REPUBLIC OF KENYA

INTERIM REPORT (1)

ON

[illegible]

[illegible]

[illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF KENYA

INTERIM REPORT (II) ON GEOTHERMAL EXPLORATION PROJECT IN THE RIFT VALLEY

MARCH, 1981

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

It is with great pleasure that I present this report entitled "Interim Report (II) on Geothermal Exploration in Geothermal Field, Rift Valley, Republic of Kenya" to the Government of the Republic of Kenya.

This report embodies the result of a geothermal exploration survey which was carried out in the Eburru area, Rift Valley from July, 1980 to February, 1981 by the Japanese survey team commissioned by the Japan International Cooperation Agency following the request of the Government of the Republic of Kenya.

The survey team, headed by Dr. Koji Motojima, had a series of close discussions with the officials concerned of the Government of the Republic of Kenya and conducted a wide scope of field survey and data analyses.

I sincerely hope that this report will be useful as a basic reference for development of the project.

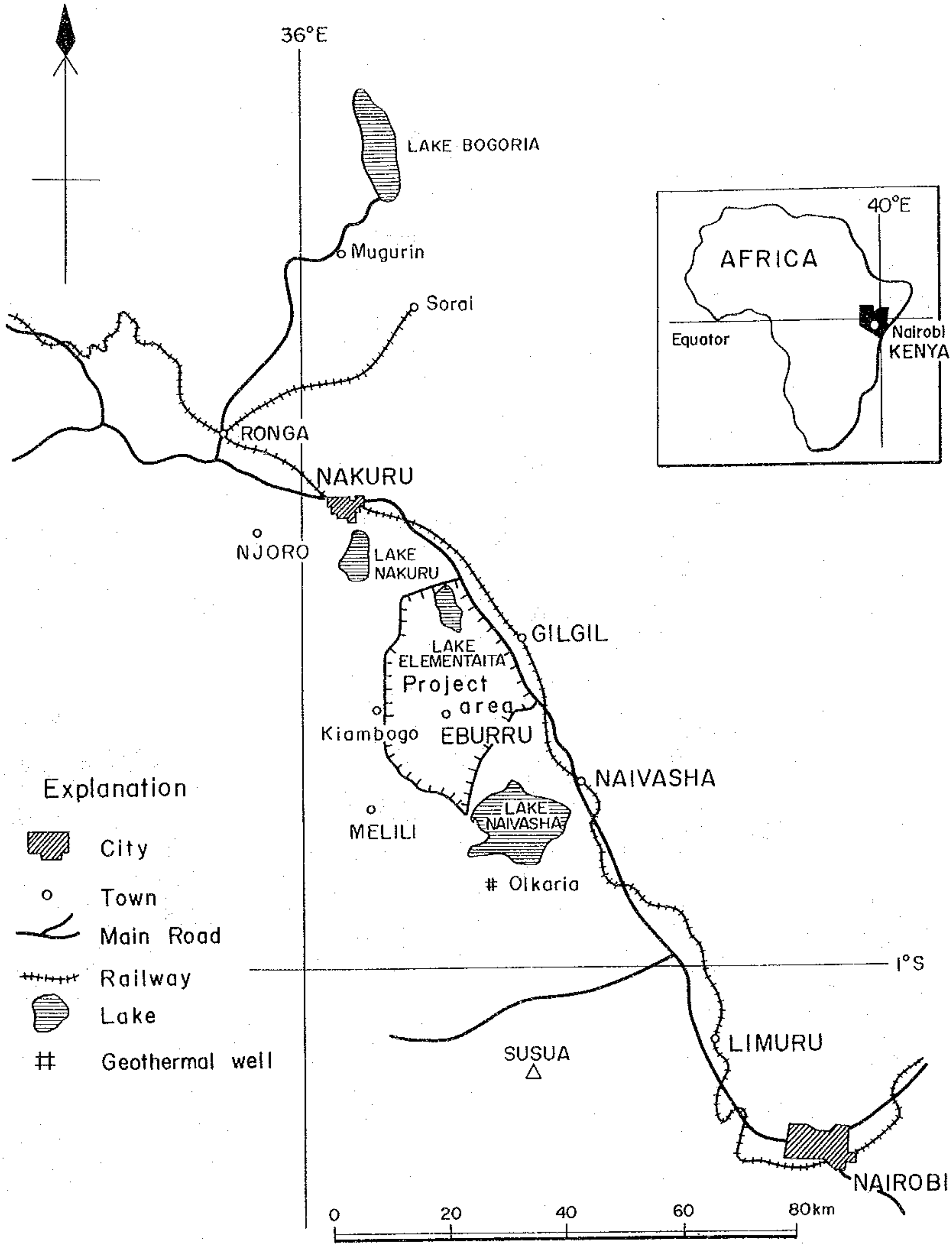
I am particularly pleased to express my appreciation to the officials concerned of the Government of the Republic of Kenya for their close cooperation extended to the Japanese team.

March, 1981

Shizuo Kishida

Shizuo Kishida
Executive Director
Japan International Cooperation Agency

Fig. 1 Location of Project Area



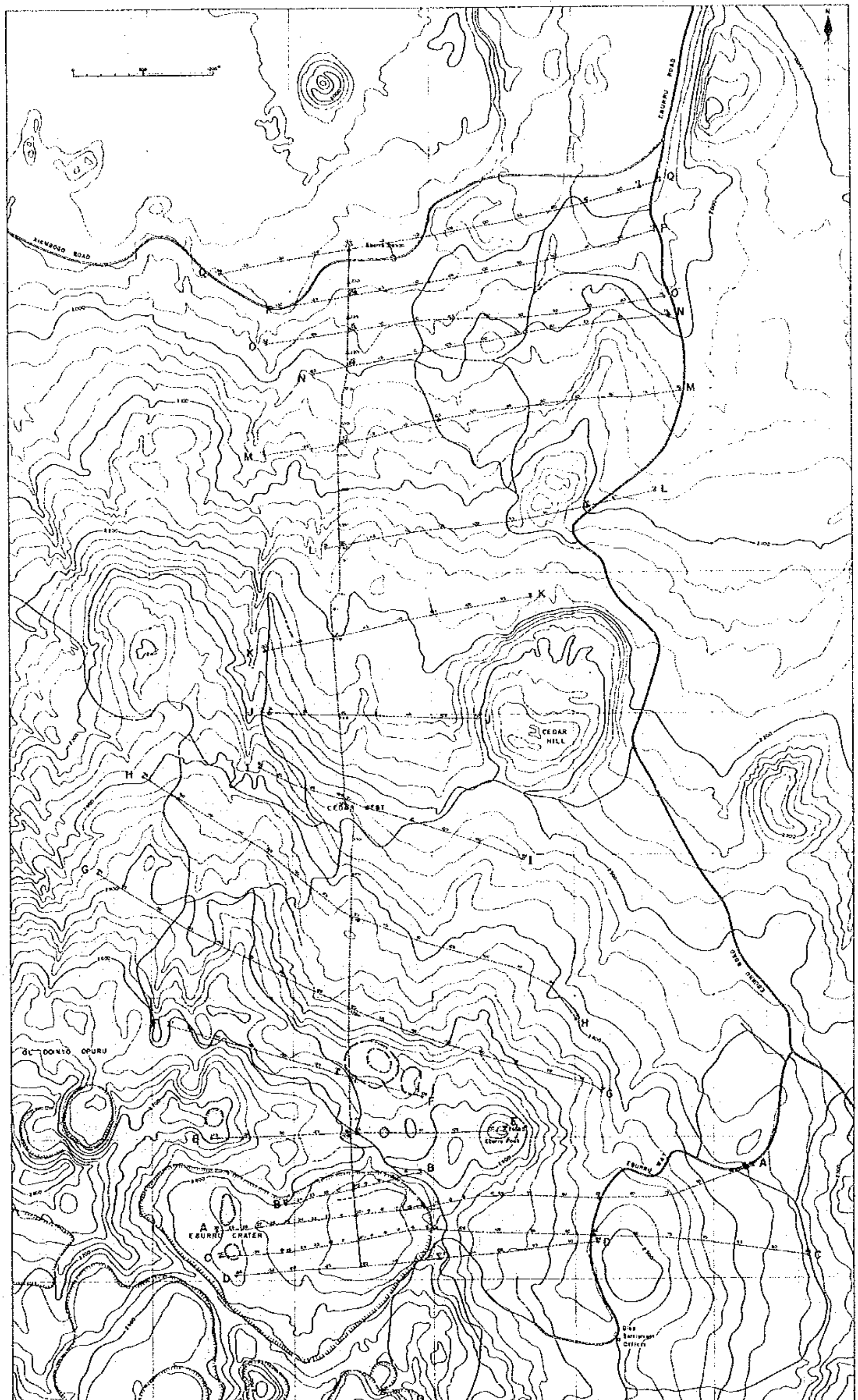


Fig. 2 Location of Project Area

SUMMARY

CONCLUSIONS

RECOMMENDATIONS

SUMMARY

The Japan International Cooperation Agency dispatched a geothermal exploration team of nine geoscientists to the Republic of Kenya during the 1980 Japanese Fiscal Year from April, 1980 to March, 1981 to explore the geothermal prospect in the Rift Valley.

The survey team has carried out geological, geochemical and geophysical surveys in the Eburru Geothermal Prospect in the Rift Valley. The field survey were carried out from September to November, 1980 and for the rest of the time, the team carried out office work and laboratory work to study previous work and to interpret collected data in the Ministry of Energy.

The geological survey, includes both field mapping of approximately 100 km^2 and alteration study. One hundred and sixty altered rock samples were collected and approximately 100 samples were studied with X-ray diffractometer.

The geochemical survey was carried out along 16 survey lines in the area of about 30 km^2. Mercury content and carbon dioxide content in soil air and 1 meter depth ground temperature were measured at 722 points and 842 pieces of soil samples were collected to be analysed of their mercury contents.

As the geophysical survey, 45 Schlumberger geoelectrical soundings were carried out along seven survey lines.

The recommendations for the further exploration in the Eburru Geothermal Prospect are stated in the report.

CONCLUSIONS

Geology

1. The survey area is composed of erupted and ejected volcanic rocks in the Rift Valley during Pleistocene and younger ages. Most of them are acidic alkaline rocks. There is no sedimentary rocks in the prospect.

2. The geological succession of the area is, in descending order, welded tuff, phonolite and comendite lava flow, Ol Doinyo Opur Pumice-fall Deposits, obsidian dike, Eburru Peak trachyte, Obsidian lava flow, lava domes and pyroclastic cones, older Badland basalt, Cedar Hill lava dome, volcanic soil, and Eburru Pumice-fall deposits.

3. The Eburru Geothermal Prospect consists mainly of Ol Doinyo Opur Pumice-fall Deposits which may be intruded by many obsidian dikes.

4. North-south trending faults develop in the prospect. Along the faults lava domes and pumice cones of obsidian, scoria cones of basalt, fumaroles, and altered zones are formed.

5. Present surface is covered with two layers of pumice-fall deposits, Eburru-a pumice-fall deposits (younger) and -b (older), respectively.

6. It is uncertain whether the welded tuff and phonolite and comondite lava flow, which are exposed in the east of the survey area, distributes widely under the prospect or not.

7. Schematic profile of the prospect in E–W direction is shown in Fig. 3. It is very necessary to confirm the thickness of Ol Doinyo Opur Pumice-fall Deposits and whether welded tuff and lava flow are extensively distributed under the prospect or not.

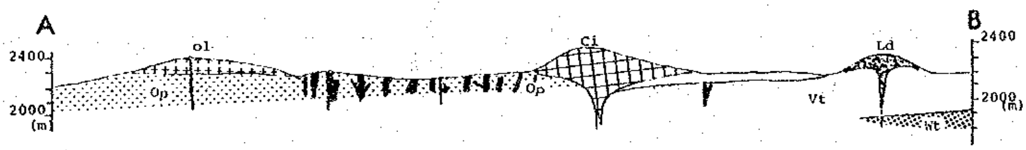


Fig. 3 Schematic Profile of The Eburru Geothermal Prospect in E–W Direction

Rock Alteration Survey

1. The rock alteration in the Eburru Geothermal Prospect can be divided into five zones and one distribution area on the basis of mineral association.

2. The alteration zones give a zonal arrangement from Zone I to Zone V in the northern area of Eburru Crater.

3. Zones I, II and III were formed under the condition of vapor-dominated geothermal system, and they are distributed in the Eburru Crater area extending E–W direction.

4. Zones IV and V were found in the northern foot of the Eburru Crater area extending N–S direction, and Zone V was formed by hot-water which flows from the Eburru Crater area to the Eburru Station area along the water table.

Geochemistry

In the course of field survey on the geochemical exploration, the Eburru Prospect was divided into three areas, the Northern, Central, and Southern ones.

1. According to the results by geochemical exploration using CO_2 measurement in 1 meter depth soil air, it is supposed that two area, the Eburru Crater area in the Southern area and the Central area, have high potential in geothermal resources within the whole survey area.

2. According to the results by 1 meter depth ground temperature measurement, however, the high temperature places have been found in both the Southern area and the Northern area including the Eburru Station area.

3. The facts stated above lead us to the following assumption:

(a) In the Southern area, high geothermal potential area may exist, especially in the Eburru Crater area and in the area of about 500 meters South of Eburru Peak may have high geothermal potential.

(b) The geothermal potential in the Central area is higher than that in the Northern area, furthermore, the distance to the groundwater table from the surface of the ground in the Central area is larger compared with that in the Northern area.

4. The distributional trend of air contamination to the steam samples reported by UN gas-geochemical expert is also supporting the above stated assumption in 3 – (b). Standing on the previous data reported by the same UN expert, we can make the assumption that the steam samples from the shallow reservoirs in the Southern area (depth is less than several hundreds meters) contain CO_2 less than 0.4 volume %. The quality of steam given by our assumption is adoptable for the ordinary usage for instance the electricity generation using turbine.

Geophysics

1. The thick low resistivity layer with resistivity of 10 Ωm to 30 Ωm underlies combinations of thin, high resistivity layers, total thickness of which is approximately 10 m to 150 m, in the Eburru Crater area and in the Eburru Station area with some exceptional area in Eburru Crater.

2. In the Eburru Crater area, we detected the higher resistivity layer under the thick low resistivity layer by several Schlumberger soundings. The depth to the top of the bottom higher resistivity layer which we could detect by the Schlumberger soundings is 500 m to 900 m, but by many Schlumberger soundings we could not detect the bottom higher resistivity layer even though the half of the maximum current electrode separation of the sounding being 1,500 m.

The resistivity of the bottom higher resistivity layer cannot be defined but it is higher than 40 Ωm.

3. The bottom higher resistivity layer can be:

i) a basement crystalline rocks with very high resistivity,

or

ii) a steam filled geothermal reservoir with moderate resistivity.

But without any further informations by drilling, we cannot conclude the geological meaning of the bottom higher resistivity layer.

4. By some Schlumberger soundings at the center of Eburru Crater, the above mentioned low resistivity layer is very think and the high resistivity layer with resistivity of over 100 Ωm underlays the low resistivity layer from the depth of 50 m to 230 m. The geological meaning of the

appearance of the high resistivity layer in shallow place can be as follows:

i) because of alteration, porocity of rocks is decreased,

ii) steam fills pore space instead of water

or

iii) compact intrusive rocks intrude in the area.

5. In the Cedar West area, we carried out only three Schlumberger soundings one of which is at the bottom of the valley like topography and two of which are at the both side of the valley.

The Schlumberger sounding at the bottom of the valley shows lower resistivities than them at the both sides of the valley. Therefore, we assume that geothermal fluid run through the bottom of the valley when it flows from the Eburru Crater area to the Eburru Station area.

6. In the Eburru Station area, we could not detect any high resistivity layer under the thick low resistivity layer. This may mean that a steam filled geothermal reservoir might be very deep (deeper than 1,000 m) in the ground or not existing in the Eburru Station area. However, the geological interpretation of the Schlumberger sounding data must be waited until further geological information of the area, especially from drilling, is obtained.

RECOMMENDATIONS

1. As a result of the survey, we recommend that shallow exploratory core wells (depth to approx. 400 m) are to be drilled at the following sites (See Fig. 4):

Site I : The rock alteration survey suggests that this site may be the center of heat source in the Eburru Geothermal Prospect and the Schlumberger electrical soundings found that the high resistivity layer is in very shallow depth (less than 100 meters). Both the concentrations of CO_2 and Hg are high and the ground temperature is also high.

Site II : This area has high concentration of CO_2 and high ground temperature and is supposed by the geochemists that the hot water table is relatively deep. Geologically Ol Doinyo Opur pumice fall deposits and banded obsidian and the underlying rocks need to be studied by drilling at the site II.

Site III : The rock alteration study shows that the site III is the most active geothermal area in the Eburru Station area. Strong steam manifestation has been seen in the area and low grade anomalies in CO_2 concentration and in ground temperature distribution have also been recognized. Geologically, the informations, e.g. thickness and distribution of the banded obsidian and rocks underlying the banded obsidian need to be obtained.

Site IV : This site is in the different drainage area from Eburru Crater. The resistivity survey suggests that a bottom relatively high resistivity layer has been seen under the thick low resistivity layer at the site IV. Gravity map shows steep gravity gradient towards west of the site IV.

Site V : The strong geothermal manifestation is in the site V and relatively low but clear anomalies in CO_2 and in ground temperature are seen. The electrical resistivity suggests that relatively thin high resistivity layer (thickness is less than 100 meters) is over the low resistivity layer, of which the bottom has not been seen by our survey in the Eburru Station area.

2. When the shallow exploratory wells will be drilled, it is necessary that rock core samples must be taken and temperature must be measured.

3. The following field survey is recommended to be carried out:

Geology: Geological lineation need to be studied and detailed alteration study is also required.

Geochemistry: The completion of the four geochemical maps, CO_2 in soil air, Hg in soil air, Hg in soil, and 1 meter depth ground temperature for the whole survey area of the Eburru Prospect is very much needed for the next step of exploration.

Geophysics: In order to complete areal geoelectrical survey, we recommend dipole-dipole survey to be carried out in the Eburru Geothermal Prospect. For the dipole-dipole survey, the electrode separation is around 200 meters and the separation constant is from one to four.

4. To obtain the reliables underground geoscientific and engineering data which lead to the evaluation of the geothermal potential in the Eburru Prospect, the drilling of the first deep exploratory well with the depth of more than 1,000 meters is recommended to be carried out.

5. Gravity map of much broader area, from Naivasha Lake to Lake Elementaita and from Nakuru – Naivasha road to the west bank of the Rift Valley is necessary to study the macroscopic mechanism of the geothermal system.

6. Around the Soysambu farm, dipole mapping survey shows very low resistivity zone, which needs to be studied in near future.

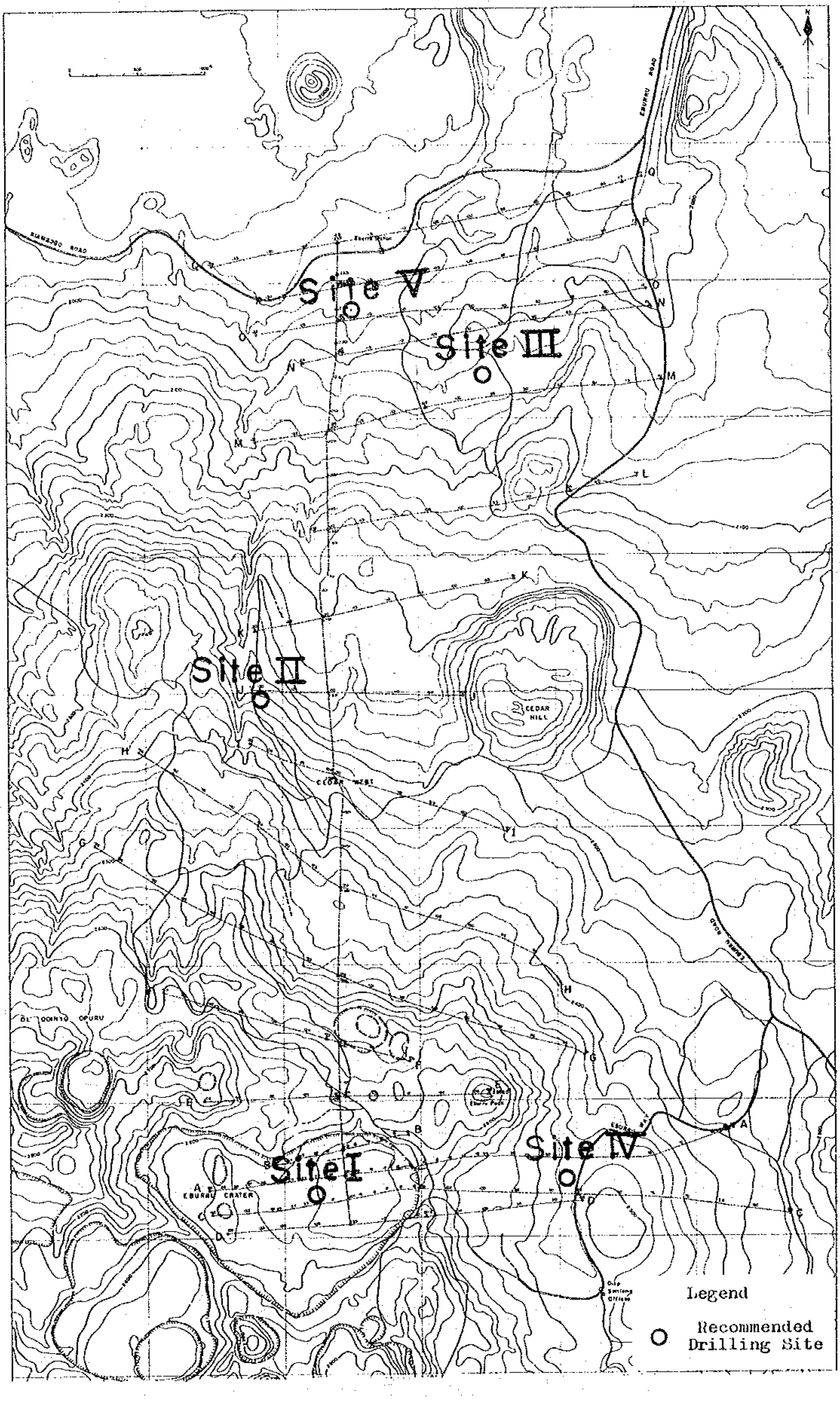


Fig. 4 Recommended 400 M Drilling Site

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

I. OUTLINE

CHAPTER 1 INTRODUCTION

1.1 Purpose of the Project

The purpose of the project is to locate underground geothermal reservoir and to evaluate geothermal potential in the Eburru Geothermal Prospect. This project is a part of the Rift Valley geothermal development project in Ministry of Energy, the Republic of Kenya.

1.2 Location and Extent of the Area

The survey area is centered by Eburru Village, Naivasha division, Nakuru district, Rift Valley Province and is approximately 950 km^2 (see Fig. 1 and Fig. 2). The survey of this phase was mostly concentrated on the area of about 100 km^2, 10 km wide in the east-west direction and 10 km long in the north-south direction.

1.3 The Survey of This Phase

(i) Geological Survey

Geological mapping was carried out in the area of 100 km^2 with petrological study of 70 thin sections under microscope, thirteen of which were made by Mines and Geological Department, the Ministry of Environment and Natural Resources, the Republic of Kenya, and fifty seven of which were made in Japan by the Geological Survey of Japan.

Alteration of rocks was studied in the area of 45 km^2. One hundred and sixty alteration rock samples were collected and about one hundred samples were studied by X-ray diffractometer in the Ministry of Energy and in Japan.

(ii) Geochemical Survey

Hg concentration	722 pts.
CO_2 concentration	721 pts.
1 meter depth ground temperature	722 pts.
soil sample	842 pcs.

The above mentioned measurements were carried out along sixteen survey lines and were mostly 50 meter internal in the area of about 30 km^2.

(iii) Geophysical Survey

Geoelectrical soundings by Schlumberger electrode array were carried out.

Total length of the survey lines	18.5 km
Number of the survey lines	7
Number of the measurements	45 pts

(iv) Topographical Survey

Before starting geophysical survey and geochemical survey, the baseline and the sixteen survey lines were topographically surveyed by Ushikata pocket compasses and bushes and small trees were cut along these lines.

1.4 Team

The members of the survey team are made up by Japanese and Kenyans and are as follows:

Japanese

Koji Motojima* (Leader)
(Geochemist/Geologist)

Yoshiaki Sato*
(Geologist)

Hiroyuki Satoh*
(Geologist)

Jiro Komai*
(Geophysicist)

Harukichi Shimode**
(Drilling Engineer)

Tadao Mizuguchi**
(Geochemist/Geophysicist)

Takashi Ohya**
(Geophysicist)

Keiji Kimbara*
(Geologist)

Isao Sato*
(Geophysicist)

Keiichi Kato***
(Coordinator)

Kenyan

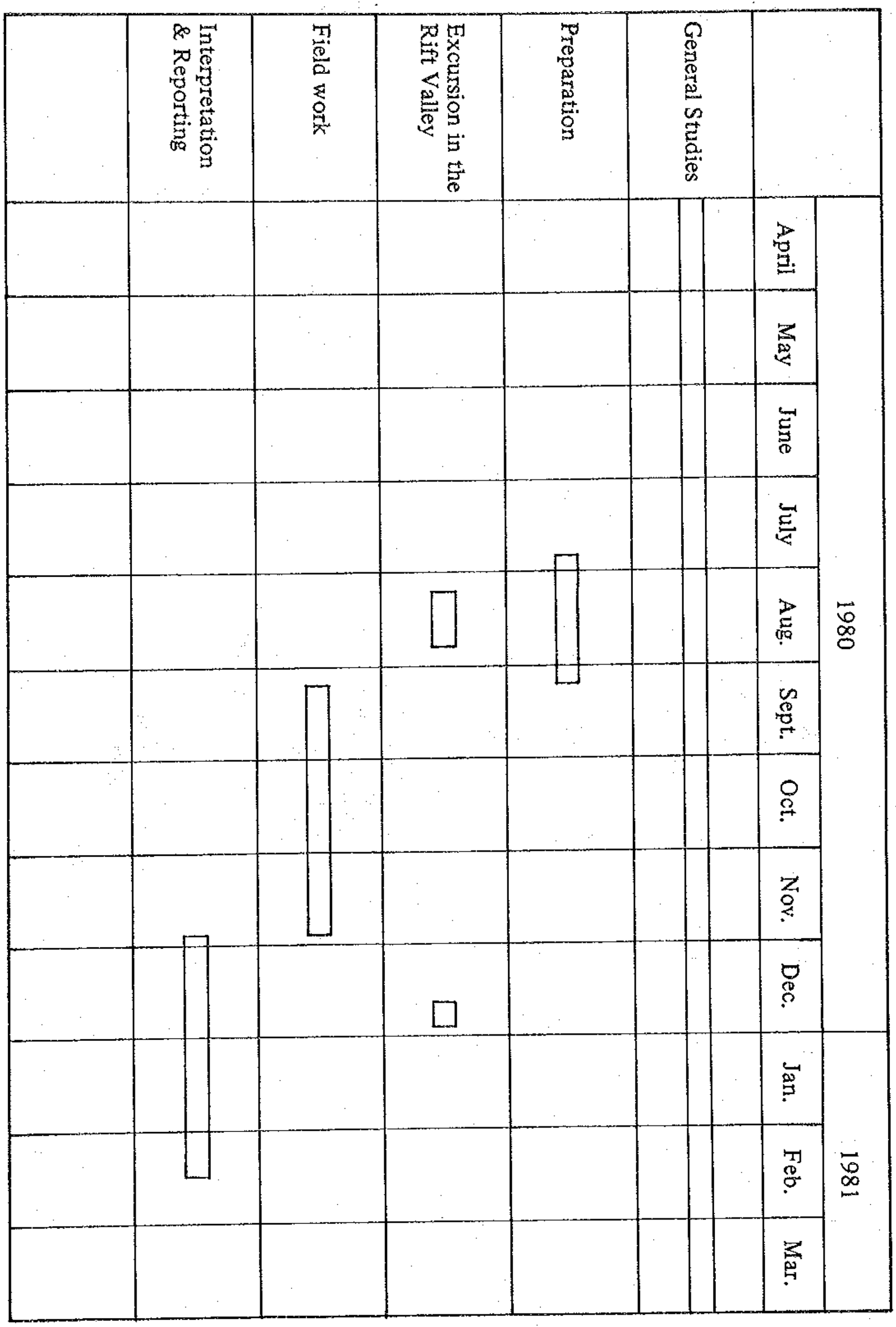
W.J. Wairegi
(Director of Technical Division)

J.K. Kinyariro
(Geochemist)

D.K. Kilele
(Geophysicist Trainee)

* Geological Survey of Japan, Ibaraki
** MESCO, Inc., Tokyo
*** Japan International Cooperation Agency, Tokyo

The work is executed as follows:



CHAPTER 2 GENERAL DESCRIPTION OF THE SURVEY AREA

2.1 Location

The Eburru Geothermal Prospect is located about 16 km to the north west of Lake Naivasha (altitude 1,890 m) in the Rift Valley. The Prospect area measures about 10 km from east to west and 10 km from north to south and in the center of the area, Eburru Peak (2,668 m) rises.

2.2 Topography

The area around Eburru Peak, 2,500 m to 2,600 m in height, has been cultivated. Toward north and east the altitude decreases and finally reaches to 2,000 m at the bottom of the Rift Valley.

To the west, however, altitude increases to 2,800 m in Ol Doinyo Opuru forest region.

Configuration of the Prospect is rather gentle, but it is broken up by Eburru Peak, lava domes, pyroclastic cones, and explosion craters. The diameter of the explosion craters vary from 100 m to 750 m and altered pumice is usually seen around them.

There is a large depression, so-called 'caldera', to the southwest of Eburru Peak. It measures 2 km from east to west and 1 km from north to south. The depression is not a caldera but a composite explosion crater.

2.3 Valley

Valleys in the Prospect have no water except during a heavy rain. Trending of the valleys runs mostly south to north, possibly having the close relationship with the direction of the major fault system in the Rift Valley area. These valleys generally have narrow valley bottoms with deeply cut wall (20 m to 40 m deep). However, the direction of valleys around Eburru Peak, the lava domes, and the pyroclastic, is variable subsequent to their prominent topography. The valleys have rather shallow and wide valley bottoms.

Where rocks are composed of pumice fall deposits, the head of valleys disappears abruptly and becomes flat.

2.4 Fault

Faults, extending from north to south, develop in the Eburru Geothermal area. Most of them are clearly reflected on the topography of the area. Details of the faults will be discussed in II Geology.

2.5 Geographical Naming

In the topographical map (scale 1 : 50,000) published by Survey of Kenya, there are not many names given in the survey area. In order to avoid difficulty of describing the area in this report, we named several places which are as follows:

Eburru Peak:	the triangular point whose elevation is 2,668 meters.
Eburru Station:	along the road E446 to Kiambogo, the place where former Eburru railway station was
Eburru Crater:	the west of Eburru Peak and the crater of approx. 2 km long.
Cedar Hill:	the lava dome on the west of the Eburru Road D322.
Cedar West:	the small village about 1 km west of the Cedar Hill.

Ⅱ. GEOLOGICAL SURVEY

CHAPTER 1 INTRODUCTION

Geology of the Eburru Geothermal Prospect and its surroundings are surveyed with the topographic map on the scale of 1 ; 25,000 extended from the map on the scale of 1 : 50,000 made by the Government of Kenya for the total number of 40 days.

Thin sections of rock samples were prepared by both the Mining and Geology Department, Ministry of Environment and Natural Resources, the Government of Kenya, and the Geological Survey of Japan, Agency of Industrial Science and Technology, MITI. Localities and list of the tine section samples are shown in Fig. II – 1 and Table II – 1, respectively.

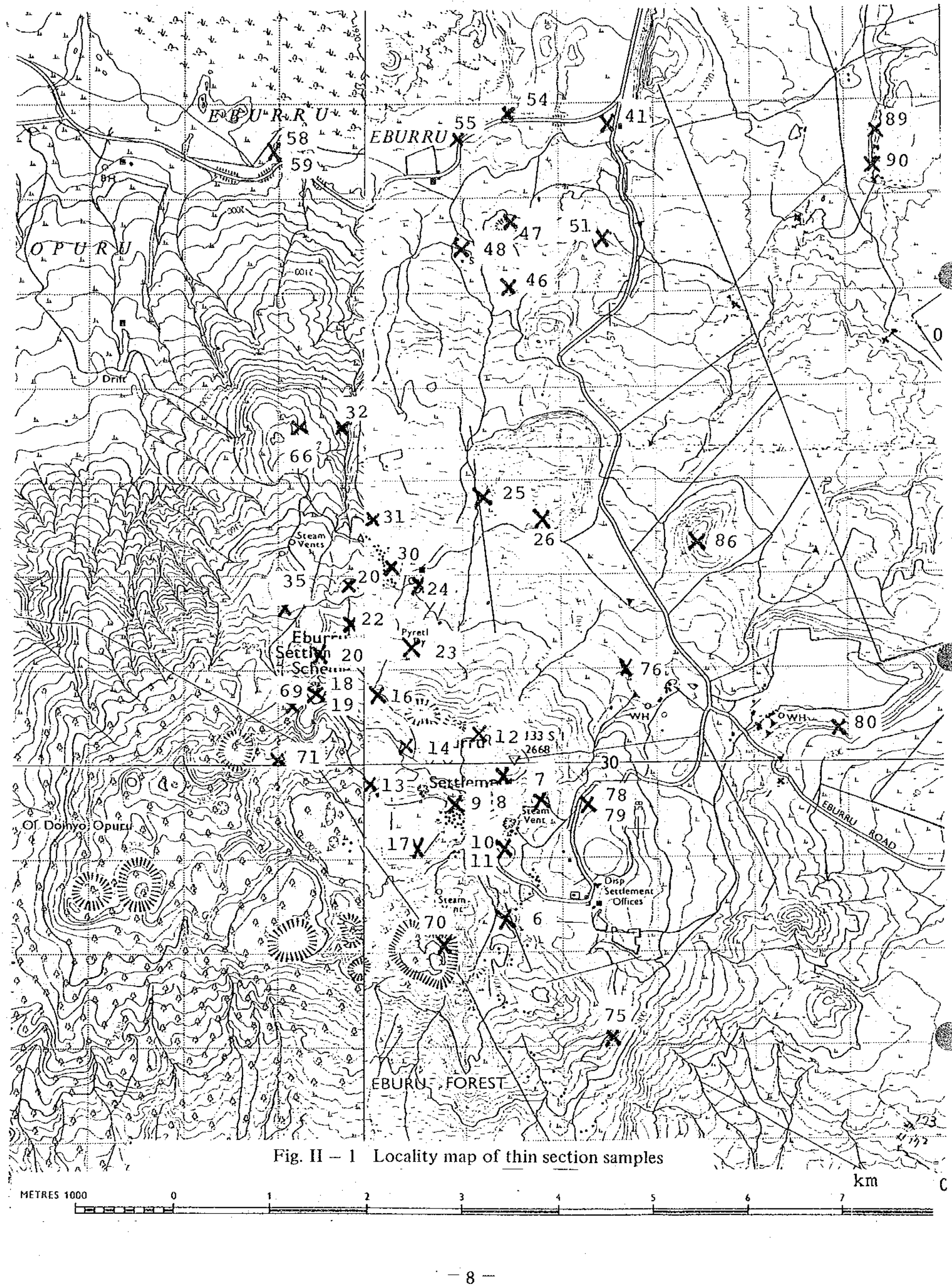


Fig. II – 1 Locality map of thin section samples

CHAPTER 2 SUMMARY OF GEOLOGY

2.1 Geology

The rocks composed of the surveyed area are erupted and ejected volcanic rocks in the floor of the Rift Valley during Pleistocene and younger ages. Most of them are acid alkaline rocks. Pyroclastic fall deposits of same composition distribute extensively in the area, and there are no sedimentary rocks.

Welded tuff, exposed in the northeast of the surveyed area, may exist under the Eburru Geothermal Prospect and is considered to be the oldest rock in the area. The Prospect consists of pumice-fall deposits and obsidian dikes intruding them.

Two layers of pumice-fall deposits are recognized on the present surface. Thickness of the beds and grain size of pumices in it are decreasing toward west. Details of their distribution and craters erupting them, however, are not known clearly.

The nomenclature of acid alkaline volcanic rocks and identification of minerals described previously by some investigators are confused. A part of rock-forming minerals included in volcanic rocks are determined by means of the electron microprove analysis. Phenocrysts are composed of sanidine (or : 36–43), arfvedsonite, aenigmatite (cossyrite) and sodium-rich ferrohedenbergite. Crystals in ground-mass are riebekite, aegirin augite and sanidine. Comendite includes quartz crystals both in phenocryst and ground-mass. Katophorite (Smith, 1931 ; Thompson and Dodson, 1963) is not yet identificated. Geological map of Prospect is shown as Fig. II – 2.

2.2 Fault

North-south trending faults develop in the Eburru Geothermal Prospect. They were formed during Holocene age. Magnitude of fault movements was rather small-scale with little vertical throw. Extension of the faults can be traced about 5 km having 5 – 20 m throw. A fault striking N 15° E at eastern part of Kiambogo Road show more than 50 m throw. Fault topography is clearly observed in the area.

Lava domes and pumice cones, scoria cone of basalt, fumaroles and altered zone are formed along the faults. On the other hand, we can estimate the presence of faults from the alignment of lava domes between Cedar Hill and Eburru Peak.

CHAPTER 3 DETAILS OF GEOLOGY

Summary of the succession of geology in the surveyed area is shown in Fig. II – 3.

3.1 Welded Tuff

The rock distributes narrowly in the northeast corner of surveyed area dipping 20° to the south with N 70°E strike. Similar rocks are underlying comendite (Thompson and Dodson, 1 1963) at northern side of Masai Gorge outside of the mapping area. The relation between the two welded tuffs is still unknown.

It is considered that the oldest known rocks in the Eburru Geothermal Prospect may be a kind of welded tuff. It is very important for further study to clarify the thickness and distribution of the welded tuff and related non-welded pyroclastic deposits under the Prospect.

3.2 Phonolite and Comendite Lava Flow

The rocks distribute to the east of the Eburru Road and are overlain by 01 Doinyo Opur Pumice-fall Deposits. Small-scale lava plateaus can be seen at south side of Masai Gorge and on the east of Eburru Road - Eburru Way intersection. Comendite which is cut by a fault is observed to the east of Eburru Road - Kianbogo Way intersection.

It is necessary for us to confirm phonolite or comendite lava flows under the Eburru Geothermal Prospect.

3.3 Ol Doinyo Opur Pumice-fall Deposits

The deposits distribute extensively in the Prospect and become thicker to west. They are intruded by many obsidian dikes (point – 175). They consist of accumulation of pumice-fall deposits, fine tuffs and tuff breccias. Thickness of a single layer is usually about 3 meters (Fig. II – 4), however, above 20 meters at point –175 (Fig. II – 11).

Pumuces are angular and show a good sorting having a maximum diameter of 15 to 30 cm. These facts together with slight stratification show the characteristics of air-fall origin. Columnar section of the deposits at point –39 is shown in Fig. II – 4.

	Eburru-a Pumice-fall Deposit		
	Eburru-b Pumice-fall Deposit		
Holocene	Volcanic soil		
	Cedar Hill Lava Dome	Ci	obsidian
	Older Badland Basalt	Bb	
	Lava dome and cone	Ld	faulting
	Obsidian lava flow	Ol	
	Eburru Peak Trachyte	Et	
	Obsidian dike		
	Ol Doinyo Opur Pumice-fall Deposits		
Pleistocene	Phonolite and comendite lava flow	Vt	
	Welded tuff	Wt	

Fig. II – 3 Geological Sequences of the Eburru Geothermal Prospect

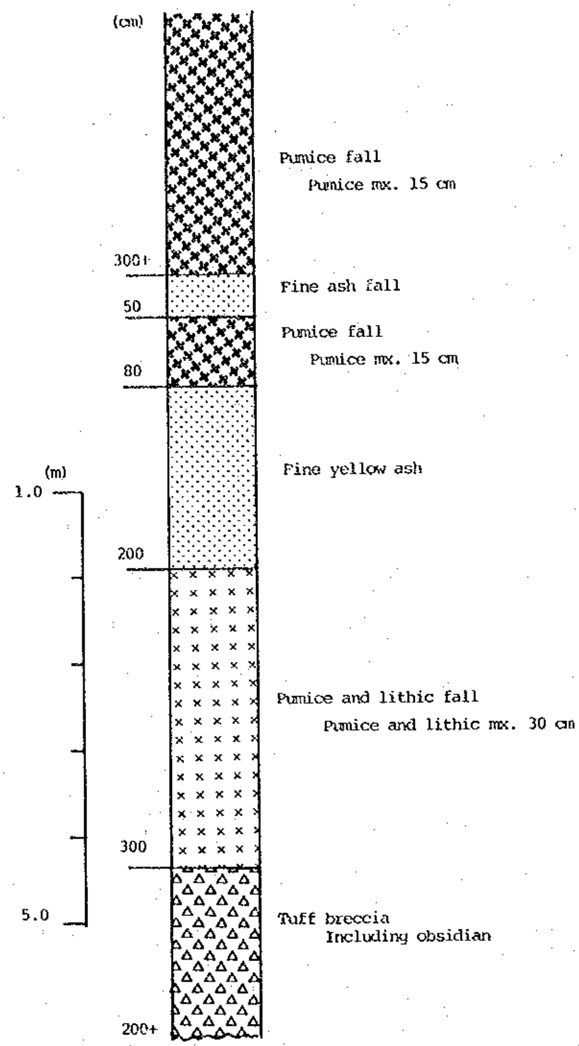


Fig. II – 4 Columnar Section of Ol Doinyo Opur Pumice-fall Deposits at Point 39

The distribution of the deposits extends further east of the Prospect, i.e. at the junction of Eburru and Kiambogo Road, hills west of the rail way and south of Masai Gorge. The deposits overlay the phonolite and comendite lava flows.

Thickness of the deposits is estimated as about 2 to 3 hundreds meters on the Prospect. We expect that it will be confirmed as soon as possibly by shallow drillings.

3.4 Obsidian Dikes

The rocks also are scattered on the ground of the Prospect. They have well developed flow structure shown by glass flow, and alignment of bubbles and/or feldspar phenocrysts. Ptygmatic folding structures are seen in several points. Sometimes band of black glass and pale green material, 3 to 5 cm in wide, are observed. Trending of the flow structure is usually north-south direction, but some shows N 50° E or W and E–W in rare case, with dipping angle of 40 to 90°.

The occurrence of the rocks is not clear because they occur as isolated exposure. However, at point –175 (Fig. II – 10), the obsidian intrudes vertically into the flat-lying pumice-fall deposits of 20 m (+) in thickness with N 40° W in strike. Chilled margin of 40 m in thickness is formed. The rock is pale green inside and black glass at chilled margin. Accordingly, it seems that obsidians in the Eburru Geothermal Prospect are dike rocks intruding into the Ol Doinyo Opur Pumice- fall Deposits and trend of the flow structure shows direction of dike rocks.

3.5 Eburru Peak Trachyte

Eburru Peak are composed of this rock. Thompson and Donson (1963) called the rock rhyolite. The rock is extruded along a north-south trending weak line connecting Cedar Hill and Eburru Peak. On the mountain side a thermal altered zone are observed. The rock and ones following this are not covered by Ol Doinyo Opur Pumice-fall Deposits.

3.6 Obsidian Lava Flow

The lava flow coveres Ol Doinyo Opur Pumice-fall Deposits in the west of the Eburru Geothermal Prospect (point –81) and a part of the flow reaches to Kiambogo Road. On the contrary to obsidian dikes, the lava has horizontal flow structure. At and near the base of a flow brecciation has developed, but the rock becomes compact upwards.

3.7 Lava Domes and Pyroclastic Cones

There are two lava domes, one to the northeast and the other to the east of Cedar Hill. Two north-south trending faults run through the latter dome. Pyroclastic cones are found, two in the southwest of the surveyed area, and one in the center. They are composed of dark gray tuff, pumice and obsidian fragments.

3.8 Older Badland Basalt

The rock is olivine basalt and is distributed in the Eburru Station area. It has undergone thermal alteration. The portion of outflow of lava may be a scoria cone in the north of the area.

3.9 Cedar Hill Lava Dome

Cedar Hill is a large obsidian lava dome having a diameter of about 1.3 km at the bottom. Well preserved grooves resulted from the movement of the lava flow can be seen on the surface of the dome. The rock consists of partly compact black glass and partly many feldspar crystals.

3.10 Volcanic Soil

Fine-grained, reddish brown volcanic soil is distributed mostly in the northeast of the Eburru Geothermal Prospect.

3.11 Eburru Pumice-fall Deposits

The present surface of the Eburru Geothermal Prospect is covered by the deposits. Two layers, older and younger ones, are recognized. The older one is named here Eburru-b Pumice-fall Deposits and the younger one Eburr-a Pumice Fall Deposits. Thickness of each decreases toward east or to Masai Gorge. The center of the eruption may be one of those explosion craters in Ol Doinyo Opur. Their thickness is shown in Fig. II – 5.

REFERENCES

NAYLOR, W.I. (1971–1972) : 1 ; 25,000 Geologic map of the Eburru Area (unpublished).

NOBLE, John W. and OJIAMBO, Sebastian B. (1975) : Geothermal exploration in Kenya.

RICHARD, J.J. and NEUMANN van PADANG, M. (1957) : Catalogue of active volcanoes of the world including solfatala field. part IV, Africa and the Red Sea. 118p.

SMITH, W.C. (1931) : A classification of some rhyolites, trachytes, and phonolites from part of Kenya Colony, with a note on some associated basaltic rocks. Quat. Jour. Geol. Soc. London, vol. LXXXVII, p. 212–258.

THOMPSON, A.O. and DODSON, R.G. (1963) : Geology of the Naivasha Area. Rep. no. 55, Geological Survey of Kenya, 80p.

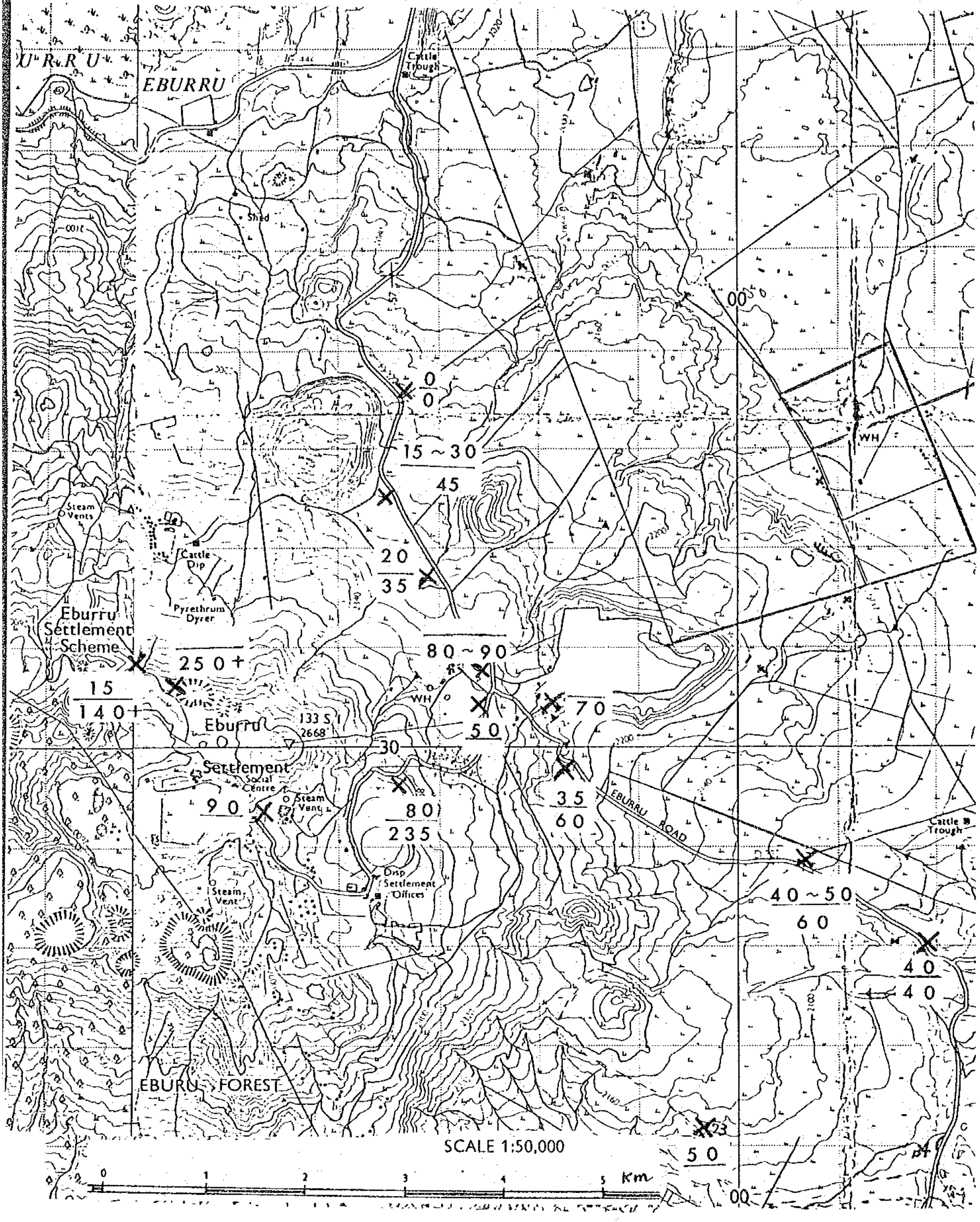


Fig. II – 5 Distribution of Eburru-a (upper) and Eburru-b (lower) Pumice-fall Deposits (cm)

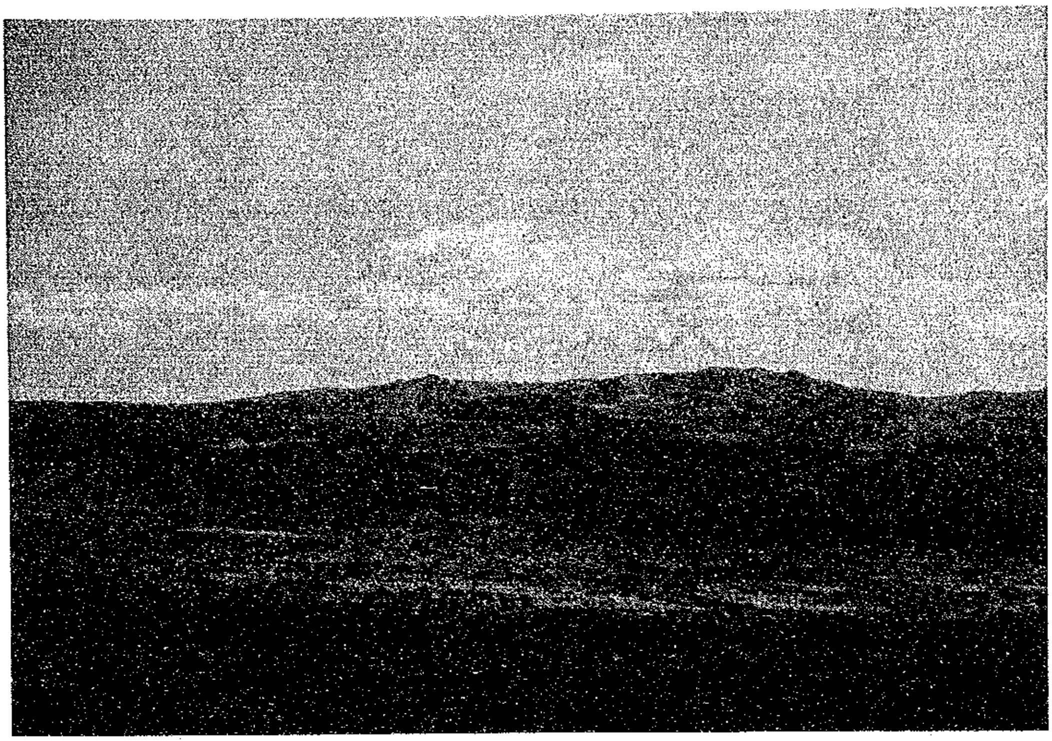


Fig. II – 6 Eburru Geothermal Prospect, Viewed from North.

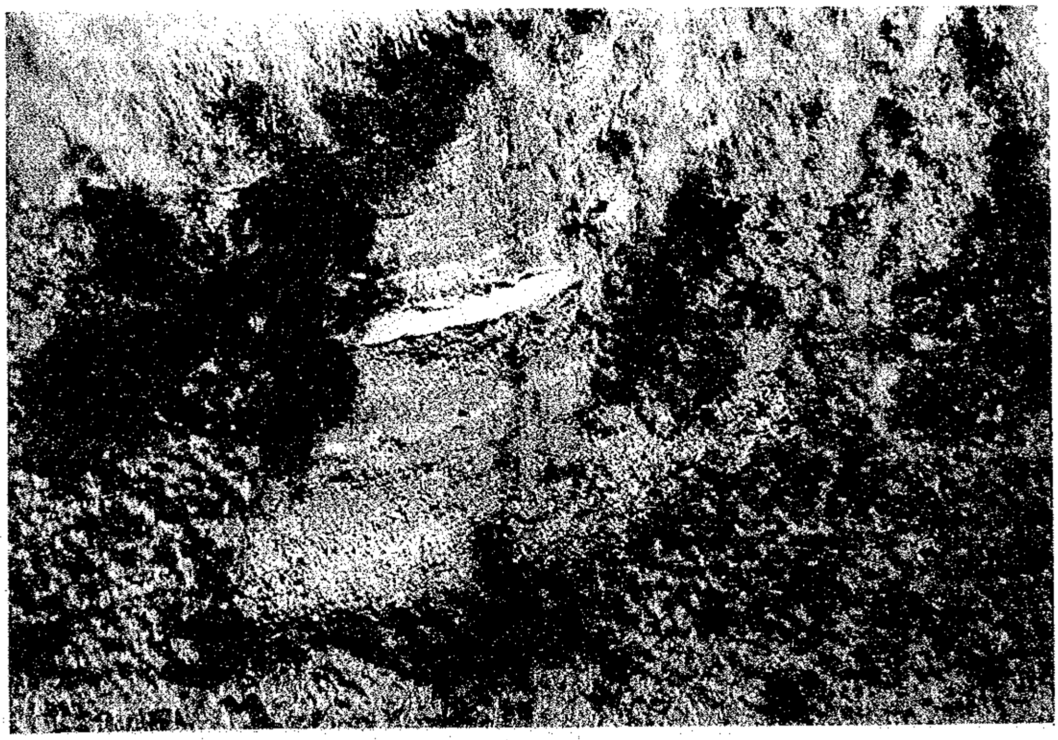


Fig. II – 7 Ol Doinyo Opur Pumice-fall Deposits at Point –291

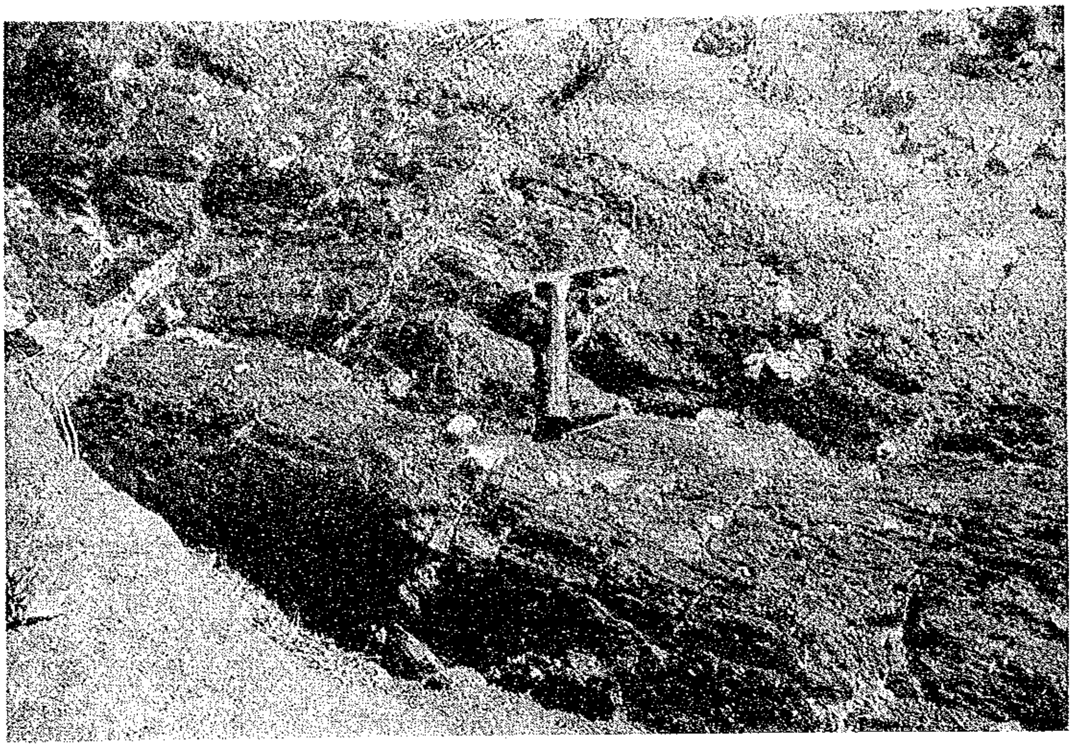


Fig. II – 8 Flow Structure of Obsidian Dike at Point –208.

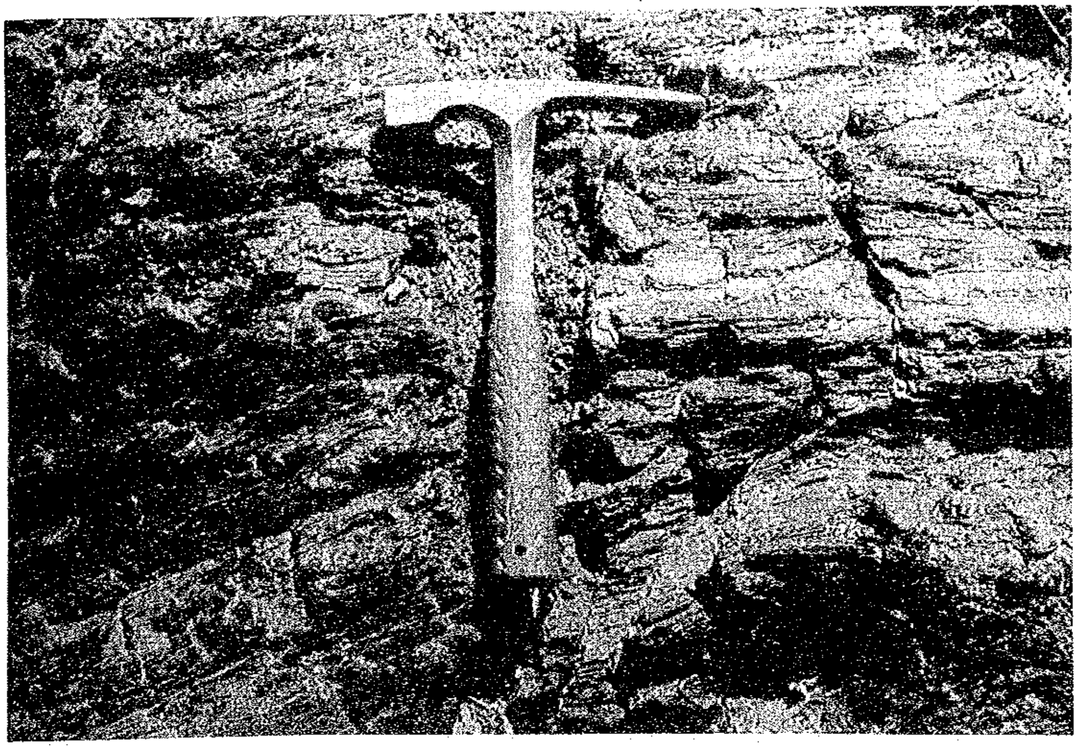


Fig. II – 9 Ditto.

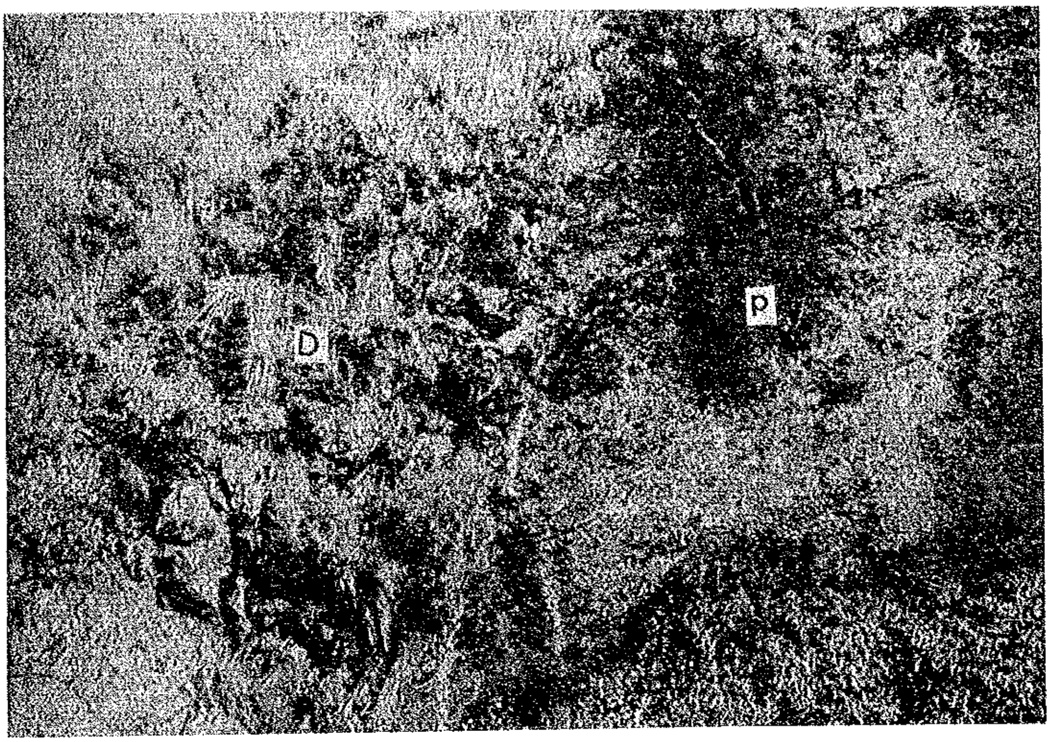


Fig. II – 10 Obsidian Dike (D) Intruding to
Pumice-fall Deposits (P) at Point –175.

Fig. II – 11 Eburru-a and -b Pumice-fall Deposits at Point –161.

Table II – 1 List of thin section samples

K – 6	Gray blue. Floating rock at kaoline mine south of Eburru Plimary School.
7	Black altered. Eburru Peak Trachyte.
8	Tufaccous green rock. Eburru Peak Trachyte.
9	Obsidian.
10	Pumice. Eburru-a.
10'	– do – (crushed)
11	Pumice. Overlain by K–10 (Eburru-a).
11'	– do – (crushed)
12	Gray rock. Eburru Peak Trachyte.
13	Altered rock at Kaoline mine in north wall of "caldera"
14	Altered rock, gray.
16	Pumice. Eburru-b.
16'	– do – (crushed).
17	Obsidian. Dike.
18	Pumice. Eburru-a.
18'	– do – (crushed).
19	Pumice. Eburru-b.
19'	– do – (crushed).
20	Rhyolite included in Pumice-fall deposits.
22	Pumice. Pumice-fall deposits.
23	Obsidian. Lava dome.
24	Pumice. Cinder cone.
24'	– do – Crushed.
25	Obsidian. Ceder Hill.
26	Green compat rock. Lava flow.
30	Obsidian. Flow-structured dike.
31	Welded tuff.
32	Obsidian. Lava.
35	Obsidian. Lava.
41	Comendite. Flow-structured.
42	Basalt. Badland Basalt. South of Lake Elementeita.

46 Green. Flow-structure. Lava flow.

47 Green comendite. Flow structure.

48 Scoria. Older Badland Basalt.

51 Floating rock. Comendite.

52 South Masai Gorge. Lava flow.

53 North of Masai Gorge. Lava flow.

54 Green compact Olivine-augite basalt. Older Badland.

55 Olivine-augite basalt. Older Badland Basalt.

58 Compact part.

59 Flow-structure.

66 Obsidian. Lava.

69 Comendite.

70 Pumice. Ejected from crater.

71' Pumice. Ejected from crater.

75 Obsidian. Flow structured. Dike.

76 Obsidian. Flow structured. Dike.

78 Pumice. Eburru-a.

79 Pumice. Eburru-b, overlain by K–78.

80 Green. Lava flow.

83 Green. East of K–83.

85 Comendite. Flow structure, at quarry south of Gilgil.

86 Vesicular. Cone.

89 Flow structure.

90 Welded tuff.

95 Welded tuff. east of Naivaoha.

Ⅲ. GEOCHEMICAL SURVEY

CHAPTER 1 INTRODUCTION

In accordance with the general geochemical knowledge, the geochemical behaviour of carbon dioxide in the igneous environment is relatively clear. The carbon dioxide of inorganic origin is distributed in the igneous areas and controlled by the igneous activities not only in large geologic scale but also in small one. Therefore, the general distributional trend of carbon dioxide in soil air from 1 meter deep from the landsurface shows the general geothermal trend of the high temperature fluid reservoirs existing in relatively shallow depth (shallower than several hundreds meters).

In addition to this, small scaled distributional pattern of carbon dioxide in soil air, sometimes, indicates the existence of faults and when the geologic environment is very convenient, even the inclination (dip) of the faults can be determined by carbon dioxide distribution. The carbon dioxide method using soil air has been adopted, successfully, by the JICA Mission since the beginning of field survey in January – February, 1980 in the Eburru Prospect.

The distribution of ground temperature at one meter deep from landsurface has shown the good coincidence with the geothermal resources at various geothermal fields in the world. Therefore, the distributional data of shallow ground temperature should be prepared in the Eburru Prospect, and the JICA Mission has adopted this work since the beginning of field survey in early 1980.

The Rift Valley in Kenya is situated on one of the world's largest tectonic lines and has the continued movement with deep faults since late Miocene.

According to the global tectonics, the geothermal areas which are located in the border regions between the two plates have some geochemical characteristics, for example high concentration in mercury and helium contents. The bottom sea sediments along the East Pacific Rise have high value in mercury content and the bottom ocean water on the Rise has also high helium content. The western region of U.S.A. is famous for its high concentration of mercury and potential geothermal fields. The fact shows that the geological phenomena related to the deeper parts of the earth have a close relationship to the distribution of mercury and helium.

Standing on the basis stated above, the JICA Mission has successfully adopted the geochemical exploration method using mercury since the beginning of the field survey in the

Eburru Prospect in early 1980 and a part of the survey results has already been reported.

Clear and reasonable coincidence has been recognized among the data on the shallow ground temperature, carbon dioxide in soil air, mercury in soil air and mercury in soil.

In the Eburru Prospect, no hot spring water from the surface of the ground has been reported and the gas-geochemical methods should be applied in the area.

CHAPTER 2 SURVEY METHOD

2.1 General Explanation

Many large and small scale faults with north-south direction have been recognized and reported in the previous papers in the Eburru Prospect. Thus, the survey lines were arranged nearly east-west direction across the general geological trend.

According to the results of the first phase survey in the southern part of the Eburru Prospect, the E–W interval of survey points is preferably less than 50 meters, and the N–S interval between survey lines is preferably less than 300 meters. However, within the limited field survey period, the whole area of the Eburru Prospect must be covered by the geochemical method, and at the initial stage of the field survey, it was decided that the E–W interval was 50 m and the N–S interval was close as possible as the survey team could.

2.2 Setting of Survey Lines and Stations

Before to decide the location of the survey lines and stations, we examined the following points:

- Prediction of weather condition during the field survey period (September–November 1980).
- Manpower which we can use in the Eburru Prospect.
- Topographic condition.
- Vegitation condition.
- Condition of wild animals.
- Duration of field survey.
- Transportation condition.
- Supply condition of daily necessity.
- Condition of camps.

Finally, the survey lines and stations were decided as shown in Pl. III–1.

The set point on the top of the Eburru Peak with the elevation of 2,668 meters above sea level was used as the starting bench-mark for survey to the whole area of the Eburru Prospect.

The base line with N–S direction for the survey was set up in the approximately central part of the area, and 16 survey lines on which many survey stations having the interval of 50 meters were arranged approximately perpendicular (E–W direction) to the base line. The direction of survey lines was determined by a magnetic compass (Torakon Ushikata) with the approximate scale reading (sensitivity) of 1/3 degree, and the distance was determined by a glass - fiber tape measure.

Total numbers of survey stations and lines were 842 and 16 respectively, and the total length of the lines reached 42.3 Km in an area of 30 Km^2 (8 Km in N–S direction and 5 Km in E–W direction).

2.3 Measurement

Survey was carried at each station as follows:

i) Two 1 meter depth holes are dug at each station.

ii) One of two holes is used to measure carbon dioxide content in soil air obtained three minutes after dug.

iii) The other hole is used to measure mercury content in soil air immediately after being dug.

iv) After the above mentioned measurements, one of the holes is used to measure 1 meter depth ground temperature.

v) Soil sample is collected at the bottom of 1 meter depth hole and is used for mercury content measurement. In the case of very dry hole, a surface soil sample is taken instead of 1 meter soil.

2.4 Mercury Content Measurement in Soil Air

For the current survey, the Scintrex mercury analyzer HGG–3 is employed because of the speed of analysis and capability of in-situ analysis.

2.4.1 Equipment

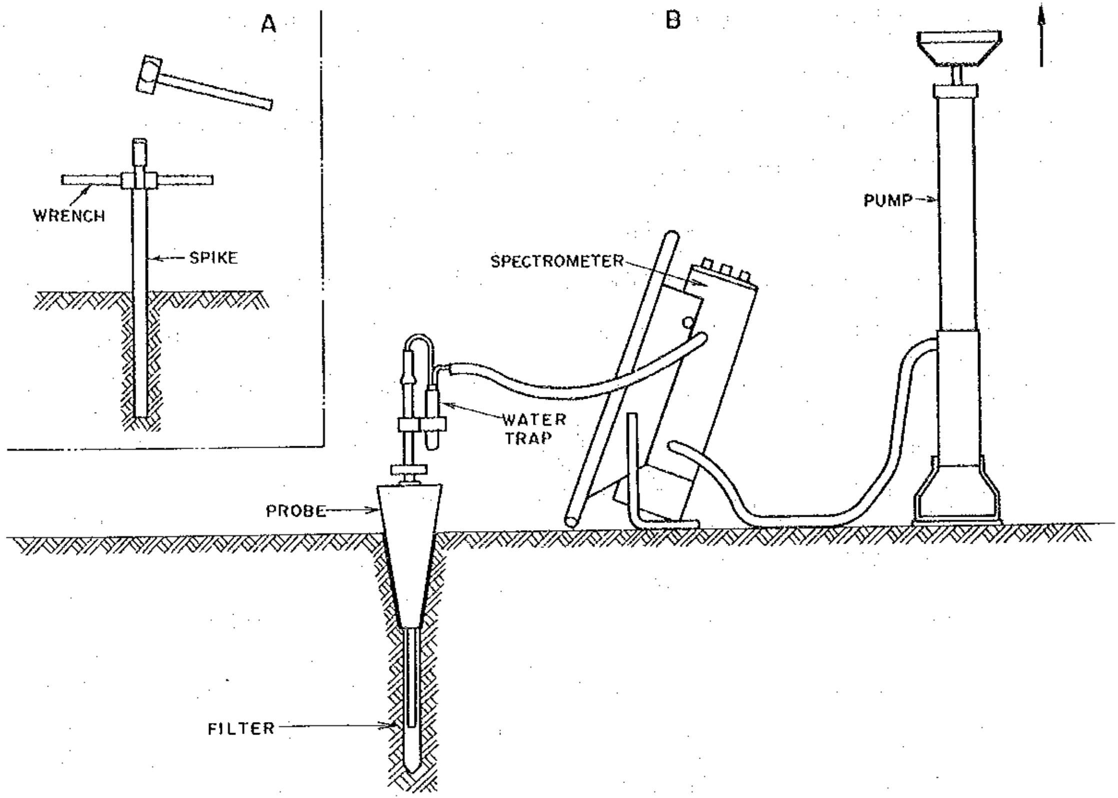
The specification of mercury spectrometer is as follows: (Fig. III – 1)

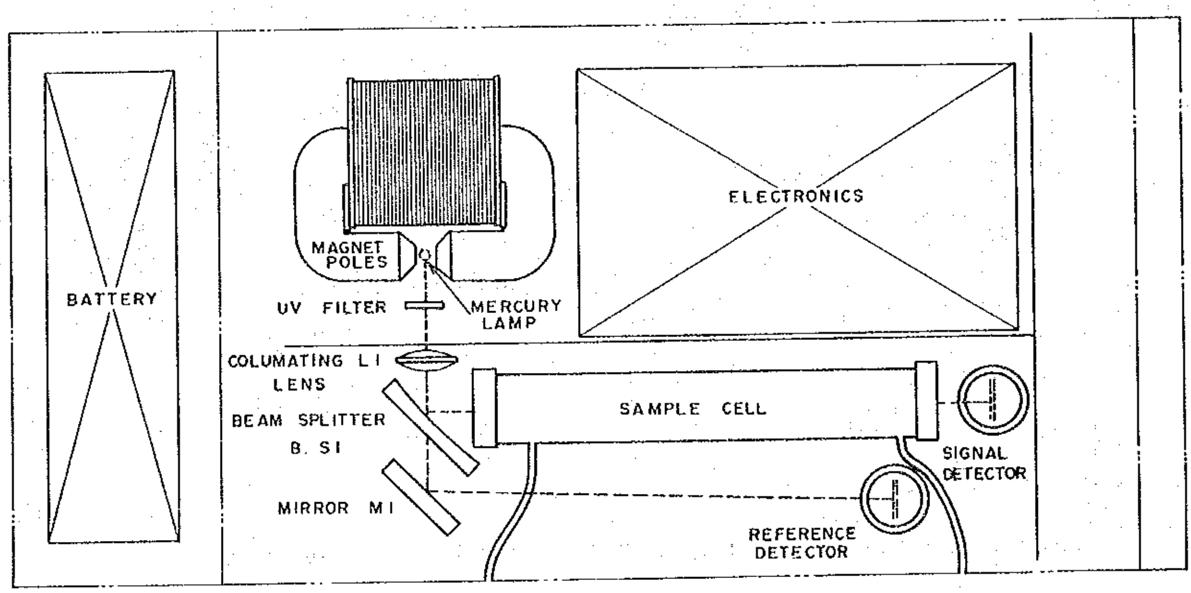
Maker:	Scintrex Ltd.
Model:	HGG–3
Sensitivity:	better than 40 x 10^{-12} grams Hg/250 ml
Power:	lead dioxide - silica gel type batteries, 60 volt 6 ampere/hour

The principle of the equipment is based on atomic absorption. The measurement is primarily the degree of attenuation by mercury vapor of the intense Hg emission line at 254 nm from a mercury lamp. There are, however, other common gases and vapors that absorb strongly but over wide wavelength ranges. The HGG–3 employs a Zeeman Effect technique to

Fig. Ⅲ - Ⅰ MERCURY SPECTROMETER

SCINTREX HGG - 3





HGG - 3 BACKPACK SPECTROMETER

generate a reference wavelength outside of the absorption envelope of the mercury spectrum. By repetitively turning on and off a strong magnetic field encompassing the mercury lamp, its emission is rapidly alternated from 254 nm to the reference wavelength. The electronics then compare the absorption at the two wavelengths and yield a measurement which is highly specific and highly sensitive for Hg.

2.4.2 Calibration

For calibrating the mercury analyzer, standard air samples of mercury vapor concentration are made by using saturated mercury vapor. As a result of its calibration, mercury concentrations and readings of the mercury analyzer in millivolt showed relatively proportional relation.

2.4.3 Field Procedure

Survey procedure for the current survey is as follows.

(i) The equipment is warmed up.

(ii) A spike with a diameter of 20 mm is driven one meter into the ground.

(iii) Immediately after the spike being pulled out, the probe is fitted with a plastic cone and forced into the opening until a good seal can be expected.

(iv) Following the procedure of the analyzer on the operating manual, the maximum reading at each station is recorded.

While moving to the next station, the heater of the analyzer is kept on.

2.5 Carbon Dioxide Content Measurement in Soil Air

2.5.1 Equipment

Carbon dioxide gas detector is used for measurement (Fig. III – 2). Its specification is as follows:

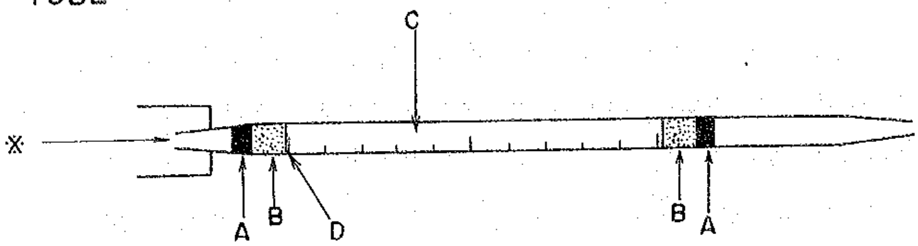
Maker:	Komei Rikagaku Co.
Model:	Kitagawa detective tube, hand pump type ST and S
Range:	1 – 10% and 1 – 20%
Sample Volume:	50 ml
Pumping Time:	30 sec., 50 sec.
Reagent in Tube:	Silica gel with special reagent

The detector is very small and light, so it is very easy to carry in the field.

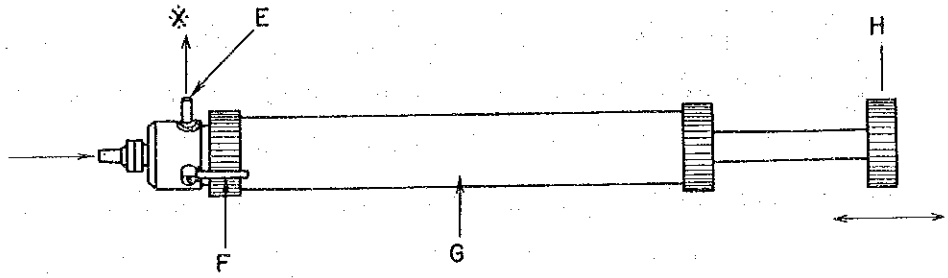
Reading of carbon dioxide content is very easy and price of a tube is very cheap.

Fig. III -2 Carbon Dioxide Detector

DETECTION TUBE



GAS COLLECTOR



A stopper
B glass grains
C detection reagent (silicagel)
D scale
E tube connector
F three ways valve
G cylinder
H piston nob

2.5.2 Influence of Obstructive Gases

Over 1,000 ppm of nitrogen dioxide, over 3,000 ppm of sulfer dioxide, or over 3,000 ppm of hydrogen sulfide gives the same type of coloring on the detector, so that it cannot tell whether carbon dioxide or other obstructive gases exists in the air.

For the current survey, we analyzed sulfer dioxide gas and hydrogen sulfide at the points P–105, L–107, L–80, and near A–18. Sulfer dioxide was not detected and hydrogen sulfide was 0 ppm except for the point near A–18 where hydrogen sulfide content was 10 ppm.

Nitrogen dioxide was not analysed because it is hardly seen in geothermal fields.

2.5.3 Survey Procedure

Survey procedure in the field is as follows.

(i) A spike with a diameter of 20 mm is driven one meter into the ground.

(ii) Immediately after the spike being pulled out, a plastic tube with a rubber plug is inserted into the hole and forced a rubber plug into the opening until a good seal can be expected. This condition was kept for about 3 minutes.

(iii) The detector pump is connected to the plastic tube. At first, air left in the plastic tube is substituted by pumping it out so that only soil air is pushed into a detector tube.

(iv) The piston of the detector pump is pulled to collect 50 ml of soil air from the ground.

(v) Collected air is pumped into a detector tube, in turn, color of detective chemical changes from pink to yellow.

(vi) The ratio of the length of yellow part to that of original glass tube filled with silica gel shows the concentration of carbon dioxide in soil air, and the value (in volume %) of CO_2 content is easily determined on the attached diagram.

2.6 1 meter Depth Ground Temperature Measurement

2.6.1 Equipment

The thermister used is as follows:

Maker:	Takara Industrial Co.
Model:	Takara thermister A600
Sensitivity:	±1.0% of reading
Temperature Range:	L: 5°C – 55°C
	H:50°C – 110°C

Power: 1.5 v D-cell battery

2.6.2 Influence of Atmospheric Temperature Variation

It is important to study how deep diurnal temperature variation affects in the ground, and at the present survey, the results obtained by the previous survey in January 1980 in the southern part of the Eburru Prospect were applied. The results show that temperature variation at 93 cm depth between 8 a.m. and 7 p.m. is only 0.6°C while atmospheric temperature changed 11.5°C. Temperature variation curve at 93 cm depth does not show significant diurnal change. Even temperature at 33 cm depth does not show significant variation. Standing on the results, temperature measurement at 1 meter deep may have a good response in the thermal condition in the relatively shallower part (shallower than several hundreds meters).

2.6.3 Survey Procedure

In the field, following procedure is taken to measure 1 m depth ground temperature.

(i) The thermister sensor is lowered into one of two 1 meter depth holes dug for soil air analysis.

(ii) The sensor is left 3 to 5 minutes in the ground to obtain stable reading on the thermister meter.

2.7 Mercury Content Measurement in Soil

In order to assure validity of mercury content in soil air and to know both the present and past geothermal activities, mercury content in 1 meter depth soil or surface soil was measured. When the soil at a survey station is too dry to take sample by an instrument, the soil sample is collected from the landsurface instead of from 1 meter deep. The survey team collected soil samples, and these had been analysed at the chemical laboratory of Mines and Geological Department, by a mercury analyser model Coleman - 50 made by Perkin Elmer.

CHAPTER 3 RESULTS

3.1 General Explanation

The geochemical survey in the Eburru Prospect was conducted from early September to late November, 1980 and the number of surveyed stations is compiled in Table III – 1.

As shown in Table III – 1, in the Northern area six survey lines (L–Q) were set, in the Central area six lines (F–K) were set, and in the Southern area five lines (A–E) were set. In Table III – 1, the words in the brackets express the number of the survey stations in the first phase field survey which had been done in January and February, 1980.

There are some survey stations at which the field survey could not carry out because of the unsuitable natural condition for the survey, and these stations were noted in the right side of the Table III – 1. The most common condition of this difficulty is caused by the outcrop of hard igneous rocks, and in this case no small diameter hole could be made, therefore, the sampling of soil air and soil and the measurement of ground temperature at 1 meter deep from landsurface were impossible.

The N–S interval of the survey lines were closer in both the Northern and Southern areas compared to that of in the Central area, and hence, in the Central area the distributional figures of each observed factor, like ground temperature and CO_2, express more general trend.

3.2 1 Meter Depth Ground Temperature Measurement

The total number of survey stations of the 2nd phase field survey is 722. The lowest ground temperature with 16.2°C was measured at the point G–158 locating about 1.5 km west of Cedar West with the altitude of 2,479.3 m above sea-level.

The highest ground temperature with 94°C was measured at the point N–83 locating about 1,500 m SE of Eburru Station with the altitude of 2,036.5 m above sea-level.

The highest elevation in all the survey stations is 2,718 m above sea-level at the point E–140 locating about 2.2 Km west of Eburru Peak, but this point does not show the lowest value in ground temperature.

The areal distribution of ground temperature is shown in Pl. III – 1. The figure shows clearly the north-south trend, and this trend is well coincide with the general trend of geological lineaments (faults).

The remarkable high temperature zones are distributed in both the Southern and Northern areas. In the Central area (F–K lines), high ground temperature is recognized in the western and central parts, however, in the two parts the values of temperature (°C) are lower than those of in the Northern and Southern areas.

The histogram of the 1 meter depth ground temperature in whole survey area is shown in Fig. III – 3. The histogram is drawn based on the data of Table III – 2. Based on the distributional trend in Fig. III – 3, to clear up the thermal characteristic in the whole area we have decided to draw the lines of 20°C, 30°C, 40°C, etc. as expressed in Pl. III – 4. The difference in elevation between the highest survey station and the lowest one reaches about 550 meters, thus, in the course of the compilation of the whole survey area, we must pay attention to the temperature difference caused by the difference in altitude. The difference in average annual temperature between the two stations is about 4°C, and in the next chapter the discussion on the matter is done.

3.3 Carbon Dioxide Content Measurement in Soil Air

The number of survey stations of CO_2 in soil air is 732, but because at the point N–109 strong microbial fermentation against recent organic matter was observed, the observed CO_2 value was abandoned, thus the total number of effective stations is reduced to 721. The general trend of distribution of CO_2 in soil air for the whole survey area as well as for the individual three areas is shown in Table III – 3, and Pl. III – 3.

The histogram of CO_2(%) in the whole survey area is shown in Fig. III – 4.

The minimum value of CO_2 content in volume % was 0.1, and this value was determined at many survey stations. The maximum values of CO_2(%) were above 20, and the values were observed at the points K–128 (Central area), C–99 (Southern area), and D–125 (Southern area).

As we can notice in Table III – 3 and Fig. III – 4, the values above 0.5% in CO_2 content may be recognized as the anomalous values from geochemical point of view.

The value of the ratio of "number of total observation stations to number of anomalous stations (0.5% $<$)" is 3.0. The value of the ratio of "number of total stations to number of highly anomalous station (1.0% $<$)" is 9.6. Therefore, one third of the total survey stations are with anomalous value, and about one tenth are with highly anomalous value.

No relationship between the areal distribution of CO_2 in soil air and the vegitation on the landsurface was recognized.

Concerning the general tendency on the distribution of CO_2 in soil air, the distributional trend is N–S, and the average value of CO_2 concentration in the Northern area is lower than those of in the Central and Southern areas.

3.4 Mercury Content Measurement in Soil Air

As shown in Table III – 1, the number of survey stations where the mercury content measurement in soil air were conducted is 722.

There was a technical problem on the measurement of mercury, because in the field, fine soil particles passed into the sample cell and this caused the instability of the equipment.

The results obtained in the field have been reexamined by us, and the detailed results and discussions will be reported in the very near future.

3.5 Mercury Content in Soil

The total number of the survey stations for the measurement of mercury content in soil is 842 as shown in Table III – 1.

The analytical results obtained by the chemical laboratory of the Mines and Geological Department are now under checking, because some values of Hg content in soil are very high composed with those of the results given in the first phase survey in January and February 1980.

In the very near future, the results and discussions on the mercury in soil will be reported.

CHAPTER 4 DISCUSSIONS

4.1 1 Meter Depth Ground Temperature

Distribution of 1 meter depth ground temperature of the whole survey area, namely the Northern area, the Central area, and the Southern area, is shown in Table III – 2.

The histograms of 1 meter depth temperature for the respective three divisional areas of the whole survey area are shown in Fig. III – 5, III – 6, and III – 7 based on the numbers shown in Table III – 2.

Comparing these three figures, the followings can be pointed out:

(1) Low temperature areas

In the Northern area (Q–L lines, Fig. III – 5): No station having the ground temperature lower than 20°C was recognized. And the value of the ratio of "number of stations below 20°C to number of stations between 20 and 25°C" is minimum (zero). Many stations of 25 – 30°C were recognised.

In the Southern area (lines A–E, Fig. III – 7): The value of the ratio of "number of stations below 20°C the number of stations between 20 and 25°C" is maximum. However, the value of the ratio of "number of stations of 25 – 29.9°C/number of stations of 20 – 25°C" is minimum.

In the Central area (line K–F, Fig. III – 6): The distributional trend of the figure lower than 29.9°C is that of the combination of the Northern and Southern areas shown in the left part of Fig. III – 6.

(2) High and moderate temperature areas

In the Northern area (Fig. III – 5), the number of points of above 30.0°C is distributed almost uniformly as seen in the figure.

In the Central and Southern area, the two figures show almost the same trend and the following tendency is observed;

30 – 65°C .... exist

70 – 80°C .... not exist

80 – 90°C .... exist

Generally speaking, the temperature distribution in the Northern area is slightly different from those in the Central and Southern areas.