REPUBLIC OF KENYA

INTERIM REPORT ON GEOTHERMAL EXPLORATION PROJECT IN THE RIFT VALLEY

JULY, 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

It is with great pleasure that I present this report entitled "Interim Report 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 October, 1979 to March, 1980 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.

July, 1980

Shizuo Kishida

Shizuo Kishida
Executive Director
Japan International Cooperation Agency

Fig. 1 Location of Project Area

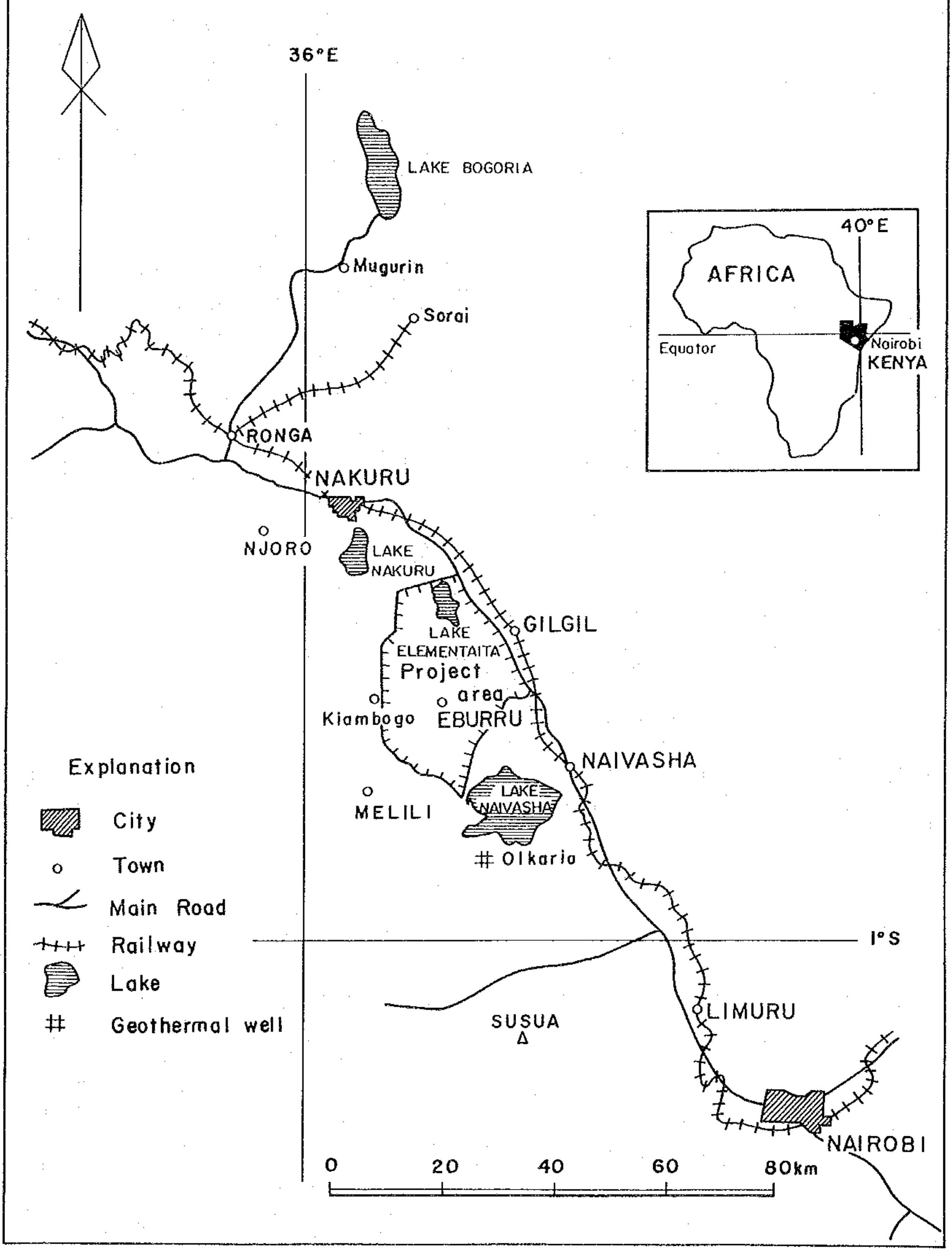
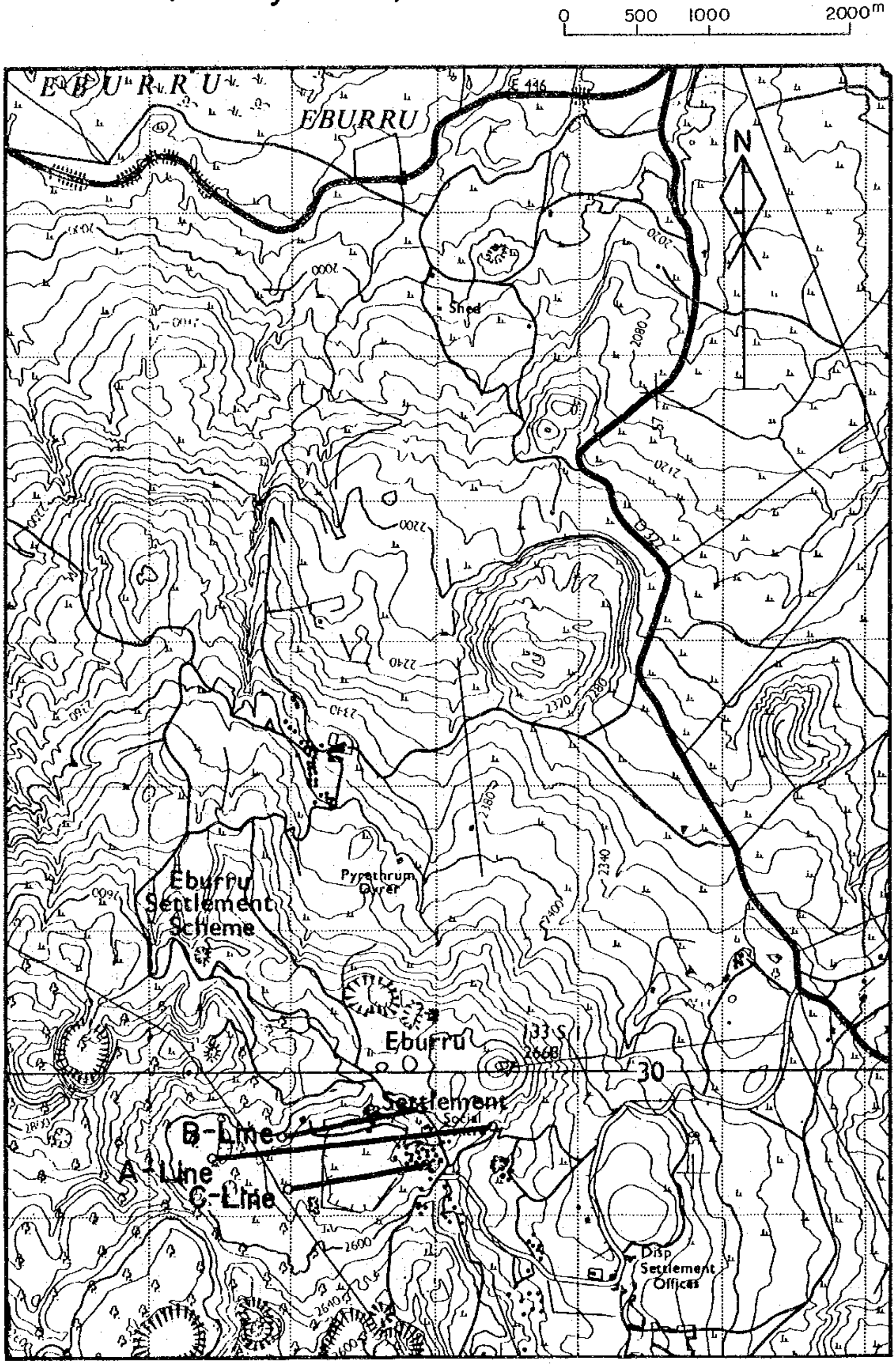


Fig. 2 Location of Project Area (Survey Lines)



SUMMARY

The Japan International Cooperation Agency sent a geothermal exploration team of five geoscientists to the Republic of Kenya during the period from December, 1979 to March, 1980 to study geothermal field in the Rift Valley.

The survey team has carried out preliminary reconnaissance survey of geology, geochemistry and geophysics in the Eburru geothermal field in the Rift Valley.

The geological survey is reconnaissance survey and temperature measurements of hot ground. The geochemical survey consists of measurements of mercury content and carbon dioxide content in soil air, and 1 m depth ground temperature along three survey lines. Supplementally, mercury content in soil was measured and some condensed water samples were collected. For geophysical survey, seven geoelectrical soundings with Schlumberger electrode array were carried out along the same survey lines for the geochemical survey.

In some places very high mercury content (6ng/1) and carbon dioxide content (50%) in soil air were measured. Coinciding with those geochemical high anomalies, high 1 m depth ground temperature of about 90°C was measured. Very low resistivity layer was detected within 100 meters from the surface of the ground.

The all techniques used for the survey are proved to be very useful for geothermal exploration in the Eburru area.

The recommendations for further exploration in the area are also stated.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

(i) There are many fumaroles and steaming grounds in the eastern part of the survey area, but we could not find any hot spring nor hot pond. Therefore, it is infered that there is no significant amount of ground water in shallow zone.

(ii) UNDP report does not report any hot ground in the western part of the area, where is covered by thick forest, but the current survey suggests that the geothermal field extends into the forest area.

(iii) In the survey area, there are many fumaroles and steaming grounds. Some of them have temperature over 90°C.

(iv) Geochemical survey detected two places with 1 m depth ground temperature being over 90°C. These two hot places extend to north-south. Around the two hot zones, mercury concentration in soil air becomes over 6 ng/1 and carbon dioxide concentration in soil air is over 20%. Background figures of them in the area are 0.5 ng/1 and 0.5% respectively. Mercury content in soil also shows the same tendency. Surface geological observation found alteration zones at about the same zones where the geochemical anomalies are.

(v) Carbon dioxide in soil air is easily dissolved in ground water and anomalous values of carbon dioxide content in soil air tend to be found in areas away from an origin of carbon dioxide. However, in the survey area, anomaly zones of carbon dioxide content in soil air are the same as them of mercury content in soil air and 1 m depth ground temperature. This fact implies that there are not large amount of shallow groundwater.

(vi) Low resistivity zone is found in all resistivity soundings. Its resistivity values as low as 10Ω•m. is very common value for a large geothermal reservoir.

(vii) In the Eburru caldera, the surface of the low resistivity zone becomes deeper toward west.

2. Recommendations

The current survey suggests that geothermal energy reserves of the survey area are sufficiently large and the survey area is very promissing for geothermal development. Survey techniques which have been used for the current survey are proved to be suitable for geothermal exploration in the Eburru geothermal area. On the basis of it, we recommend the following steps to choose the definite places to be developed and to evaluate geothermal potentiality of the area.

2-1 Reconnaissance Survey

Reconnaissance survey consisting of the follows is to choose some detail survey areas of approximately 2 km x 2 km from the whole survey area. Reconnaissance survey is also used to decide several (about five) drilling sites for shallow wells (around 400 meter deep) for measuring underground temperature gradient and studying geological formations.

(i) Measurements of mercury concentration and carbon dioxide concentration in soil air, and 1 m depth ground temperature are to be carried out at more than 600 points where infrared photo and surface temperature measurement prove as high heat flow areas for geothermal development.

(ii) Geoelectrical soundings by Schlumberger array with maximum current electrode separation being 3,000 meters are to be carried out along survey lines (total length being more than 15 km) at the high heat flow areas.

(iii) Reconnaissance survey and laboratory survey of alteration zones are needed to be done. In laboratory, mineralogy of alteration will be studied. Geological and geothermal structure in the area will be inferred by collective study of all survey.

2-2 Detail Survey

The following survey is needed in the detail survey areas being selected by reconnaissance survey. The inferred geological and geothermal structure of the area will be made more accurate, and the positions of a deep well will be decided.

(i) About five shallow wells will be drilled to study temperature gradient and geological structure of the area.

(ii) The same techniques as used for the reconnaissance survey will also be carried out in the detail survey areas for studying details of their geology and deciding the place where a deep well to reach a geothermal reservoir will be drilled.

2-3 Deep Well Drilling

A deep well to reach a geothermal reservoir will be drilled at the place which is chosen by the detail survey as the most suitable place for geothermal development.

The deep well will be drilled to study geological structure, and position and nature of a geothermal reservoir. If possible, production test of the well will be done. Considering depth of the geothermal reservoir and the elevation of the Olkaria geothermal field about 50 km south of the Eburru field and elevation of water surface of Naivasha Lake, a geothermal reservoir in the survey area may be below 1,000 meters. Therefore a deep well will need to be over 1,000 meter deep.

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I OUTLINE

CHAPTER 1 INTRODUCTION

1-1 Purpose of the Survey and Survey Items

1-1-1 Purpose

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

1-1-2 Survey Items

(i) Study of Existing Papers and General Examination

Existing papers concerning the survey area were collected and their results were studied to make the survey plans and to familiarize the survey team to the area.

(ii) Geological Survey

Basic geothermal structure was studied by using many publications. Moreover ground-surface temperature was measured at many geothermal manifestations by an infrared spot sensor.

(iii) Geochemical Survey

Geothermal underground structure was inferred by measuring concentrations of volatile elements (Hg and CO_2) in soil air and 1 meter depth ground temperature.

(iv) Geophysical Survey

Galvanic geoelectrical sounding was carried out to study underground structures and geothermal reservoir.

1-2 Location of The Survey Area

The survey area is in the Rift Valley centered by the Eburru colony and about 950 km^2.

Field survey done is as follows:

(i) Geological Survey

Ground surface temperature measurement by a spot sensor at 9 points.

(ii) Geochemical Survey

Hg concentration in soil air	72 pts.
CO_2 concentration in soil air	72 pts.
1 meter depth ground temperature	72 pts.
Soil sample	72 pcs.
Condensed water sample	8 pcs.

(iii) Geophysical Survey

geoelectrical sounding by Schlumberger electrode array

Length of survey line	4 km
Survey points	7 pts.

1-3 Survey Team

The members of the survey team are as follows:

Leader	Dr. Koji Motojima (geologist/geochemist)	Geological Survey of Japan.
	Dr. Kenzo Baba (geologist/geophysicist)	Geological Survey of Japan.
Deputy Leader	Dr. Takashi Ohya (geophysicist)	MESCO Inc.
	Tadao Mizuguchi (geophysicist/geochemist)	MESCO Inc.
	Kazuo Hirowatari (geochemist)	MESCO Inc.
Coordinator	Setsuo Takemoto	JICA

	1979			1980		
	Oct.	November	December	January	February	March
S/W Mission	22	5				
Preparation			3	19		
Field Survey			19		4	
Reporting					5	10

1-4 Circumstances

There has not been found any notable energy resource in Kenya except some hydro-power and geothermal resources. Development of new energy resource has been long waited in Kenya, because electricity consumption has been increasing very rapidly.

UNDP (United Nations Development Program) carried out geothermal exploration in the Rift Valley in six years from 1970 till 1976.

The UNDP survey recommended the following three geothermal development programs;

(i) continue to drill production wells in Olkaria area and obtain enough steam to generate electricity,

(ii) drill slim holes in Olkaria area in order to evaluate geothermal reserves of the area and to decide locations of production wells, and

(iii) do reconnaissance survey in the following three areas (total area: 45 km x 10 km) to obtain information about geothermal potential.

(a) Kedong Valley: Area between Suswa Mountain and Hells Gate

(b) Naivasha-Eburru: Area between Olidien Bay and Lake Elementeita

(c) East Molo: Area between Meneugai Crater and Lake Hannington (now being called Lake Bogoria)

The Kenya government ordered Mines and Geology Department of Ministry of Natural Resources (MNR) to follow up the above mentioned programs. MNR requested the Japanese government to take up the above mentioned program (iii) and survey the geothermal areas in the Rift Valley. In turn, Ministry of International Trade and Industry (MITI) of the Japanese government sent the preliminary survey team on February, 1979 through the Japan International Cooperation Agency (JICA).

The current geothermal exploration survey team were sent to conduct geological survey, geochemical survey, and geophysical survey, following the recommendation of the preliminary survey mission.

The survey area, the Eburru area, neighbors the Olkaria geothernal area. Its geological environment is similar to that of the Olkaria area, and if electricity is generated in the Eburru area, it might be operated together with the Olkaria power plant. Therefore, the Eburru area was chosen as the project area.

In the Kenyan government structure, underground energy resources were formerly under MNR, but it was transferred to newly created Ministry of Energy on November, 1979.

CHAPTER 2 ENERGY OF KENYA

2-1 Energy Resources

The Republic of Kenya does not have found any energy resources except hydropower and geothermal energy in the Rift Valley. Therefore, she depends heavily upon imported petroleum energy and wood. Demand for crude oil as fuel for industries and thermal power stations increases rapidly and it is hoped to discover and to develop new energy resources.

Quantity and value of imports and exports of petroleum products between 1974 and 1978 are shown in Table I-1, and trade and consumption of energy is shown in Table I-2.

2-2 Electric Power Generation

Electric power generation and its distribution are done by the following three organizations under the governmental guidance of Ministry of Energy.

i) East African Power & Lighting Co., Ltd. (EAPL)
   EAPL owns power stations and power lines, distributes electricity all over the country, and joins in the management of KPC and TRDC.

ii) Kenya Power Co., Ltd. (KPC)
   KPC buys 30 MW of electricity from Uganda and sells it to EAPL, and owns two hydropower stations in the upstream of the Tana River.

iii) Tana River Development Co., Ltd (TRDC)
   TRDC was established to develop hydropower resources in the midstream of the Tana River and owns two hydropower stations.

Energy consumption in Kenya increased very rapidly accompanying with promotion of industry and escalation of living standard.

Electricity consumption has increased about 10% every year (see Table I-3), furthermore its consumption for industries increased remarkably. On 1970, industrial consumption of electricity was 27% of total electricity consumption of the country, but it became about 50% on 1974.

Before 1970, 30% of total electricity supply came from Uganda, but it gradually decreased as 26% on 1974, 22% on 1975, 18% on 1976, 20% in 1977, and 14% on 1978.

Internal electric power generation mostly comes from hydropower stations along the Tana River and thermal power stations around Mombasa. Because, after the oil crisis, price for petroleum increased drastically, the Kenya government re-considered capability of electricity generation of the Tana River (3,570,000 MWH) and is developing the Tana River.

Installed capacity of hydropower generation became larger and ratio of hydro and thermo power generation was about one on 1977 and became 7/4 on 1978.

Electricity supply is forecasted to depend more upon hydropower generation and is expected to come from geothermal power generation.

2-3 Outline of Geothermal Field

General geology of the Rift Valley, which is the geothermal area in Kenya, is as follows (see Fig. II-1).

Kenya is in the eastern edge of the African shield, and two thirds of she is covered by Precambrian basement. The Precambrian basement is in the center and the western part of the country, and basalts and its clastics of Miocene are distributed around the Rift Valley over the basement.

The Rift Valley runs in north-south of Kenya from the Tanzanian border to the Ethiopian border and is very large graben with a width of 30 ~ 65 km and a fall of 600~900 m. The both edges of the Rift Valley are cut mostly by normal faults with a dip of 60 degree.

Most cases, many normal faults are combined to form a single edge of the Rift Valley like steps. In the Rift Valley, there are many volcanoes and salt lakes except Naivasha Lake. There have been many anomalous geophysical phenomena observed, like micro earthquakes, Bouguer anomalies, high heat flow, magnetic anomalies, etc. Many fumaroles accompanied by kaolinization are seen. Reasons for these anomalous phenomena have been studied and many hypotheses such as horizontal expansion or shrinkage of crust, uplift of crust, activity of magma, etc. have been advocated.

The United Nations Development Program (UNDP) has carried out preliminary survey about geothermal energy in the Rift Valley. As its result, some geothermal production wells are drilled in the Olkaria area, south of Naivasha Lake.

2-4 Geothermal Development and Power Generation Plan

UNDP carried out the following survey during 1970 and 1976 because of anomalous high heat flow in the Rift Valley.

i) Geological and geophysical reconnaissance were carried out in the stretched area (480 km long) between north of Lake Magadi and south of Lake Turkana.

ii) As detailed survey, two holes were drilled with bottom temperature of 250°C and 320°C, and geological survey was carried out in the Olkaria area, south of Lake Naivasha.

iii) As a result of the above survey, the Kenyan government continued to drill many production wells and is constructing power plant, which is supposed to be completed on 1981, in the Olkaria area.

UNDP survey pointed out three potent geothermal areas, namely, Kedong Valley, Naivasha-Eburru Area, and East Molo Area.

The detail geological survey in the Olkaria area reported that the geothermal deposit is distributed in one square kilometer and its potential is 32,000 kWh. Therefore, the Kenyan government ordered KPC to drill production wells under a guidance of EAPL with financial aid of the Second World Bank. Following to the start of drilling, construction of a power plant with capacity of 15 MW is starting as the first phase which ends by 1981. As the second phase, construction of a 15 MW power plant is planned to be completed on 1983.

Table I-1 Quantity and Value of Imports and Exports of Petroleum Products, 1974-1978

	1974		1975		1976		1977		1978	
	Quantity '000 tonnes	Value KŁ'000	Quantity '000 tonnes	Value KŁ'000	Quantity '000 tonnes	Value KŁ'000	Quantity '000 tonnes	Value KŁ'000	Quantity '000 tonnes	Value KŁ'000
Imports -										
Crude Petroleum	2,902.9	67,027.0	2,824.9	86,822.4	2,496.7	93,469.5	2,551.5	100,158.4	2,369.2	92,337.6
Petroleum Fuels	129.9	6,279.7	16.7	1,249.1	47.7	3,345.7	104.7	8,269.9	258.3	16,899.4
Lubricating oils	100.5	6,885.4	77.6	6,158.1	53.0	5,678.9	73.9	6,927.7	65.4	6,636.1
Lubricating greases	0.4	95.9	0.3	73.7	0.1	41.5	0.2	65.1	0.2	75.2
Total	3,133.7	80,288.0	2,919.5	94,343.3	2,597.5	102,535.6	2,730.0	115,421.1	2,693.1	115,948.3
Exports -										
Petroleum Fuels	1,588.7	37,981.3	1,318.1	45,988.4	1,372.0	57,603.4	1,365.0	72,398.3	1,173.3	60,372.6
Lubricating oils	60.4	6,728.5	57.3	8,670.7	57.3	10,584.7	50.0	10,253.8	38.9	8,172.2
Lubricating greases	2.7	469.8	2.2	478.7	1.5	372.2	1.5	350.3	1.3	378.7
Total	1,651.8	45,178.8	1,377.9	55,137.4	1,430.8	68,560.3	1,416.5	83,002.4	1,213.5	68,923.5

Source: E.A. Oil Refinery.

Table I-2 Production Trade and Consumption of Energy Expressed in Terms of the Primary Sources, 1974-1978

'000 Tonnes Oil Equivalent

	1974	1975	1976	1977	1978
Coal and Coke Imports	46.6	32.1	44.9	43.8	34.8
Oil -					
Imports of crude oil	2,902.9	2,824.9	2,496.7	2,551.5	2,369.2
Net exports of petroleum fuels	-1,458.8	-1,301.4	-1,324.3	-1,260.3	-1,195.9
Stock changes and balancing item	-91.4	-130.7	391.1	314.7	486.6
Total Consumption of Liquid Fuels	1,352.7	1,392.8	1,563.5	1,605.9	1,659.9
Hydro Energy -					
Local production of hydro-power	131.3	155.8	140.0	167.4	275.5
Imports of hydro-power	71.0	62.6	58.1	65.2	52.1
Total Consumption of Hydro-Energy	202.3	218.4	198.1	232.6	309.8
Total Local Energy Production	131.3	155.8	140.0	167.4	257.5
Total Imports	1,561.7	1,618.2	1,275.5	1,400.2	1,260.3
Use of stock and balancing item	-91.4	-130.7	391.1	314.7	486.6
Total Energy Consumption	1,601.6	1,643.3	1,806.5	1,882.3	2,004.4
Local Production as Percentage of Total	8.2	9.5	7.7	8.9	12.8
Per Capita Consumption in Terms of Kilogram of Oil Equivalent	123	125	130	131	135

Source: Central Bureau of Statistics.

* Modern sector only: fuelwood and charcoal are excluded.

Table I-3 Electricity Energy Supply and Demand Balance, 1974-1978

GWH

	1974	1975	1976	1977	1978
Demand -					
Residential	205.6	300.9	300.1	303.5	328.5
Commercial and light intustrial	246.6	263.3	272.9	301.2	321.2
Industrial	532.7	496.6	568.9	658.1	710.4
Street Lighting	10.1	10.7	10.6	10.8	10.4
Total	995.0	1,071.5	1,152.5	1,273.6	1,370.5
Transmission losses and unallocated demand	144.7	121.1	196.6	83.7	203.2
Total Demand = Total Supply	1,139.7	1,192.6	1,322.1	1,357.3	1,573.7
Of which imports*	296.0	260.8	241.9	271.8	217.0
Net generation	843.8	931.8	1,080.2	1,085.5	1,356.7

Source: The E.A. Power and Lighting Co. Ltd.

* Imports from Uganda

Table I-4 Installed Capacity and Generation of Electricity, 1974-1978

	Installed Capacity* MW**			Generation* GWH[1]		
	Hydro	Thermal	Total	Hydro	Thermal	Total
1974	139.1	145.1	284.1	547.1	322.6	869.7
1975	139.1	144.0	283.1	649.1	322.2	971.2
1976	171.4	181.7	353.1	583.2	574.7	1,157.9
1977	173.5	182.9	356.4	749.3	364.0	1,113.3
1978	311.5	171.6	483.1	1,072.8	308.9	1,381.7

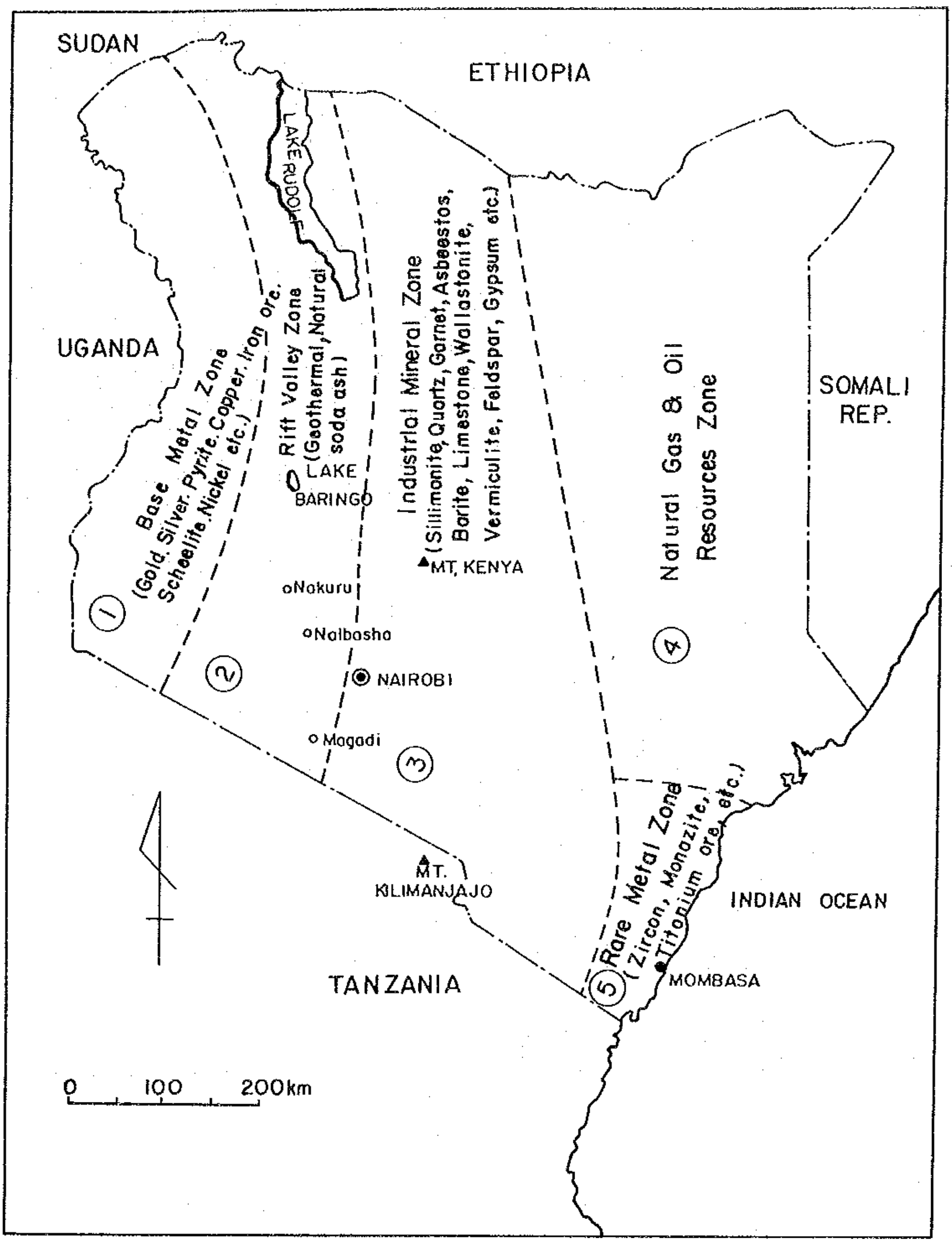
Source: The E.A. Power and Lighting Co. Ltd.

* Includes estimates for industrial establishments with generation capacity.

** 1 megawatt = 1 million watts = 1,000 Kilowatts.

[1] 1 gigawatt hour = 1,000,000 kilowatt hours.

Fig. I-1 Mineral Resources Map of Kenya



CHAPTER 3 GENERAL DESCRIPTION OF THE SURVEY AREA

3-1 Location and Transportation

The survey area is centered at the latitude 0°39' south and the longitude 36°17' east and is 25 km long east-west and 30 km north-south. It belongs administratively to Rift Valley district.

Naivasha Lake at the south of the area is the only fresh water lake in the Rift Valley. Olkaria where new geothermal power plant is being constructed is 20 km south of the lake. At the north of the survey area there are Lake Elementita and townships of Gilgil and Nakuru.

Road leading from Nairobi to the area is the international highway A104 up to Naivasha, which is the most important highway to Uganda, and from Naivash to the survey area is an unpaved local road. It takes about two hours from Nairobi by an automobile.

3-2 General Nature of the Area

The survey area is neighboring to the west edge of the Rift Valley. Topography of the western side and the eastern side of the area is different.

The eastern side of the area is mostly gentle hills at the altitude of about 2,000 m, semi-arid weather and is partly cultivated where principal agriculture products of the area are potato, pyrethrum, and maize.

The western side of the area is more mountainous with peaks over 2,500 m. Mountains range to the western fringe of the Rift Valley. The mountains are mostly covered by heavy eucalyptus forest and many wild animals, like buffalos, are living in the forest. In the mountains there are craters and calderas.

Climatically, the area has modest amount of rain fall. Temperature rises to over 20°C in the daytime and falls below 10°C during the night time (see Fig. I-2, and Table I-6).

Table I-5 Projected Supply Potential and Demand, 1983-2000

(Megawatts)

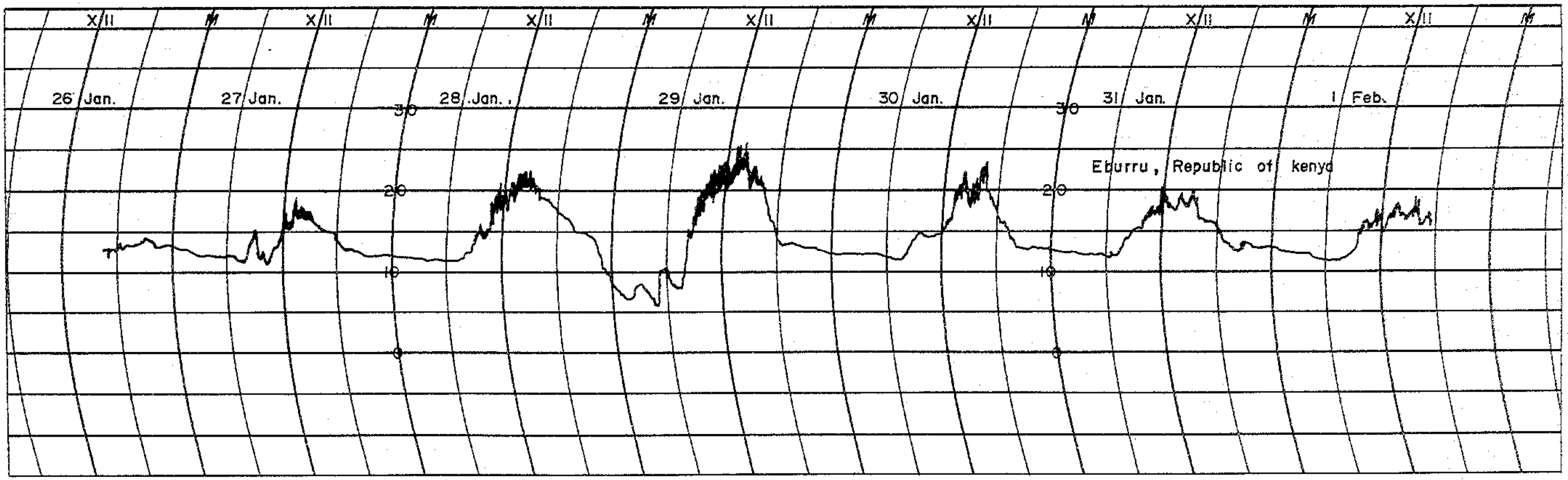
	1983	1988	1993	2000
Hydro	600	600	600	600
Geothermal	30	170	500	500
Total supply potential	630	770	1,100	1,100
Projected demand	362	517	747	1,267
Surplus/deficit	268	253	353	-167

Source: Central Bureau of Statistics.

Table I-6 Atmospheric Pressure Measurement

Location	At Mine and Geological Department NAIROBI, KENYA		
Elevation	1,633.0 m		
Date	24, Jan.	11, Feb.	3, Mar.
Temperature	25.0 °C	23.0 °C	26.0 °C
Atmospheric Pressure	633.0 m/mHg	632.0 m/mHg	630.0 m/mHg

Fig. I - 2 Diurnal Temperature Variation in the Eburru Area



II RECONNAISSANCE SURVEY
OF
GEOTHERMAL FEATURES
AT EBURRU GEOTHERMAL AREA

The field survey at the Eburru geothermal area was carried out for about ten days from 25 January, 1980 by the JICA survey mission of 1979 fiscal year. The present writer conducted the reconaissance geologic survey concentrated especially to the surface geothermal features there during his stay as a member of the mission. The survey was done with the cooperation of counterparts of Ministry of Environment and Natural Resources and Ministry of Energy of the Kenya Government. This is a preliminary note of the survey.

The Eburru geothermal area of which northern, southern, eastern, and western boundaries are respectively about two kilometers north of old Eburru station, about three kilometers south of Eburru mountain (2,668 meters above the sea level), about one kilometer east of the mountain and about three kilometers west of the mountain, covers about 44 square kilometers area. The distance from east to west of the area is about four kilometers and the one from north to south is about eleven kilometers.

The area is entirely covered by the volcanic products from the Lower Pleistocene to the Recent. The Eburru mountain range in the area is a big composite volcano which has many craters and cinder cones ranged from north to south. In the same direction, there are distributed many geologic faults along which surface geothermal activities can be seen. Many surface geothermal features are distributed widely in the area and they are often associated with hydrothermally altered zones. The alteration on the surface is mainly kaolinization.

Glover (1972) showed a hundred and seventy points of warm ground by utilizing the result of the infrared survey applied in the Eburru area. They are distributed widely in this area.

The surface geothermal features are generally classified into hot spring, geyser, fumarole, steaming ground, hot pool, mud pot, etc. The main geothermal features in the Eburru geothermal area are the fumaroles and steaming grounds. The steaming ground is defined as the ground where the distinct fumarole can not be seen but steam is being discharged from the underground.

The geothermal features which have the large mass-flow rate like hot spring or hot pool can scarcely be seen in this area, and this is thought to be due to the lack of the underground water especially at the shallow places. The geothermal fluid discharged from fumarole and steaming ground consists of mainly wet steam in the saturated state.

The temperatures measured in this reconnaissance survey are shown in the table II-1. The locality numbers used in the table are the same to ones given by Glover. Judging from this measurement, it is thought that the temperature of discharging steam is almost in the saturated one (between 90°C and 95°C). All of features other than fumarole and steaming ground are in very small scale. The features at the locality No. 52-55 which is situated in the western end of the area, seem to show the most activity from the view point of heat discharge. Though there is not yet found any surface geothermal features in the Eburru forest which is situated in the western side of the site of No. 52-55, this shows the possibility that the geothermal area extends to there.

The geochemical work done by Glover as a survey on the surface geothermal feature in this area is very useful for the exploration of geothermal reservoir hereafter. Besides it, the geological work on the hydrothermally altered zones, most of which are associated with the present thermal anomally, will give another useful result for the exploration. Mentioning on the geological work, it should be quite interesting to apply photogeologic method for making clear the relation between the fault structures and the distribution of the surface geothermal features. Heat discharge measurement at the surface feature will also give a useful information to decide the target for the future detailed survey.

Table II-1 Temperature Measured at Geothermal Features

(Temperature in °C)

Place No.	Fumarole	Steaming Ground	Hot Pond
17	84.7	70.0, 77.8, 78.4	
38		56.0	
52 - 55	90.7	88.2	56.0
60		77.0	
71, 72	88.0		

Fig. II - 1 Geological Map of Kenya

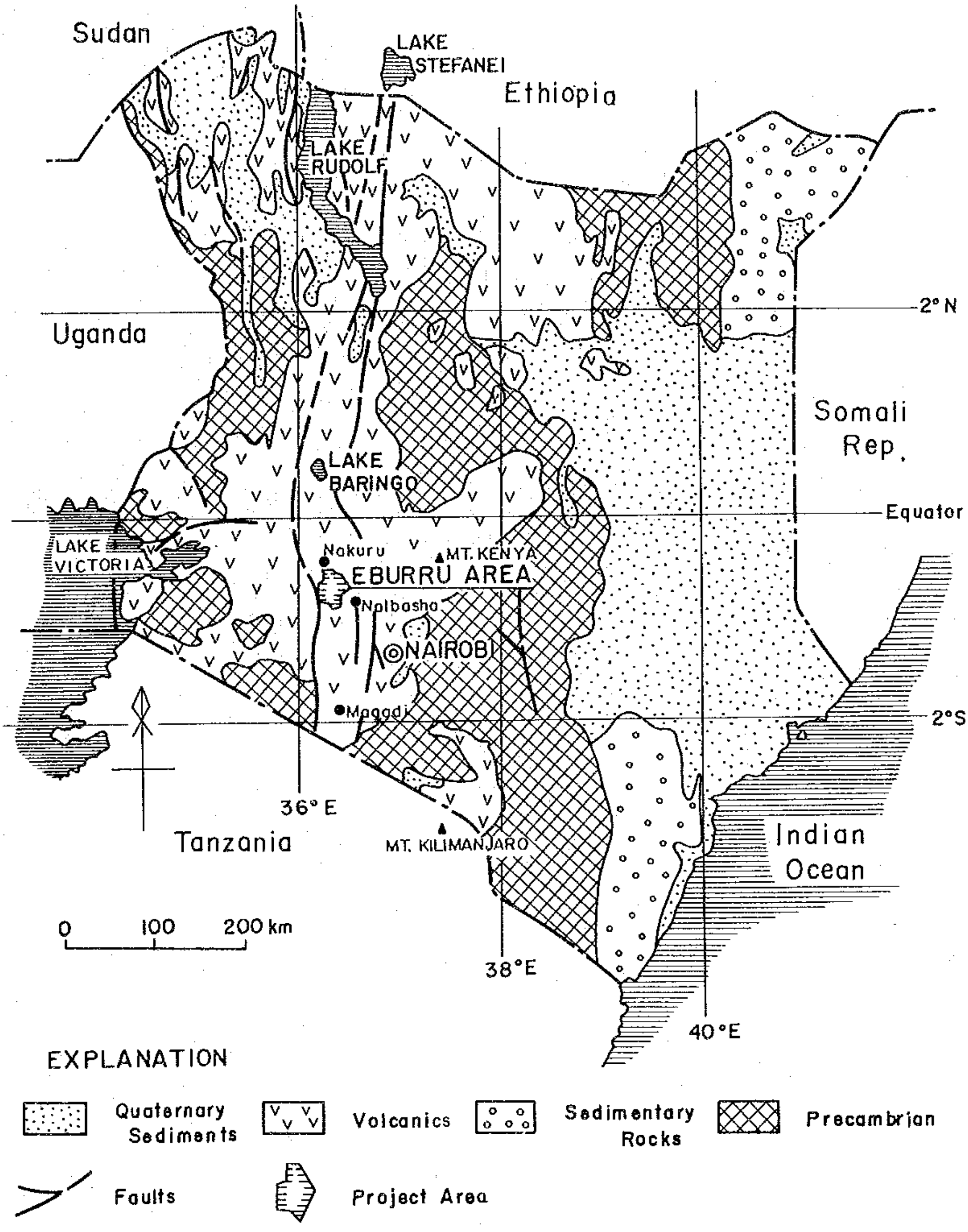
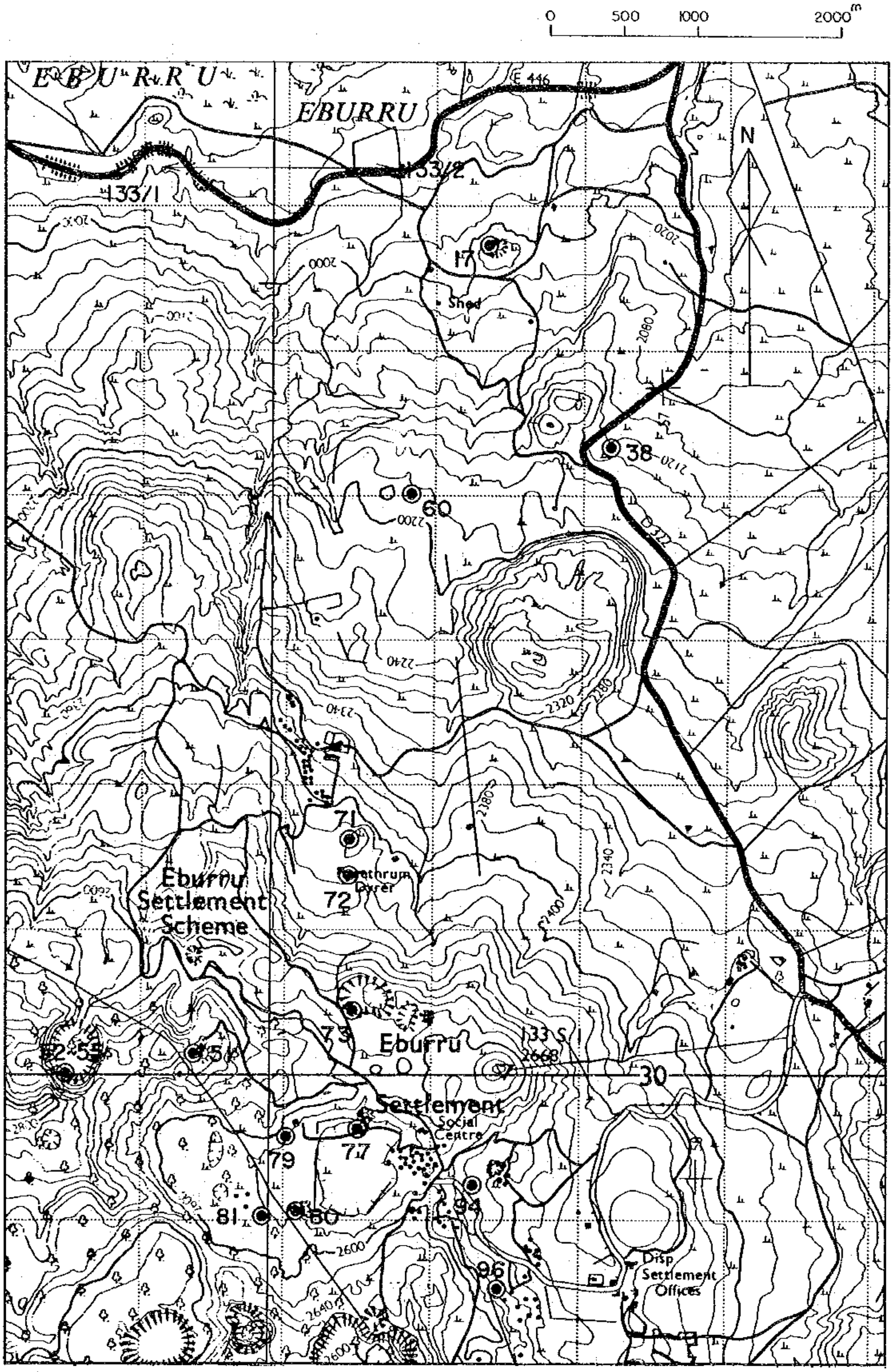


Fig. II-2 Location Map of Temperature Measured at Surface Geothermal Features EBURU FOREST



III GEOCHEMICAL SURVEY

CHAPTER 1 INTRODUCTION

Geothermal features in the survey area, which are easily seen on the ground, are hot springs, fumaroles, and alteration zones. Geochemical exploration technique has been developed for steam dominated and hot water dominated geothermal reservoir.

In the past, geochemical exploration technique was mostly employed for hot water dominated geothermal system. For hot water system, water samples from many hot springs are analyzed to estimate temperature and origin of underground hot water reservoir.

In steam dominated geothermal area, gas content in fumarole, and volatile matter content (namely Hg, As etc.) in condensed water or in alteration clay are measured to evaluate and to explore geothermal reservoir.

Recently, some geothermal areas with very little or without any surface manifestations are geochemically surveyed by analyzing mercury content in soil air.

As a result of the reconnaissance survey of the area, there have been found many fumaroles and alteration zones but no hot springs. Therefore, it is suggested to use "mercury analysis method" as the main geochemical exploration tool, because of its quickness and easiness of execution.

For the current geochemical survey, the following are employed:

(i) Mercury content in 1 meter depth soil air,

(ii) carbon dioxide content in 1 meter depth soil air,
and

(iii) temperature distribution in 1 meter depth ground.

The (iii) is usually considered as a geophysical technique but here we classified it as a geochemical technique because for measuring temperature at 1 meter deep, a hole drilled for analysis of soil air is used.

Furthermore, we took samples to study following items. Samples were analyzed by geochemical section of Mines and Geology Department, Ministry of Environment and Natural Resources.

(i) Distribution of mercury content in 1 meter depth soil.

(ii) Mercury and arsenic content in condensed water from fumaroles.

(iii) Sodium and potassium content in condensed water from fumaroles.

Most fumaroles in the survey area are covered by water condensers to collect condensed water for drinking, so it was not easy to collect gas samples from those fumaroles.

CHAPTER 2 SURVEY METHOD

2-1 Reconnaissance

In the survey area, there are many small faults in north-south direction accompanying fumaroles and alteration zones. It is thought that geothermal fluid rises through those faults and branched fissures from deep ground.

Geochemical reconnaissance was carried out around the Eburru Caldera. Eight condensed water samples were collected at fumaroles shown in Fig. III-1.

Point F in Fig. III-1, south of Ex-Lews Village, is not pointed out on UNDP report.

At point C on Fig. III-1, there are two hot water ponds neighboring to fumaroles. Those hot water ponds are not hot water springs but just collection of condensed water from fumaroles which are used for washing.

2-2 Measurement

Three survey lines, A (2 km long), B (1 km) and C (1 km), directing east to west are set in and around the caldera south west of the Eburru mountain. Stations are established 50 meters intervals in the caldera and every 100 meters at periphery of the caldera. Total number of stations is 72 points. The three survey lines are also used for the electrical survey. At the base stations A-20, B-20 and C-20, concrete bench marks were buried and wooden pegs were used for other stations.

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 immediately after being 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.

Eight condensed water samples were collected from fumaroles in and around the caldera. The condensed water samples were added concentrated nitric acid to give their pH below one and were sent for analyses of mercury and arcenic.

In order to study influence of diurnal temperature variation to 1 meter depth ground temperature, temperature at 33 cm depth, 60 cm depth, and 93 cm depth was continuously measured at the camp site.

2-3 Mercury Content Measurement in Soil Air

2-3-1 Equipment

Mercury Spectrometer is used for mercury content measurement in soil air. Its specification is as follows:

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 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.

Gold thread has also been used for mercury analysis in soil air. Gold thread can absorb mercury vapor in soil air as gold amalgam of mercury, and absorbed mercury is analyzed by mercury analyzer after gold thread is being heated to free mercury atoms.

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

2-3-2 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 (see Fig. III-3). The analyzer was calibrated twice, before and after the field survey. The two calibration results show good agreement.

2-3-3 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.

2-4 Carbon Dioxide Content Measurement in Soil Air

2-4-1 Equipment

Carbon dioxide gas detector is used for measurement (see Fig. III-4). 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.

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.

2-4-2 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 can not 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 station A-22.5. Sulfer dioxide was not detected and hydrogen sulfide was under 2 ppm. Nitrogen dioxide was not analyzed because it is hardly seen in geothermal field.

2-4-3 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.

(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.

2-5 1 meter Depth Ground Temperature Measurement

2-5-1 Equipment

The thermister used is as follows.

Maker:	Takara Industrial Co.
Model:	Takara thermister A600
Sensitivity:	$\pm$ 1.0% of reading
Temperature Range:	L 5°C ~ 55°C
	H 50°C ~ 110°C
Power:	1.5 v D-cell battery

2-5-2 Influence of Atmospheric Temperature Variation

It is important to study how deep diurnal temperature variation affects in the ground. Temperature at 33 cm depth, 60 cm depth and 93 cm depth in the ground is continuously measured at the camp site.

The result is shown in Fig. III-5. 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. Temperature gradient into the ground is 2°C every 30 cm and is very high, so it can say that the camp site is not far from underground heat source.

2-5-3 Survey Procedure

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

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

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

2-6 Mercury Content Measurement in Soil

In order to assure validity of mercury content in soil air, mercury content in 1 meter depth soil is measured. The survey team only collected soil samples and sent them to Mines and Geology Department for analysis.

Collected samples were analyzed by a mercury analyzer model Coleman-50, made by Perkin Elmer.

2-7 Mercury, Arsenic, and Other Element Content in Condensed Water

For background geochemical knowledge of the area, eight condensed water samples were collected and were sent to Mines and Geology Department for analysis. When condensed water samples were collected, five milliliter of concentrated nitric acid was added to samples to give their pH below one so that solved mercury is protected from vaporizing away.

Fig. III-1 Location of Condensed Water Sampled

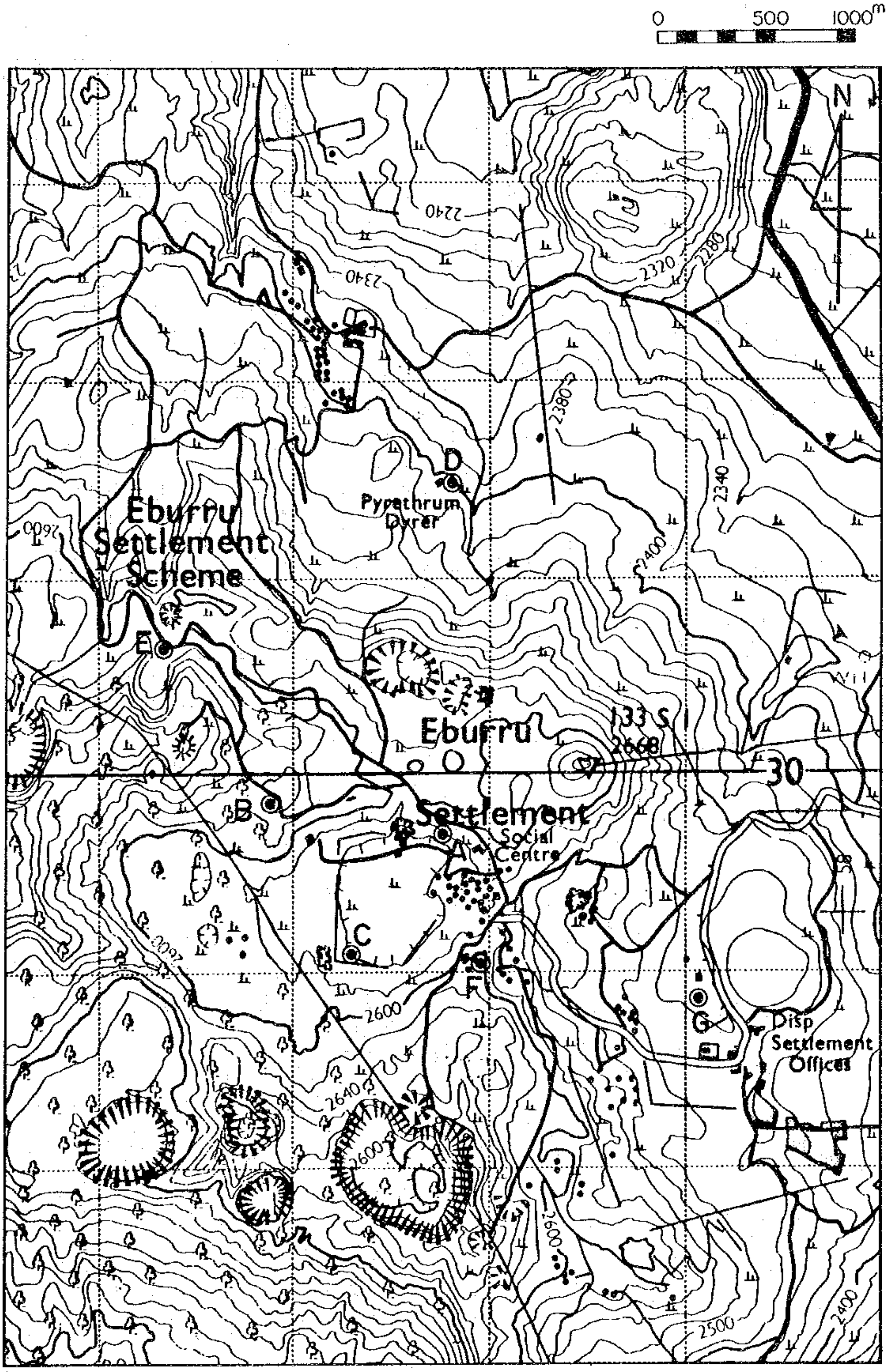
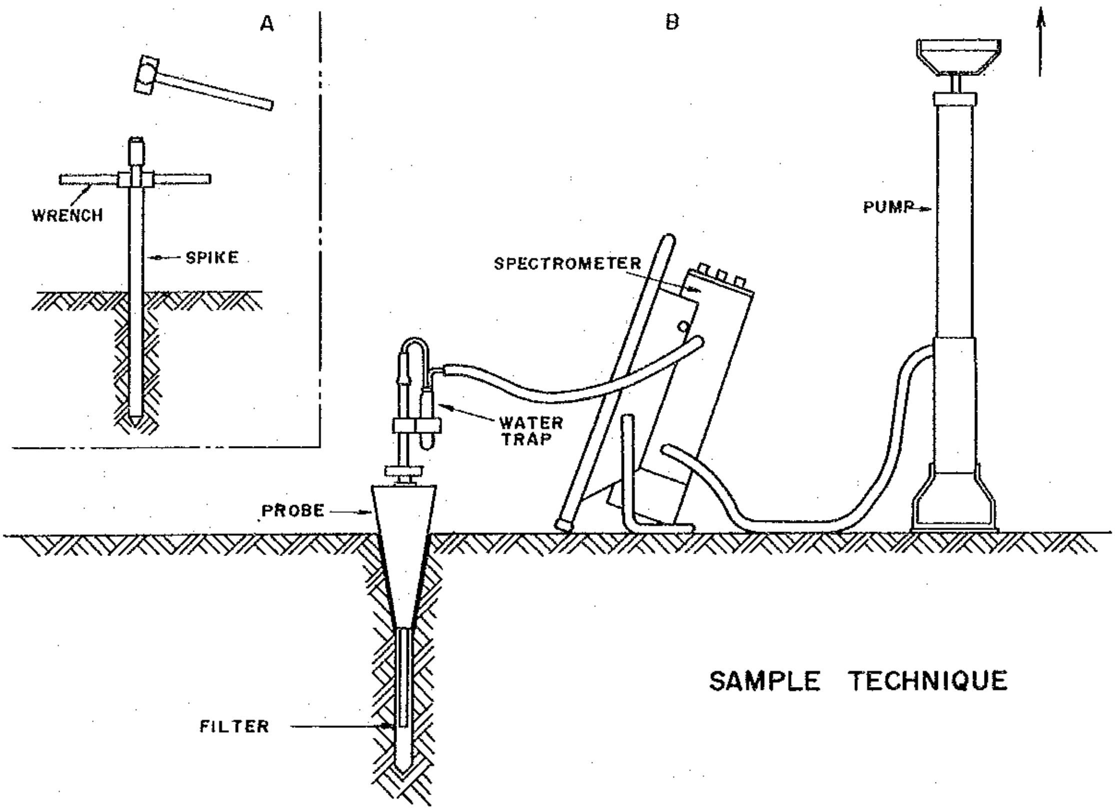
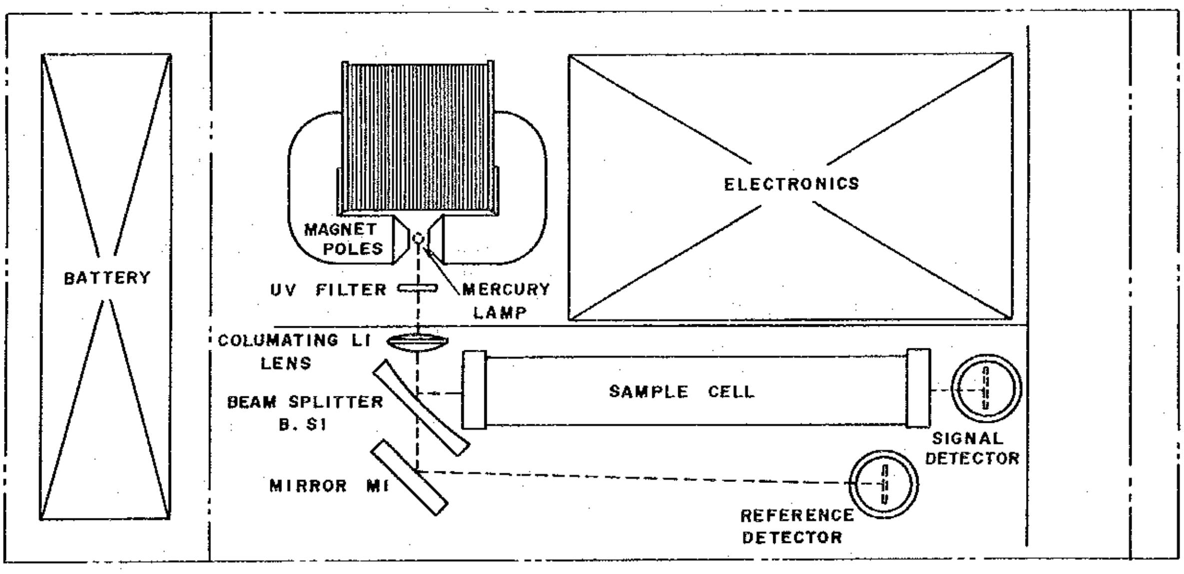


Fig. Ⅲ-2 MERCURY SPECTROMETER

SCINTREX HGG - 3



SAMPLE TECHNIQUE



HGG - 3 BACKPACK SPECTROMETER

Fig. Ⅲ - 3 Calibration Curve of Mercury Spectrometer

1980

Before work 23. Jan.	Standard gas (ng/ℓ)	1.69	3.37	5.06	6.75	8.43	10.12	12.65
	Indicator (m V)	34	70	104	136	171	193	233
After work 5. Feb.	Standard gas (ng/ℓ)	0.74	2.96	5.92	8.88			
	Indicator (m V)	18	60	114	170			

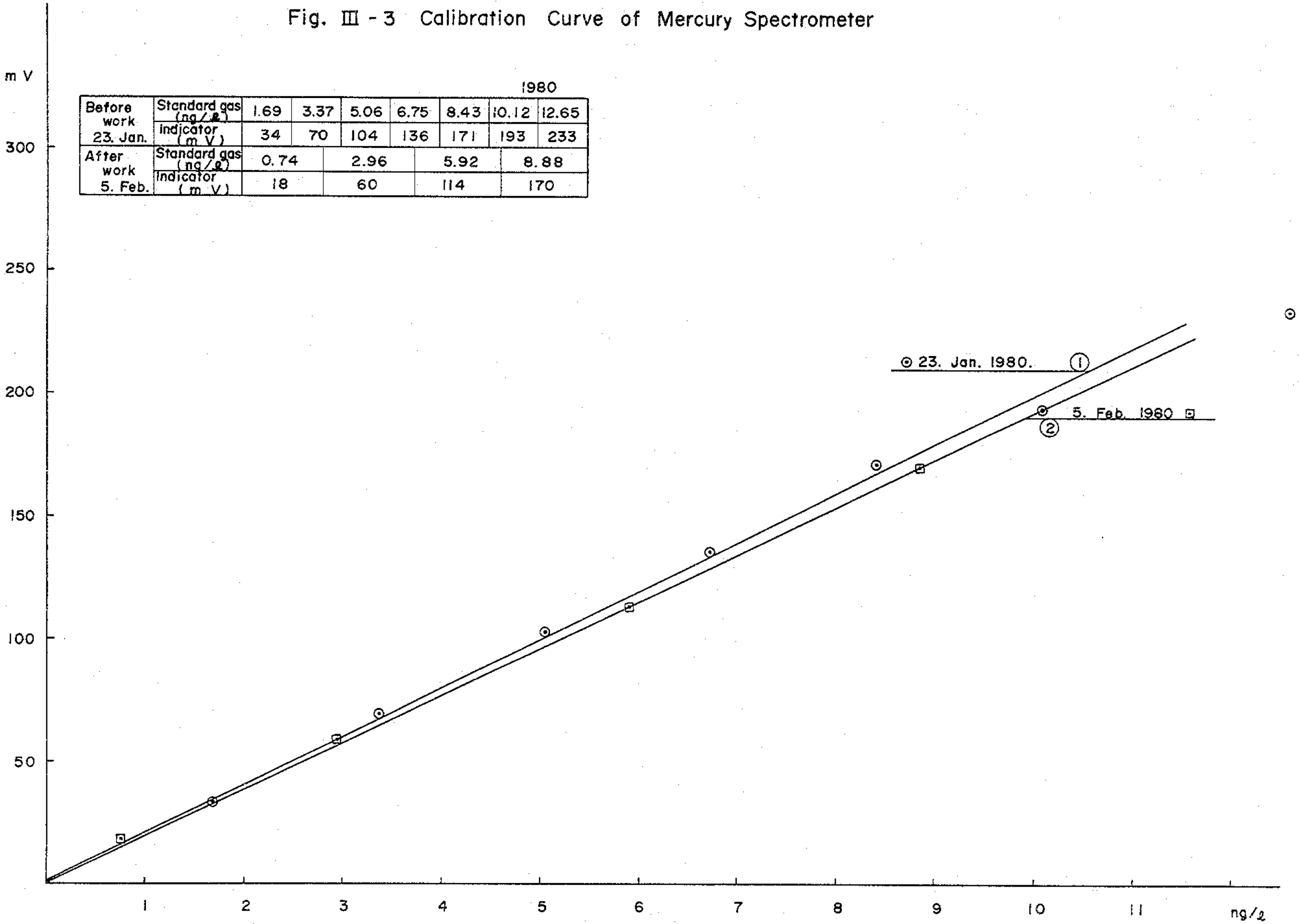
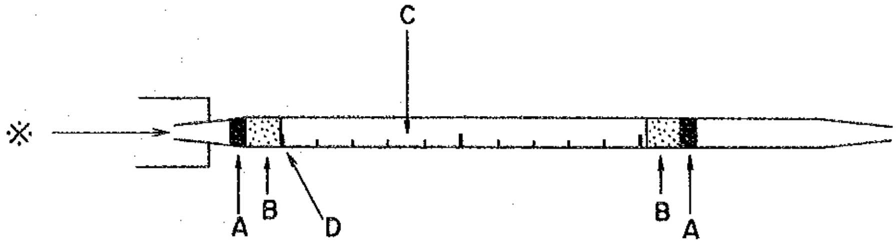
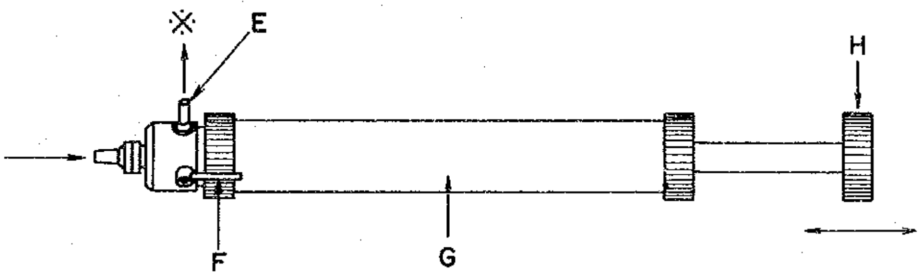


Fig. Ⅲ - 4 Carbon Dioxide Detector

DETECTION TUBE



GAS COLLECTOR



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

CHAPTER 3 RESULT

3-1 Geochemical Survey for Vapor Dominated Geothermal Reservoir

It has been reported that mercury ore deposits were found in geothermal areas in USA and Italy. In Zunil geothermal area, Guatemala, aboriginal people produced medicine from mercury in the ground where mercury content of alteration clay is up to 700 ppm. In Odake-Hatchobaru geothermal area, Japan, 70 ppm of mercury content has been measured in alteration clay.

It is inferred that mercury may be concentrated in the ground where geothermal reservoir is underneath.

Sergeyev (1957) reported that mercury content in the air around non-industrial area is under $0.01\mu g/m^3$ (1.0×10^{-14} g/cc) and is in the order of $0.001\mu g/m^3$ (1.0×10^{-15} g/cc). Eshleman et al. (1971) reported that mercury content in the air around volcanoes is 10^3 to 3×10^3 times of background figure.

Mercury is extremely volatile compare with other metal elements, and is hard to be dissolved in water. Moreover, radius of a mercury atom is small therefore when it passes through soil as soil air, it may easily pass through and go straight up. Therefore, mercury method can be used as a geochemical exploration tool for geothermal exploration. Measurement of mercury content in soil air, soil, or condensed water can be interpreted to assume location of geothermal reservoir, and geological structure such as fault.

Relation of mercury contents in soil and soil air may be interpreted as follows. Mercury content in soil air shows the present state of geothermal field and it in soil shows an integrated mercury concentration which tells historical change of mercury passageway. By measurement of mercury content in soil air, we will know where geothermal reservoir or geological fault is, and measurement of it in soil can tell us historical development of or movement of geothermal reservoir or fault.

Recent development in chemical analysis technique made minute amount of mercury possibly be analyzed in the field.

Carbon dioxide gas is main constituent gas from fumarole and is relatively inactive. It is very easy to measure carbon dioxide concentration in air at the field.