface river	Mar.14,95	291	9.0	25.2		+++	++	++
14	Kirarumo River	3° 22.117' 35° 50.427'	1,080	Surface river	Mar.14,95	344	8.8	25.5		0	clear	none
15	Moduli Urban	3° 17.148' 36° 26.926'	1,625	Tank Rasharasha	Dec.16,94	106	8.3	19.8	5	2	clear	none
16	Moduli Urban	3° 17.148' 36° 26.926'	1,625	Tank Kiliman	Dec.16,94	103	8.3	18.4	10	10+	clear	none
17	Monduli Mountains	3° 15.513' 36° 28.035'	1,950	Spring	Dec.30,94	126	8.4	17.5	11	0	clear	none
18	Emairete Monduli Juu	3° 15.085' 36° 23.432'	1,765	Spring	Dec.16,94	364	7.4	18.9	+++	++	+++	+++
19	Enguik Monduli Juu	3° 13.902' 36° 25.703'	1,905	Spring	Dec.16,94	75	7.5	21.2	-	-	clear	none
20	Essimingor	3° 24'43.85" 36° 06'05.4"	1,615	Spring	Feb.13,95	642	7.6	21.2	+++	0	clear	none
21	Mungu Crater	3° 31.351' 36° 35.108'	1,160	Spring	Dec.26,94	400	8.5	25.7	50+	20+	+	+
22	Tukusi	3° 41.066' 36° 36.237'	1,130	Spring	Dec.29,94	802	7.5	28.2	15	20+	clear	none
23	Tukusi	3° 42.237' 36° 34.682'	1,180	Spring	Dec.29,94	1,145	7.7	26.5	50+	50+	clear	none
24	Lashaine Pump Station	3° 19.324' 36° 27.027'	1,410	Pipe from Meru Spring	Feb.27,95	226	8.2	25.3	50+	0	clear	none
25	Mt. Meru TMA source	3° 18'26.4" 36° 43'27.3"	1,860	Spring	Mar.08,95	177	8.1	18.5	5	0	clear	none
26	Lolkisare	3° 22.097' 36° 50.422'	960	Spring	Mar.15,95	308	8.4	21.6	50+	30+	clear	none
27	Arkatan Nanja Swamp	3° 22.703' 36° 16.757'	1,390	Dug pit	Jan.17,95	1,892	7.7	23.1	+++	0	clear	+
28	Mswakini	3° 40.775' 36° 00.553'	1,055	Borehole 110/79	Feb.13,95	1,406	7.4	28.1	50+	0	clear	none
29	Makuyuni	3° 33.302' 36° 05.461'	1,050	Borehole 10/52	Feb.09,95	1,032	7.5	27.1	+++	+++	clear	none

Table A-5-2 RESULTS OF WATER QUALITY ANALYSES

1) Surface River, Spring & Lake

No.	Name of Village	Kind of Sources	Turb'ty (NTU)	Colour (mg/l Pt)	Odour	Taste	pH	EC (μS/cm)	TDS (mg/l)	Alkali. (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Mn (mg/l)	Cr (mg/l)	PO4 (mg/l)	Cu (mg/l)	Na (mg/l)	K (mg/l)	Hard. (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	NO2 (mg/l)	SO4 (mg/l)	Cl (mg/l)	F (mg/l)	KMnO4 (mg/l)	NH3 (mg/l)
QS-1	Kilimani	Spring	2	20	nil	good	8.00	123	62	100	8	19.52	0.34	0.10	0.04	0.48	0.21	3	1	80	100	14.08	0.10	0	5	0.45	0.30	0.00
QS-2	Losimingor	Spring	5	30	nil	good	7.80	630	345	320	64	17.08	0.15	0.60	1.78	0.04	0.23	30	4	230	320	17.16	0.17	36	15	0.72	1.73	0.02
QS-3	Monduli Juu	Spring	160	1,020	humic	poor	6.80	425	263	205	20	12.20	5.70	19.00	0.39	2.95	2.54	19	11	70	205	39.16	0.40	40	5	3.51	54.72	0.20
QS-4	Nanja	Swamp	250	1,500	organic	muddy	8.20	385	193	160	40	12.20	3.15	9.50	0.15	2.01	0.95	95	20	150	160	299.20	3.00	80	70	2.51	27.36	0.60
QS-5	Lashaine	Reservoir	12,000	97,000	organic	obj'ble	8.00	384	192	190	12	7.32	0.40	0.20	2.75	6.50	18.00	50	150	60	190	275.00	2.60	200	10	7.58	0.30	2.00
QS-6	Tukusi	Spring	3	19	nil	sl.sali.	7.70	1,374	687	730	28	100.00	0.12	0.00	0.06	0.03	0.31	64	15	480	730	5.72	0.30	52	80	2.10	0.00	0.00
QS-7	Meru	Spring	2	12	nil	good	8.10	175	89	130	2	3.66	0.10	0.00	0.02	0.16	0.12	20	5	20	130	7.48	0.06	0	3	4.32	0.00	0.00
QS-8	Makuyuni	River	14,000	98,000	nil	obj'ble	8.90	294	147	100	8	19.52	0.34	0.10	1.00	1.46	1.21	37	46	60	100	114.08	1.10	5	5	1.45	0.30	2.00
QS-9	Manyara	Lake	12,000	97,000	organic	saline	10.34	12,400	6,200	11,000	80	63.44	2.34	5.10	1.04	0.68	0.34	130	70	460	8,000	364.08	3.64	1200	2500	35.45	14.67	3.52
QS-10	Kirurumo	River	12	50	nil	good	8.34	365	182	184	24	17.80	0.05	0.20	0.03	0.04	0.01	10	3	480	184	6.16	0.03	5	9	0.62	0.58	0.00
QS-11	Lolkisale	Spring	3	17	nil	good	8.40	308	154	70	24	9.76	0.05	0.70	0.06	0.03	0.31	13	2	100	70	7.48	0.03	22	25	0.65	2.00	0.00
QS-12	Mto Wa Mbu	River	0	0	nil	good	7.40	360	180	240	36	24.40	0.05	0.30	0.01	0.01	0.01	11	4	190	240	14.52	0.14	0	5	0.38	1.15	0.00
QS-13	Ingulupani	River	2	12	nil	good	8.20	369	189	240	36	21.96	0.00	0.00	0.01	0.01	0.00	15	7	180	240	14.52	0.14	0	5	0.63	0.00	0.00
QS-14	Tukusi	River	10	49	nil	good	8.14	991	496	430	36	63.44	0.04	0.00	0.03	0.15	0.07	22	5	350	430	5.28	0.05	28	45	1.66	0.00	0.00
QS-15	Enguik	Spring	12	63	nil	good	8.12	237	119	100	12	12.20	0.70	0.08	0.02	0.34	0.04	28	8	80	100	7.04	0.07	1	5	0.60	0.23	0.01
QS-16	Lepurko	Reservoir	67	351			7.5	425	213	190	16	2.44	0.73	1.40	0.08	0.79	0.10	16	7	50	190	14.06	0.14	13	10	6.16	4.03	0.19
QS-17	Lendikinya	Reservoir	5,475	21,500	smell	unobj.	7.53	130	65	210	12	4.90	1.34	9.60	0.43	0.74	0.15	14	4	50	210	11.00	0.10	27	5	2.29	27.65	0.42
QS-18	Emaoi, Meru	Spring	13	71	nil	good	7.63	216	108	100	4	2.44	0.01	0.10	0.04	0.43	0.08	12	2	20	100	4.83	0.50	1	3	3.63	0.30	0.00
QS-19	Mferaji	River	12	64	nil	good	8.17	136	68	60	10	6.10	0.03	0.10	0.02	0.18	0.07	32	9	50	60	7.04	0.07	0	3	0.56	0.30	0.00
QS-20	Meserani B.	Reservoir	1,060	5,800	smell	unobj.	7.78	360	180	60	16	2.44	0.65	4.15	0.44	1.35	0.08	20	8	50	60	14.52	0.15	14	5	4.17	11.95	0.40
QS-21	Mbuyuni	Reservoir	1,100	5,960	smell	unobj.	8.33	669	335	340	16	9.76	1.29	3.04	0.58	2.21	0.03	18	6	80	340	7.04	0.08	27	10	6.60	8.76	0.35
QS-22	Moita K.	Reservoir	226	1,360	smell	unobj.	8.02	642	321	300	12	4.90	0.54	5.01	0.25	1.76	0.10	34	12	80	300	11.00	0.11	12	10	14.12	14.43	0.10
QS-23	Oltukai	Dug well	79	444	nil	good	6.95	1,103	560	750	24	0.85	6.00	0.03	1.27	1.27	1.50	180	24	430	750	8.60	0.05	19	5	1.20	17.28	0.08

Note-QS-1 to QS-13 tested on March, 1995 and QS-14 to QS-23 atested on Aug. to Oct., 1995.

2) Borehole

No.	No. of Borehole	Location	Turbidity (NTU)	Colour (mg/l Pt)	Odour	Taste	pH	EC (μS/cm)	TDS (mg/l)	Alkali. (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Mn (mg/l)	Cr (mg/l)	PO4 (mg/l)	Cu (mg/l)	Na (mg/l)	K (mg/l)	Hard. (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	NO2 (mg/l)	SO4 (mg/l)	Cl (mg/l)	F (mg/l)	KMnO4 (mg/l)	NH3 (mg/l)
QB-1	110/29	Mawakini	3	18	nil	sl.sali.	7.09	1,400	700	620	60	70.76	0.11	0.30	0.04	0.69	0.16	70	13	440	620	6.60	0.07	120	5	9.54	0.86	0.00
QB-2	10/52	Makuyuni	4	24	nil	good	7.09	813	407	450	20	21.96	0.04	0.20	0.55	0.02	0.14	71	12	140	450	12.32	0.12	1	15	1.99	0.58	0.03
QB-3	EX-3	Tukusi	32	438	nil	good	8.83	796	398	410	40	73.20	0.08	0.30	0.04	0.11	0.46	60	12	400	410	6.16	0.60	34	30	2.20	0.66	0.00
QB-4	23/68	Makuyuni	15	77	nil	good	6.85	864	432	500	16	31.72	0.02	0.10	0.03	0.30	0.10	31	3	170	500	4.84	0.05	0	6	1.31	0.30	0.00
QB-5	EX-7	Emairete	12	59	nil	good	7.61	491	246	240	24	43.90	0.04	0.00	0.04	0.36	0.08	13	11	160	240	5.28	0.05	0	5	1.90	0.00	0.00
QB-6	Burko BH-2	Buka Est.	5	30	nil	good	7.67	705	360	50	6	3.66	0.44	0.10	0.03	0.44	0.10	20	7	30	50	4.84	0.05	18	10	6.30	0.30	0.00
QB-7	Selian BH	Selian	3	21	nil	good	8.54	987	494	210	22	8.54	0.04	0.00	0.02	0.24	0.06	21	4	90	210	10.56	0.12	27	15	4.57	0.00	0.01
QB-8	Burko BH-14	Buka Est.	16	86	nil	good	7.22	1,262	631	510	20	4.69	0.01	0.10	0.03	0.36	0.15	23	2	70	510	10.20	0.11	110	35	5.30	0.30	0.01
WHO Drinking Standard			25	50			6.5-9.2		1,500		200	150.00	1.00	0.50			1.50			500				150	600	8.00		

Note: QB-1 to QB-3 tested on March, 1995 and QB-4 to QB-8 atested on Aug. to Oct., 1995.
WHO Standard is limitation of maximum permissibl level

Table A-5-3 WHO DRINKING STANDARDS

Substance or Characteristics	Undesirable effect that may be produced	Highest desirable level	Maximum permissible level
Total solids	Objectionable taste	500 mg/ ℓ	1,500 mg/ ℓ
Colour	Discoloration	5 units	50 units
Suspended matter	Turbidity	5 units	25 units
Substances causing taste	Objectionable taste	Unobjectionable	Unobjectionable
Iron(Fe)	Taste, discoloration, turbidity, deposits	0.1 mg/ ℓ	1.0 mg/ ℓ
Manganese(Mn)	Taste, discoloration, turbidity, deposits	0.05 mg/ ℓ	0.5 mg/ ℓ
Copper(Cu)	Taste, discoloration, corrosion	0.05 mg/ ℓ	1.5 mg/ ℓ
Calcium(Ca)	Excessive scale	75 mg/ ℓ	200 mg/ ℓ
Magnesium(Mg)	Hardness, taste, gastrointernal irritation	30 mg/ ℓ	150 mg/ ℓ
Sulphate(SO_4)	Gastro-internal irritation	30 mg/ ℓ	150 mg/ ℓ
Chloride(Cl)	Taste, corrosion	200 mg/ ℓ	600 mg/ ℓ
pH	Taste, corrosion	7 to 8.5	6.5 to 9.2
Total hardness (Ca CO_2)	Objectionable taste	100 mg/ ℓ	500 mg/ ℓ
Mineral oil	Taste and Odour after chlorination	0.01 mg/ ℓ	0.3 mg/ ℓ

Table A-5-4 PHYSICAL AND CHEMICAL DRINKING WATER STANDARD

Group	Parameter	Unit	Criterion
Substances which may affect palatability	Total hardness ($CaCO_3$)	mg/ℓ	< 600
	Calcium(Ca)	mg/ℓ	n.m.
	Magnesium(Mg)	mg/ℓ	n.m.
	Sulphate(SO_4)	mg/ℓ	< 600
	Chloride(Cl)	mg/ℓ	< 800
Substances which may affect palatability	Colour	mgPt/ℓ	< 50
	Turbidity	NTU	< 10
	pH		6.5 - 9.2
	Taste		n.o.
	Odour		n.o.
Substances which may affect palatability	Iron(Fe)	mg/ℓ	< 1.0
	Manganese(Mn)	mg/ℓ	< 0.5
	Copper(Cu)	mg/ℓ	< 3.0
	Zinc(Zn)	mg/ℓ	< 15.0
Substances which may affect human health	Fluoride(F)	mg/ℓ	< 8.0
	Nitrate(NO_3)	mg/ℓ	< 100
Substances which may be toxic	Lead(Pb)	mg/ℓ	< 0.10
	Cadmium(Cd)	mg/ℓ	< 0.05
	Arsenic(As)	mg/ℓ	< 0.05
	Chromium(Cr)	mg/ℓ	< 0.05
	Cyanide(CN)	mg/ℓ	< 0.20
	Silver(Ag)	mg/ℓ	n.m.

Note: n.m. = not mentioned
n.o. = not to be rejected

Table A-5-5 WATER QUALITY TYPE IN MONDULI DISTRICT

1)Surface River, Reservoir and Spring

Sample No.	Location	Type of Sources	Water Type		SAR	Geology of Drainage
			Stiff	Piper		
QS-1	Kilimani	Spring	Mg-Bc	Carb-Hard	0.13	Younger Extrusive
QS-2	Lossimingor	Spring	So-Bc	Carb-Hard	0.86	Younger Extrusive
QS-3	Monduli Juu	Spring	So-Bc	Carb-Hard	0.83	Younger Extrusive
QS-15	Enguik	Spring	So-Bc	Carb-Hard	1.36	Younger Extrusive
QS-16	Lepurko	Reservoir	So-Bc	Carb-Hard	0.98	Younger Extrusive
QS-17	Lendkinya	Reservoir	So-Bc	Carb-Hard	0.86	Younger Extrusive
QS-19	Mfereji	Spring	So-Bc	Carb-Alka	1.97	Younger Extrusive
QS-10	Kirurumo	River	Mg-Bc	Carb-Hard	0.38	Younger Extrusive
QS-12	Mto wa Mbu	River	Mg-Bc	Carb-Hard	0.35	Younger Extrusive
QS-13	Ingulupani	River	Mg-Bc	Carb-Hard	0.49	Younger Extrusive
QS-4	Nanja	Swamp	So-Ni	Nonc-Alka	3.37	Plateau Lava
QS-5	Lashaine	Reservoir	So-Ni	Nonc-Alka	2.81	Plateau Lava
QS-20	Meserani B.	Reservoir	So-Bc	Carb-Hard	1.23	Plateau Lava
QS-21	Mbuyuni	Reservoir	So-Bc	Carb-Hard	0.88	Plateau Lava
QS-22	Moita K.	Reservoir	So-Bc	Carb-Alka	2.09	Plateau Lava
QS-8	Makuyuni	River	So-Ni	Carb-Alka	1.61	Plateau Lava
QS-7	Meru	Spring	So-Bc	Carb-Alka	1.91	Meru Volcanics
QS-18	Meru	Spring	So-Bc	Carb-Alka	1.17	Meru Volcanics
QS-9	Manyara	Lake	So-Bc	Carb-Hard	2.64	Lake Dep.
QS-23	Oltukai	Dug Well	So-Bc	Carb-Hard	3.78	Lake Dep.
QS-6	Tukusi	Spring	Mg-Bc	Carb-Hard	1.27	Basement
QS-14	Tukusi	River	Mg-Bc	Carb-Hard	0.51	Basement
QS-11	Lolkisale	Spring	So-Bc	Carb-Hard	0.56	Basement

Mg-Bc = Magnesium Bicarbonate
So-Bc = Sodium Bicarbonate
So-Ni = Sodium Nirate
Ca-Bc = Calcium Bicarbonate
SAR = Sodium Adsorption Ratio

2)Borehole

Sample No.	Location	Type of Sources	Water Type		SAR	Geology of Aquifer
			Stiff	Piper		
QB-1	Mswakini	110/29	Mg-Bc	Carb-Hard	1.45	Lake Dep.
QB-4	Makuyuni	23/68	Mg-Bc	Carb-Hard	1.03	Lake Dep.
QB-2	Makuyuni	10/52	So-Bc	Carb-Alka	2.61	Lake Dep.
QB-5	Monduli Juu	EX-7	Mg-Bc	Carb-Hard	0.37	Younger Extrusive
QB-3	Tukusi	EX-3	Mg-Bc	Carb-Hard	1.30	Basement
QB-6	Burka Est.	Burko BH-2	So-Bc	Carb-Alka	1.59	Meru Volcanics
QB-7	Selian	Selian BH	Ca-Bc	Carb-Hard	0.96	Meru Volcanics
QB-8	Burka Est.	Burko BH-14	So-Bc	Carb-Hard	1.20	Meru Volcanics

Carb-Har(= Carbonate hardness
Nonc-Hard = Noncarbonate hardness
Carb-Alk(= Carbonate alkali
Nonc-Alka = Noncarbonate alkali

Figure A-5-1 TRILINEAR PLOTTING OF WATER SAMPLES OF SURFACE WATER-1

Project : ARUSHA WATER DEVELOPMENT
Organization : JICA/RDD

Label	Seq.No	Sample Identification
1	1	KILIMANI SPRING
2	2	LOSIMINGOR SPRING
3	3	MONDULI JUU SPRING
4	4	NANJA SWAMP
5	5	LASHAINE DAM
6	6	TUKUSI SPRING
7	7	MERU SPRING
8	8	MAKUYUNI RIVER
9	9	LAKE MANYARA
A	10	KIRURUMO RIVER
B	11	LOLKISALE SPRING
C	12	MTO WA MBU RIVER
D	13	INGULUPANI RIVER

SURFACE RIVER, SPRING AND RESERVOIR -1

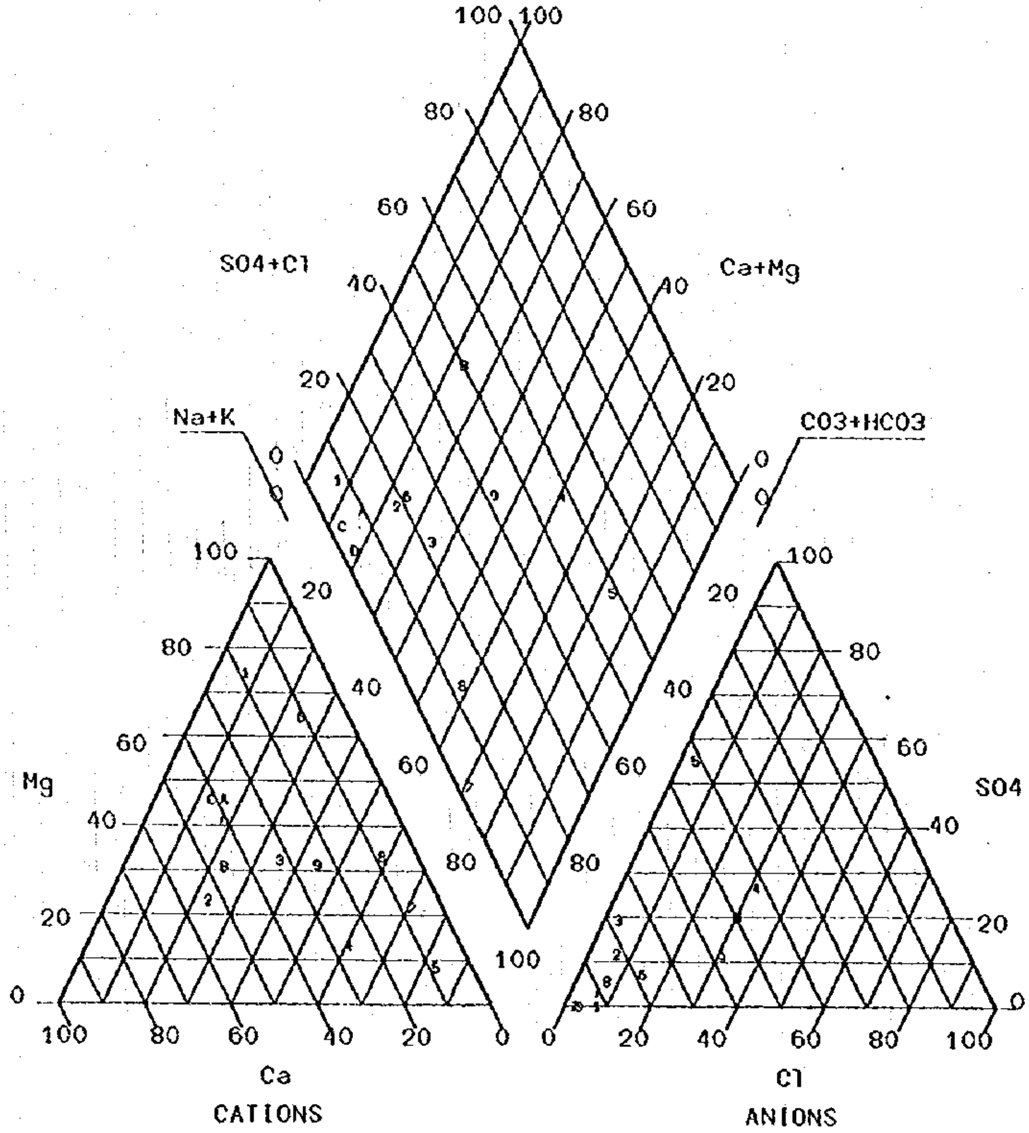


Figure A-5-2 TRILINEAR PLOTTING OF WATER SAMPLES OF SURFACE WATER-2

Project : MONDULI GROUNDWATER
Organization : JICA/RDD

Label	Seq.No	Sample Identification
1	1	TUKUSI SR
2	2	ENGUIK SPRING
3	3	LEPURKO DAM
4	4	LENDIKINYA DAM
5	5	EMAOI SPRING
6	6	MFEREJI SR
7	7	MESERANI BWAWANI
8	8	MBUYUNI DAM
9	9	MOITA KILORITI DAM
A	10	OLTUKAI DUG WELL

SURFACE RIVER, SPRING AND RESERVOIR -2

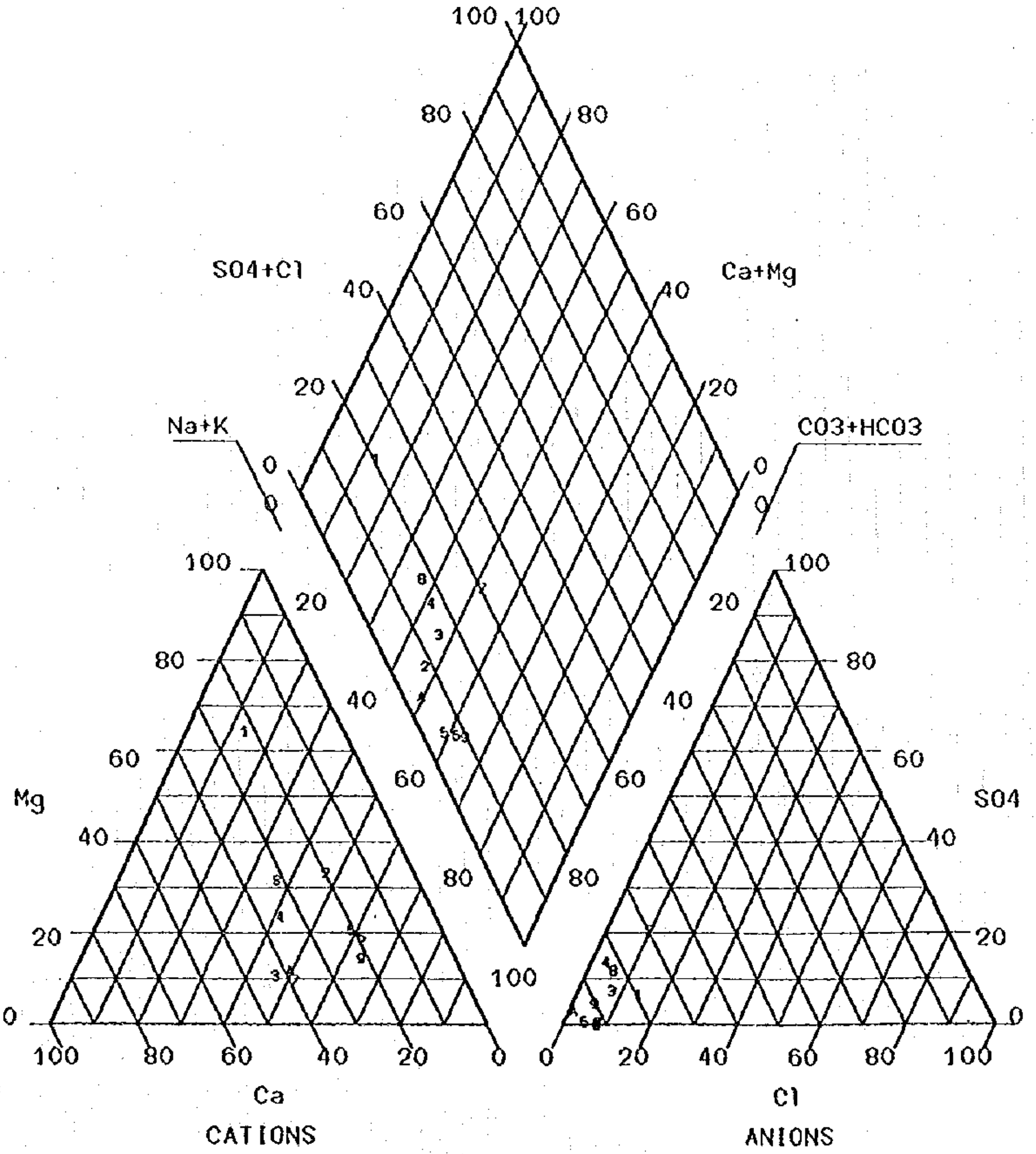
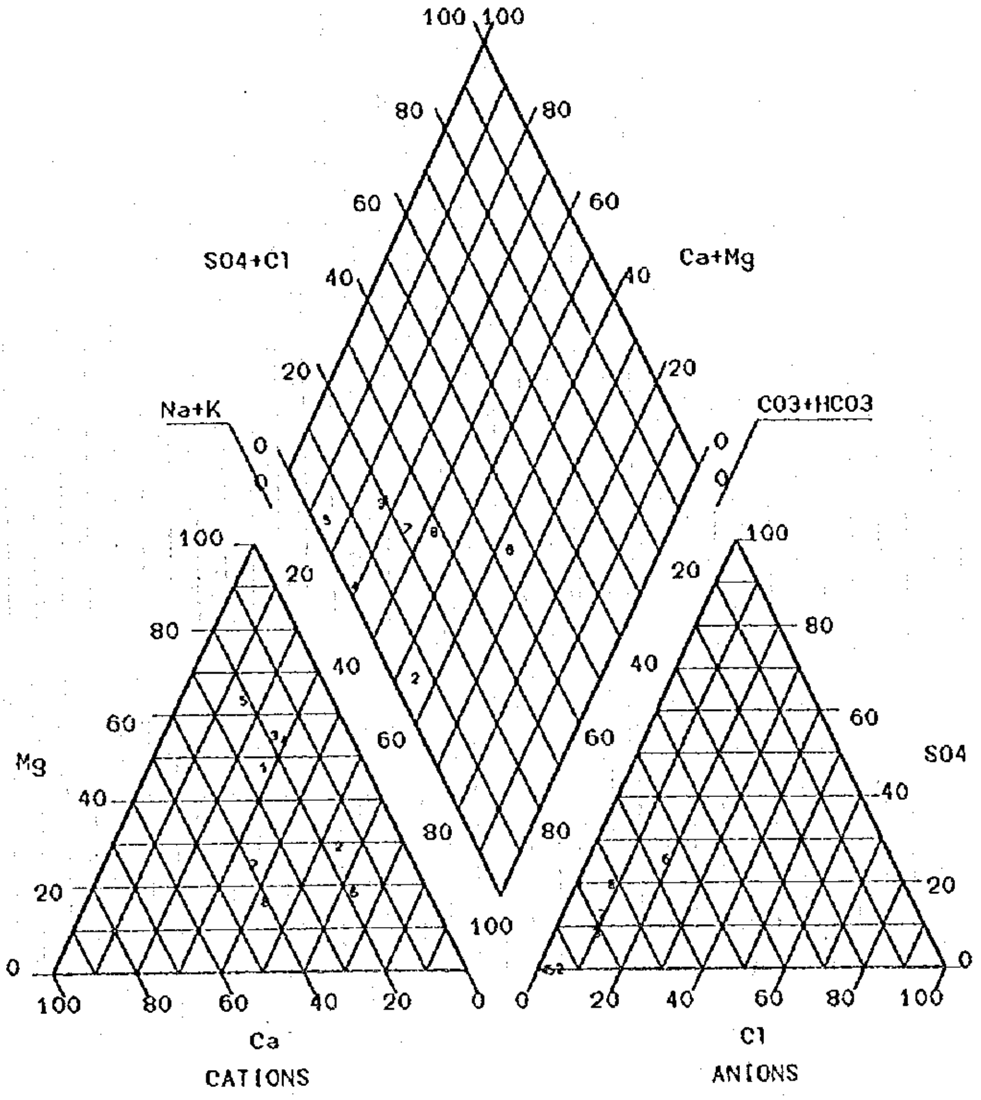


Figure A-5-3 TRILINEAR PLOTTING OF WATER SAMPLES OF BOREHOLES

Project : ARUSHA WATER DEVELOPMENT
Organization : JICA/RDD

Label	Seq.No	Sample Identification
1	1	MSWAKINI BH 110/29
2	2	MAKUYUNI BH 10/52
3	3	EX-3 TUKUSI
4	4	MAKIYUNI BH23/68
5	5	EMAIRETE EX-7
6	6	BURKO BH-2
7	7	SELIAN BH
8	8	BURKA BH-14

MONDULI BOREHOLE
Project : ARUSHA WATER DEVELOPMENT
Organization : JICA/RDD



MONDULI BOREHOLE

A - 6 GROUNDWATER RESOURCES EVALUATION

A-6-1 General

The size and extent of the aquifer systems vary in hydrogeological units as stated in previous chapter. Although well yield is most practical way for groundwater resources evaluation, but it is remarkably variable due to inadequate well completion techniques, e.g. inadequate well development procedure and mismatching screen section. On the other hand, to provide maximum development of groundwater resources for beneficial use requires thinking in terms of an entire groundwater basin. In order to maintain the resource indefinitely, a hydrologic equilibrium must exist between all waters entering and leaving the basin. Groundwater budget study is one of evaluation method to keep sustainable resource development.

Well yield for respective hydrogeological units and basin-wide groundwater potential are evaluated by data of exploratory wells drilled by RDD and JICA Study Team, and the climatologic water budget.

Distribution of respective hydrogeological units shows in Figure A-1-1, Hydrogeological Map of the Study Area.

A-6-2 Evaluation of Aquifer Potential

Groundwater potential is initially evaluated by existing well data of RDD. These data are summarized in Table A-2-1, Successful borehole in the Monduli District. Well yield for respective hydrogeological units is shown in Table A-6-1.

(1) Lake Manyara Beds

As is shown in the table, well yield of the Lake Manyara Beds ranges from 37 to 527 ℓ /min. and specific capacity of Well No. 110/79 in Mswakini is 12.3 ℓ /min./m. Calculated transmissivity in Makuyuni borehole indicates 23 m^2/day.

Screens are installed in calcareous beds on the top of the basement. Static water level deepens from 24 mbgs at Makuyuni to 51 mbgs near the Lake.

The trend described above suggests that well yield of unconsolidated aquifer of the Lake Manyara Beds shows excellent among respective hydrogeological units in the Study area.

The exploratory well EX-1 was drilled in Naitolia, the southwestern edge of the Beds, but it was dry. From this it may be inferred that the well yield in the Beds depends only its location whether it drilled near by an outlet of river which is discharging from recharge area.

(2) Colluvial Beds

A well yield in the colluvial beds in Monduli Juu was tested in the exploratory well, EX-7. Results of 24 hours pumping test reveals that well yield and maximum drawdown from static water level of 72 mbgs are 21 ℓ/min. and 3.3 m respectively. Calculated specific capacity and transmissivity are 6.4 ℓ/min./m and 8 m^2/day. Lithology of major aquifer is quartzose volcanic sand which is located from 68 to 100 mbgs and screen was installed in this bed with 20 meters total length (see Figure A-4-7 Exploratory Well Log, EX-7).

There is a possibility to increase screenable length of permeable beds when drilling depth increase up to 150 meters, according to results of resistivity prospecting in Monduli Juu.

(3) Younger Extrusive

No well records in the Younger Extrusive nearby the Study Area are available.

(4) Plateau Lava

Most of exploratory wells for water sources of Monduli Town are aimed at providing aquifers in the Plateau Lava. Exploratory well, EX-11 was drilled in an immediate foothill of the Monduli mountain slope where probably Younger Extrusive underlies, however drilling encountered pressure gas in cavern volcanic rocks at 150 mbgs. As well-known, the Plateau Lava is characterized by the presence of pressure gas in cavern lava. So the Younger Extrusive is only underlain in the mountainous terrain.

Although no record of drawdown is available from tested data of RDD wells at Tarosero in No. 2/36, static water level and well yield indicate 26 mbgs and 38 ℓ/min. respectively. The lithology of aquifers is the colluvial beds which overlies the Younger Extrusive according to the exploratory well, EX-11.

Well record of exploratory wells in the Ardai Basin reveals that the Plateau Lava consists mostly of alternating beds of basaltic lava and pyroclastic rocks with some intercalated sandy tuff. Thickness of these beds indicate more less within few meters. The lava is characterized by the presence of pressure gas in a volcanic cave where drilling have encountered heavy circulation loss.

Static water level show more than 250 mbgs at EX-6 in the middle part of Ardai Basin and it rises 122 mbgs in EX-4, the northern edge of the Basin.

The data of RDD well 7/82 in Meserani Bwawani, the south of Ardai Basin, indicate that well yield and maximum drawdown are 28 ℓ/min. and 7.3 m, and calculated specific capacity is 3.8 ℓ/min./m. A static water level shows so deep, that is 90 mbgs, by pyroclastic rocks.

Exploratory well of EX-2 in Mbuyuni, the southwestern part of Plateau Lava area reveals that drilling was not encountered saturated fractured volcanic rocks up to 60 meters depth.

There is an important subject to evaluated groundwater potential in the Ardai Basin because there are no pumping test data in it. Results of resistivity prospecting suggest that high resistivity layers which can be correlative with massive volcanic rocks, is not detected until prospecting limitation of 1,000 meters depth with some exception (see Figure A-3-32 and A-3-33, Resistivity Profile of PLMT Prospecting).

(5) The Basement

Basement aquifers are of particular importance in the southern part of the Study Area because of their widespread extent in Arusha Region. The aquifer are developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and/or metamorphic origin which are mainly of Precambrian age.

Results of borehole record by Arusha Region Water Mater Plan indicate that static water level and well yield in an average among 97 wells show 31 mbgs and 8 m^3/h respectively (ARWMP, 1994).

Exploratory well, EX-3 was drilled up to 100 meters depth in Tukusi. Obtained static water level and well yield by air-lifting are 62 mbgs and 1 ℓ/min. respectively. Static water level in RDD Exploratory Well in Naitolia shows 104 mbgs and yield obtains 18 ℓ/min., but no record of drawdown.

Above two wells were screened in weathered beds of gneiss with resistivity of 200 Ω-m by borehole logging.

A-6-3 Evaluation of Aquifer Potential in Engare Olmotoni Area near Airport

The study team of RDD led by Regional Water Engineer have been tried to investigate supplemental water sources for Monduli Town since several years ago. The survey covered Lakilaki Coffee Estate, Kisongo and Arusha Airport. Main work was comprised of hydrogeological survey and resistivity prospecting. Prior to this survey, several number of exploratory wells were drilled in the tributary of Engare River, southwestern slope of Mt. Meru. Tested well data is summarized in Table A-6-2.

The area is underlain by the Meru Volcanic Lava and it is covered by volcanic debris. Drilling log of BH 75/86 reveals that the debris has a thickness of more than 50 m (see Figure A-6-1, Exploratory Well Log of BH 75/86). The Lava is subjecting heavily weathering and fracturing where may act a part of aquifers. The Lava is interbedded with coarse volcanic sand and it also expect to the aquifers.

Table A-6-2 shows that static water levels ranges from 30 to 45 mbgs except BH 142/79, and average well yield and drawdown indicate 33 m^3/hr and 12 m respectively. Calculated maximum specific capacity and transmissivity are 15.8 m^3/hr/m and 752 m^2/day respectively. The tested data is highly variable in specific capacity and transmissivity. It is not due to location of wells site but may be of inadequate well completion techniques and mis-locating of screen interval.

A-6-4 Water Balance

(1) General

Along with the development of groundwater resources, several types of water balance studies have been created to evaluate the groundwater potential and to obtain a reasonable limit for its utilization.

As the global water balance, it must exist between the quantity of water supplied to the basin and the amount leaving the basin. The equation can give the static water balance at a certain period very easily, but not the dynamic balance:

$$\left[\begin{array}{l}\text{surface inflow + subsurface inflow + precipitation + imported water}\\ \text{+ decrease in surface storage + decrease in groundwater storage}\end{array}\right]$$

$$= \left[\begin{array}{l}\text{surface outflow + subsurface outflow + consumptive use}\\ \text{+ exported water + increase in surface storage + increase in}\\ \text{groundwater storage}\end{array}\right]$$

Inadequate data base makes any assessment of water balance for the Study Area more or less questionable, especially lack of data for change of groundwater storage.

More simplified, but fundamental water balance equation which applies the climatological and hydrological water balance, can be expressed as follows:

$$P = R + E + \delta S \quad \text{..} \quad (1)$$

where:

P = Precipitation
R = Runoff
E = Evapotranspiration
δS = Change in storages of surface and groundwater

A parameter of change in storage in the area is the most doubtful one, but an important for the equation. A series of water level observation record is one of parameter to calculate the change of groundwater storage, however, groundwater observation network is not yet set in the area. So that it couldn't be verified by the measured data of groundwater table.

An initial calculation of the groundwater budget is tried by monthly basis in the drainage area of Mt. Monduli where geophysical survey and drilling works are concentrated during the study. The area is topographically composed of volcanic mountains and broad extended plain and is underlain by the Younger Extrusive and the Plateau Lava. Total area of Monduli drainage is calculated at 389 ㎢ inclusive of 170 ㎢ of mountain area.

The mountain area act a part of recharge area and the plain is a part of discharge area.

(2) Calculation of Parameters

a) Meteorological Network

Four meteorological networks nearby the Study area consists of Tenguri meteorological station, Monduli District station, Magugu TPRI and Arusha Airport. These stations represent the physiographic characteristics of the Study Area which are down part of Mt. Meru and Mt. Monduli, Lowland and intermediate land between Mt. Meru and Monduli respectively. The basic climatic parameters recorded at the stations include rainfall, evaporation, temperature, wind velocity, sunshine duration, relative humidity, dew point and radiation.

The climatic data in Monduli District on 1950 utilized for the calculation.

b) Precipitation

Data from Monduli District on 1950 which is estimated 10 years recurrence intervals of annual rainfall, can be used for the calculation. A daily rainfall on 1950 in Monduli District Station is tabulated in Table A-6-3.

c) Runoff

Surface runoff is composed of three components, that is surface runoff, flood runoff and base flow runoff. The surface runoff occurs immediate after the rainfall, but rate of it vary depend on soil condition of the ground surface. Field evidence shows that Monduli foothill were subjected to heavy soil erosion which is caused by a high rate of surface runoff.

Two gauging stations are located in Arusha Region. Record of runoff data in Station No. 24021 and 24031 which are located near Mto Wa Mbu, are applied to estimate a runoff coefficient. Calculated average annual runoff rate by these two station is 22.5 %(see Table A-6-4 , Summary of Annual Runoff Rate in St. 24021 and 24031).

Geologic conditions in the drainage area play the most important role to estimate a rate of the runoff, especially it of base flow. For estimation of base flow rate, discharge measurement was tried in the study area during drought month of September. Measured data is tabulated in Table A-6-5. As is shown in Table, Engongo Emsereji Spring, Mferegi village discharge indicates that the base flow runoff from the volcanic mountains is calculated at 0.08 ㎜/day.

d) Evapotranspiration

An averaged daily potential evapotranspiration in five meteorological is calculated by ARWMP as following Table A-6-6.

An averaged evapotranspiration is applied for the estimation of total amount of potential. Distribution of daily rainfall is an important parameter to estimate potential evapotranspiration. On a calculation procedure, daily potential evapotranspiration can be subtracted from a daily rainfall, but a debt shouldn't carry over to succeeding days. It can not be counted if no rainfall is recorded.

Calculation of monthly evapotranspiration based on the rainfall in Monduli District Station on 1950 is tabulated in following Table(see Table A-6-7, Monthly Evapotranspiration in the Study Area).

e) Base Flow Discharge

The surface river discharge which occurs during dry season, is called base flow discharge. In other words, it is groundwater runoff. Discharge measurement in surface river and spring were conducted near the study area on September, 1995. The measured discharge seems to base flow discharge because of no rainfall was recorded a preceding month.

The rate of base flow discharge vary in aerial extent and geologic conditions of drainage area. Engongo Emsereji Spring, Mfereji village, is located northern slope of Monduli Mountain and is underlain by the Younger Extrusive. Measured discharge of the spring is 3.12 ℓ/sec. flowing from drainage area of 3.5 ㎢ which equivalent to 0.077 ㎜/day of specific discharge.

Calculated specific discharge can be applied to the study area, northern slope of Monduli Mountain, because of same amount of rainfall and similarity of geologic conditions of drainage area.

(3) Calculation of Groundwater Budget

An calculation of groundwater budget in the Monduli Drainage Area is tried used by above parameters. Results is summarized in following Table A-6-8.

Table shows that change in storage of groundwater is estimated at 156 ㎜/a year which is 29 % of total rainfall.

Groundwater recharge to the Ardai Basin can be estimated by following equation:

$$
\begin{aligned}
GR &= \delta S \times \text{mountain area} \\
&= 156.2\ \text{㎜} \times 170\ \text{㎢} \\
&= 26.554\ \text{MCM}
\end{aligned}
$$

Major part of recharge induced during month of March and April and it eke out during dry season, from May to November. Base flow discharge may probably compensate deficient.

Major component of runoff in the Ardai Basin is a surface runoff because clayey soil is underlain with more than 10 m thick according to the drilling record. Presence of deep eroded gully on the surface support this assumption.

It appears from above surface conditions that the evapotranspiration in the Ardai Basin is greater than the mountain area and the groundwater runoff (change in storage of groundwater) is hardly occurs in the Basin itself.

Table A-6-1 GROUNDWATER POTENTIAL IN RESPECTIVE HYDROGEOLOGICAL UNITS

Hydrogeologiclal Unit	BH. No.	Depth of Well (m)	SWL (mbgs)	DWS (mbgs)	Yield (l/min)	D/d (m)	S. C. (l/m/m)	T (m2/d)	Aquifer	Location
Lake Manyara Bed	10/52	104	31.0	34	78	7.5	10.4	23	calcareous	Makuyuni
Lake Manyara Bed	23/68	145	24.0	95	37	–			w. basement v. ash	Makuyuni
Lake Manyara Bed	110/79	104	30.0	43 85	527	43.0	12.3		calcareous	Mswakini
Lake Manyara Bed	78/86	–	51.6	–	188	–			w. basalt	Manyara ranch
Colluvial Beds Monduli Juu	112/84	29	5.2	10, 20 25	36	–			soft soil clay	Emairete
Monduli Juu	EX-7	100	72.3	–	21	3.3	6.4	8	vol. sand	Emairete
Younger Extrusive	2/36	73	26.1	36	38	–			w. lava	Tarasero
Younger Extrusive	3/36	73	26.2	37	38	–			w. lava	Tarasero
Plateau Lava	7/82	107	89.9	–	28	7.3	3.8		c. sand grav, granu.	Meserani Bwawani
Basement	54/55	155	104.0	153 154	18	–			w. gneiss	Naitolia

Remark : SWL = Static Water Level DWS = Depth water struck D/d = Drawdown
S. C. = Specific capacity T = Transmissivity

Table A - 6 - 2 DATA SUMMARY OF EXPLORATORY WELLS IN ENGARE OLMOTONI, ARUSHA

BH.No.	Depth (m)	Well Dia (mm)	Screen (m-m)	SWL (mbgs)	Yield (m^3.hr)	D/d (m)	Duration (hrs)	S.C. (m3/h/m)	T (m^2/day)	Aquifer	Location	Alt. (mamsl)	Coordinate
AR 75/86	119.0	200	52-57,61-72 81-91,101-111 =36 m	40.6	10.30	13.54	8.7	0.76	270	fractured basalt	Burka Coff. Estate	1,385	3 ° 20. 661' 36 ° 36. 991'
AR 79/77	97.6	150	total=19.5 m	30.1	33.77	8.05	—	4.19	—	—	Magereza Air port	1,375	3 ° 22. 041' 36 ° 37. 375'
AR 142/79	94.6	168	40-69.3 =29.3 m	1.5	89.10	10.75	6.0	8.29	752	sand & gravel	Kirany Mission	1,385	3 ° 21. 216' 36 ° 40. 068'
AR 37/80	152.5	219 -156	21-30,49-59 71-81,119-124 =34 m	45.7	47.88	3.03	18.0	15.80	—	sand & gravel	Arusha Seed Farm	1,500	3 ° 18. 475' 36 ° 38. 066'
AR 47/80	127.2	219	37-49,61-73 85-98 =24 m	38.0	6.01	8.80	5.0	0.68	7	basalt	Arusha Seed Farm	1,495	3 ° 18. 425' 36 ° 37. 943'
AR 79/80	91.5	168	44-63 =19 m	42.7	5.08	25.30	4.3	0.20	6	fractured basalt	Arusha Seed Farm	1,495	3 ° 18. 580' 36 ° 37. 995'
AR 96/80	140.0	200	57-72,90-105 =30 m	31.7	39.60	12.44	14.0	3.18	578	sand & gravel	Arusha Seed Farm	1,480	3 ° 18. 665' 36 ° 37. 875'

Note : W.D.= Well diameter
S.C.= Specific capacity
SWL = Static water level
T = Transmissivity
D/d = Drawdown
Alt. = Altitude
Duration = Tested duration

Table A-6-3 DAILY RAINFALL OF MONDULI DISTRICT STATION, STN. No.9336014

Date	Rainfall, 1950											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	11.7	0	0	10.4	0	0	0	0	0	0	0	0
2	3.8	0	0	6.9	0	0	0	0	0	0	0	0
3	0	0	0	15.8	0	0	0	0	0	0	0	0
4	0	0	0	10.7	0	0	2.3	0	0	0	0	0
5	0	18.0	0	3.3	0	0	0	0	0	0	0	0
6	0	0	0	9.1	0	0	1.3	0	0	0	0	11.4
7	0	0	0	18.8	0	0	0	0	0	0	0	0
8	0	0	8.9	19.6	0	0	0	0	0	0	0	0
9	0	0	4.6	3.6	0	0	0	0	0	0	0	0
10	0	0	0	9.1	0	0	3.6	0	0	0	0	0
11	0	0	0	13.2	0	0	0	0	0	0	0	0
12	0	0	0	49.0	0	0	0	0	0	0	0	0
13	0	0	0	7.6	0	0	0	0	0	0	0	0
14	0	9.6	4.1	1.0	0	0	0	0	0	0	0	0
15	0	0	17.0	0	0	0	0	0	0	0	0	0
16	0	0	7.9	7.9	0	0	0	0	0	0	0	0
17	0	0	8.9	21.3	0	0	0	0	0	0	0	0
18	0	0	17.5	0	0	0	0	0	0	0	0	5.3
19	0	0	0	2.8	0	0	0	0	0	0	0	0
20	0	0	23.4	3.3	0	0	0	0	0	0	0	0
21	0	0	17.5	9.4	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	23.4	0	0	0	0	0	0	0	0	0
24	0	0	17.5	0	0	0	0	0	0	0	0	0
25	0	0	2.3	9.6	0	0	0	0	0	0	0	0
26	0	0	5.8	3.8	0	0	0	0	0	0	0	0
27	0	0	1.3	12.7	0	0	0	0	0	0	0	0
28	0	0	10.4	0	0	3.8	0	0	0	0	0	0
29	0		17.8	0	0	1.0	0	0	0	0	0	0
30	0		15.0	1.3	0	0	0	0	0	0	0	0
31	0		4.6		0		0	0		0		0
Total	15.5	27.6	207.9	250.2	0	4.8	7.2	0	0	0	0	16.7
Max.	11.7	18.0	23.4	49.0	0	3.8	3.6	0	0	0	0	11.4

Table A-6-4 SUMMARY OF ANNUAL RUNOFF RATE

Year	Annual Rainfall (mm)	Station No. 24021		Station No. 24031	
		Total Runoff (mm)	Runoff Rate (%)	Total Runoff (mm)	Runoff Rate (%)
1977	702.5	150.811	21.5	–	–
1979	654.4	152.391	23.3	174.354	26.6
1984	863.6	158.606	18.4	206.790	23.9
1985	816.8	–	–	–	–
1986	572.5	131.854	23.0	180.062	31.5
1969	596.2	163.991	27.5	–	–
1990	593.3	171.301	28.9	67.018	11.3
1991	241.3	–	–	26.780	11.1
1992	295.4	–	–	–	–
Mean	592.9	154.826	23.8	131.001	20.9

Table A-6-5 SUMMARY OF DISCHARGE MEASUREMENT

Ser. No.	Name of Villige	Name of Source	Coordinate Lat. Lon.	Altitude (masl)	Type of Source	Discharge (l/s)	Drainage Area (km2)	Specific Runoff (mm/day)	Geology of Drainage Area	E.C. (μS/cm)	pH	T (℃)	Turbidity	Colour	Measured Date
1	Ilkiloriti	Tololia	3° 20.758' 36° 41.285'	1,475	Spring	60			Meru Vol. Slope				none	clear	05/09/95
2	Moivo	Oleikurkur	3° 20.770' 36° 41.796'	1,480	Spring	0.5			Meru Vol. Slope				none	clear	05/09/95
3	Moivo	Lekishemur2	3° 21.500' 36° 42.011'	1,450	Spring	3.3			Meru Vol. Slope				none	clear	05/09/95
4	Moivo	Lekishemur1	3° 21.515' 36° 42.031'	1,450	Spring	2.62			Meru Vol. Slope				none	clear	05/09/95
5	Moivo	Lekishemur3	3° 21.556' 36° 42.031'	1,450	Spring	1.31			Meru Vol. Slope				none	clear	05/09/95
6	Kiranyi	Twalolosek	3° 21.060' 36° 40.011'	1,390	Spring	24.1			Meru Vol. Slope				none	clear	06/09/95
7	Kiranyi	Sheleni	3° 21.266' 35° 40.051'	1,375	Spring	3.04			Meru Vol. Slope				none	clear	06/09/95
8	Ilkidinga	Ngarenarok	3° 18.841' 36° 41.075'	1,600	River	67			Meru Vol.				none	clear	06/09/95
9	Ilkidinga	Saitera	3° 18.970' 36° 41.036'	1,575	Spring	4.52			Meru Vol.				none	clear	06/09/95
10	Ilkirevi	Enjoro Fredli	3° 19.958' 36° 41.815'	1,515	Spring	12.46			Meru Vol.				none	clear	06/09/95
11	Ngarenarok	Burka	3° 21.386' 36° 39.280'	1,365	Spring	60.44			Meru Vol. Slope	553	8	20.8	none	misty	07/09/95
12	Kiauoyak	Enjoroemavii	3° 16.550' 36° 39.775'	1,580	Spring	3.98			Meru Vol.	353	8.3	19.1	none	clear	07/09/95
13	Sambasha	Sambasha	3° 16.396' 36° 41.086'	1,905	Spring	5.88			Meru Vol.	351	7.8	15.6	none	clear	07/09/95
14	Sambasha	Magereza	3° 16.396' 36° 41.086'	1,905	Furrow	6.37			Meru Vol.	351	7.8	15.6	none	clear	07/09/95
15	Shiboro	Shiboro	3° 17.420' 36° 42.370'	1,885	Spring	9.464			Meru Vol.	190	7.6	14.7	none	clear	08/09/95
16	Oleleruno	Enjoroekiasi	3° 18.685' 36° 41.521'	1,650	Spring	27			Meru Vol.	194	7.5	17.6	none	clear	08/09/95
17	Olasiti	Enjikata	3° 24.043' 36° 37.945'	1,320	Spring	7.82			Alv/Meru	1,516	8.5	22.3	none	Brownish	08/09/95
18	Engikaret	Engikaret	3° 10.040' 36° 43.020'	2,050	Spring	3.1	2.5	0.000	Meru Vol.	324	7.8	14.5	none	clear	09/09/95
19	Leaongo	Marok	3° 12.340' 36° 41.063'	2,075	River	18.28	1.8	0.001	Meru Vol.	520	8.8	13.6	slight	Brownish	09/09/95
20	Oldonyosamb	Elatia	3° 11.720' 36° 40.538'	1,895	Spring	5.71	3.74	0.000	Meru Vol.	448	8.5	13.9	slight	Brownish	09/09/95
21	Tukusi	Tukusi	3° 41.156' 36° 36.303'	1,150	River	0.89	876.5	0.000	Basement	655	7.4	25.3	none	clear	10/09/95
22	Lolkisale	Lolkisale	3° 45.826' 36° 24.905'	1,590	Spring	0.45	0.4	0.097	Basement	277	7.9	20.5	none	clear	10/09/95
23	Lolkisale	Lengolwa	3° 45.576' 36° 23.815'	1,590	Spring	0.1	0.8	0.011	Basement	671	7	23.4	none	clear	10/09/95
24	Msaakini	Tarangire	3° 46.820' 36° 12.195'	1,040	River	18.2	36.5	0.043	Basement	4,350	9.6	31.7	slight	Brown	11/09/95
25	Olgilai	Themi	3° 20.176' 36° 43.116'	1,565	River	107.27	5.3	1.743	Meru Vol.	208	8.6	18.7	none	clear	12/09/95
26	Enguik	Elangata Enduroto	3° 14.421' 36° 28.685'	1,445	Spring	0.76	0.7	0.034	Monduli Vol.	63	7.6	14.7	none	misty	13/09/95
27	Mfereji	Engongu Easereji	3° 13.183' 36° 29.241'	1,715	River	3.12	3.5	0.077	Monduli Vol.	120	8.2	18.4	none	clear	13/09/35
28	Engaruka Juu/chini	Engaruka	2° 59.681' 35° 57.565'	915	River	255.3				197	8.5	23.7	none	Brownish	14/09/95
29	Selela	Lossitete	3° 11.816' 35° 55.926'	1,150	Spring	55.11	6.6	0.721	Young. Extrusive	147	8.1	20.1	none	clear	14/09/95
30	Selela	Kabambe	3° 12.900' 35° 55.468'	1,030	Spring	22.17	2.4	0.820	Young. Extrusive	278	8.3	23.1	slight	clear	14/09/95
31	Esilalei/ Esirua	Engulupani1(E)	3° 17.295' 35° 52.346'	1,085	Spring	126.3	17.7	0.617	Young. Extrusive	372	8.5	22.4	none	clear	15/09/95
32	Esilalei/ Esirua	Engulupani2(W)	3° 17.400' 35° 52.355'	1,045	Spring	13.7	31.3	0.038	Young. Extrusive	369	8.3	22	none	clear	15/09/95
33	Maoengo	Misaleni	3° 18.946' 35° 51.340'	1,015	Spring	12.38	5.7	0.188	Young. Extrusive	346	8.4	20.7	none	clear	15/09/95
34	Migombani	Jelule	3° 20.115' 35° 50.016'	1,140	Spring	6	73.81	0.007	Young. Extrusive	306	8.4	21.8	none	clear	15/09/95
35	Olgilai	Emaoi Etemi	3° 18.128' 36° 43.128'	1,770	Spring	19.53			Meru Vol.	186	7.5	15.7	none	clear	16/09/95

Table A-6-6 AVERAGE DAILY POTENTIAL EVAPOTRANSPIRATION IN ARUSHA REGION IN mm/day (ARWMP, 1994)

Station	KIA	Tengeru	Magugu	Bassotu	Kibaya	Average
January	5.6	4.7	7.1	7.9	4.7	6.0
February	6.2	4.6	7.8	6.6	4.4	5.9
March	5.7	4.7	7.9	5.4	4.2	5.6
April	4.6	3.8	7.0	6.4	3.8	5.1
May	3.7	3.3	6.9	7.1	3.0	4.8
June	3.6	2.9	6.1	7.2	2.9	4.5
July	3.4	2.9	6.6	6.1	2.7	4.3
August	3.8	3.3	6.5	7.4	3.3	4.9
September	4.7	3.8	6.6	8.1	4.0	5.4
October	5.1	4.2	7.6	8.5	4.7	6.0
November	5.6	4.5	7.6	8.4	5.0	6.2
December	5.4	4.0	8.1	8.0	4.6	6.0

Table A-6-7 MONTHLY EVAPOTRANSPIRATION IN THE STUDY AREA

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
ET(mm)	9.8	11.9	89.3	100.7	0	4.8	7.2	0	0	0	0	11.3

Table A-6-8 SUMMARY OF GROUNDWATER BUDGET IN THE MONDULI AREA

Month	Rainfall	Runoff			ET	δ S
		SR	FR	BF		
Jan.	15.5	0	0.9	2.5	9.8	2.3
Feb.	27.6	2.8	1.1	2.2	11.9	9.6
Mar.	207.9	20.8	22.4	2.5	89.3	72.9
Apr.	250.2	25.0	27.6	2.4	100.7	94.5
May	0	0	0	2.5	0	-2.5
Jun.	4.8	0	2.4	2.4	4.8	-4.8
Jul.	7.2	0	4.7	2.5	7.2	-7.2
Aug.	0	0	0	2.5	0	-2.5
Sep.	0	0	0	2.4	0	-2.4
Oct.	0	0	0	2.5	0	-2.5
Nov.	0	0	0	2.4	0	-2.4
Dec.	16.7	1.7	0	2.5	11.3	1.2
Total	529.9	50.3	59.1	29.3	235.0	156.2

Note:SR = Surface runoff, 10 % of rainfall more than 16 mm is counted
FR = Flood runoff, 22 % of rainfall minus SR+BF
BF = Base flow, 0.08mm/day
ET = Evapotranspiration
δ S = Change in storage of Groundwater

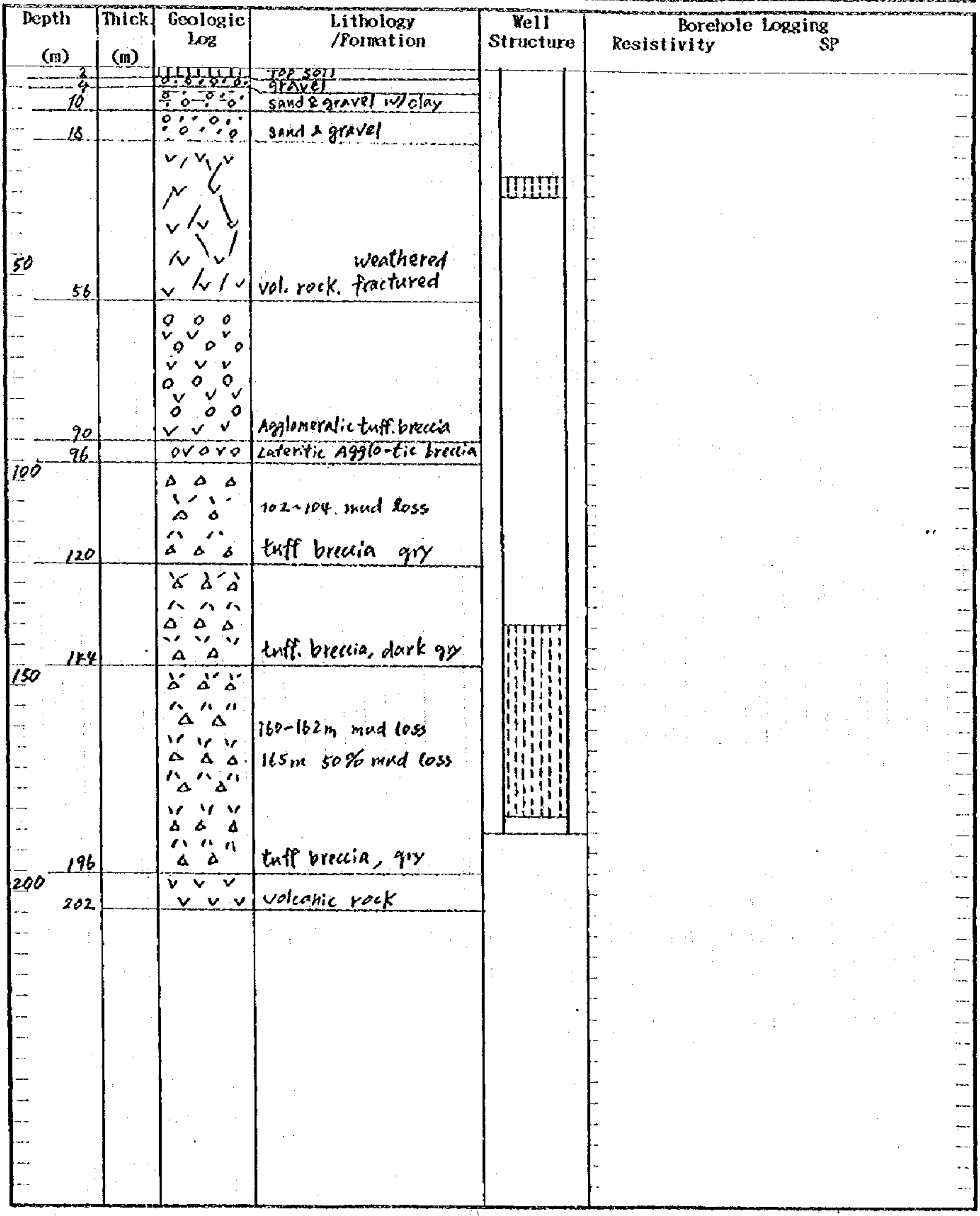
Figure A-6-1 EXPLORATORY WELL LOG OF BH 75/86

WELL No.	75/86	LOCATION	Bulka Coffee Estate, ARUMERU			SITE ALT.	1,440 msl
DEPTH	119 m	DRILL. DIA	300 mm	CASING DIA.	200 mm	RIG TYPE	Mud-Rotary
S. W. L.	40.62 mbgs	Y I E L D	12.9 l/s	DRAWDOWN	13.54 m	SPEC. CAP.	0.95 l/s/m
TRANS.	270 sqm/d	SCREEN	51.9-56.9 66.5-71.5 81.4-91.4 101.2-111.2=35 m-m			D A T E	Oct 29–Dec 4, '86

Depth (m)	Thick. (m)	Geologic Log	Lithology /Formation	Well Structure	Borehole Logging Resistivity SP
1.5			Top soil		
6.1			clay		
12.2			clay w/ f.c. sand		
13.7			clay		
15.3			clay w/ c. sand		
18.3			clay		
19.8			clay w/ gravel		
24.4			gravel		
27.5			clay w/ gravel		
29			gravel		
30.5			gravel/clay		
35.1			clay w/ f. sand		
36.6			clay		
39.7			clay w/ f. sand	SWL	
42.2			clay w/ gravel		
47.3			clay w/ pebble		
50 51.9			clay w/ sand		
58			basalt, weathered		
77.3			clay w/ sand		
82.4			basalt, weathered		
85.4			basalt		
99.1			basalt, weathered		
100 101.8			f.-c. sand		
111.3			clay w/ sand		
119			clay		

Figure A-6-2 EXPLORATORY WELL LOG OF BH 164/95

WELL No.	164/95	LOCATION	Sinodi, Monduli			SITE ALT.	1,540 masl
DEPTH	202 m	DRILL. DIA.	222 mm	CASING DIA.	150 mm	RIG TYPE	Mud drill
S. W. L.	130 mbgs	Y I E L D	0.2 l/s	DRAWDOWN	– m	SPEC. CAP.	– l/s/m
TRANS.	sqm/d	SCREEN	25.9~29.9, 133.9~181.9 = 52m m-m			D A T E	Dec. 1995



Depth (m)	Thick (m)	Lithology /Formation
2		Top soil
4		gravel
10		sand & gravel w/clay
18		sand & gravel
56		weathered vol. rock, fractured
90		Agglomeratic tuff breccia
96		Lateritic Agglo-tic breccia
120		102~104 mud loss tuff breccia gry
144		tuff breccia, dark gry
196		160-162m mud loss 165m 50% mud loss tuff breccia, gry
202		volcanic rock