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A Coordinated Exploration Program for Geothermal Sources on the Island of Hawaii

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A COORDINATED EXPLORATION PROGRAM FOR GEOTHERMAL SOURCES ON THE ISLAND OF HAWAII

Augustine S. Furumoto
Hawaii Institute of Geophysics
University of Hawaii
2525 Correa Road
Honolulu, Hawaii 96822

April 30, 1975

ABSTRACT

Staff members of the Hawaii Institute of Geophysics carried out an exploration program for geothermal sources on the island of Hawaii by using all relevant geophysical and geochemical methods. Infrared scanning surveys by aircraft followed by reconnaissance-type electrical surveys and ground noise surveys narrowed down the promising area to the east rift of Kilauea.

The surveys carried out over the east rift included magnetic, gravity, and electrical surveys by various methods; microearthquake surveillance, temperature profiling of wells; and chemical analysis of water samples. Aeromagnetic, regional gravity, and crustal seismic refraction data were available in the published literature.

A model of the thermal structure of the east rift was put together to account for the data. The dike complex through which magma from the central vent of Kilauea travels laterally occupies a zone 3 km wide extending from 1 km to

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On the other hand, there are some encouraging speculations that have been proposed in the last decade or so. The concept of a self-sealing geothermal reservoir (Facca and Tonani, 1967) could very well apply to basaltic rocks in Hawaii. Furthermore, in recent years we have seen progress in experiments attempting to utilize hot rock or magma. Because of these developments, a research program was conceived to determine whether Hawaii had a conventional type of geothermal reservoir brought about by self-sealing mechanism or whether thermal energy was limited to the form of hot rock and magma. If the latter were the case, then the research program should determine utilizable energy content of the sources.

Although Hawaiian volcanoes have been investigated more than any other in the world, examination of the literature showed it would be necessary to carry out a coordinated series of surveys in order to define the thermal processes associated with the volcanoes. With this in mind, a proposal was submitted to the National Science Foundation for support of the research. The proposal was accepted and funded.

Exploration Program

The coordinated exploration program as carried out is shown in schematic form in Figure 1. The actual program differed from what was planned because of the funding level, and the slow delivery of equipment and instruments from manufacturers. When the program was begun in May 1973, the nation was facing an acute shortage of material, especially electronic and electrical components and parts.

The persons involved in the exploration program were the following from the Hawaii Institute of Geophysics (HIG):

A. S. Furumoto	professor
A. T. Abbott	professor
P. F. Fan	associate professor
W. Suyenaga	graduate assistant
D. P. Klein	graduate assistant
J. Halunen	graduate assistant
E. Epp	graduate assistant
G. McMurtry	graduate assistant
J. Kauahikaua	graduate assistant
R. Norris	research associate
C. Dodd	electronics technician

In addition to the above, G. V. Keller of the Colorado School of Mines was engaged to conduct an electrical resistivity survey over the summit area and east rift of Kilauea. Throughout the survey he kept in contact with the HIG group and provided timely inputs. Independent of the HIG effort, C. Zablocki of the U.S. Geological survey was carrying out self-potential surveys in areas of mutual interest. In exchange for field assistance, Zablocki made his data available to the HIG exploration program.

Electrical Surveys

The electrical surveys were conducted by G. Keller (1973) and D. Klein and J. Kauahikaua (1975). The techniques used included dipole-bipole mapping, line-loop time domain inductive sounding, galvanic sounding, and loop-loop frequency domain sounding. The composite results of the surveys given in Figure 3 show five areas (A, B, C, D, and E) of low resistivity. Also shown is the generalized trend of the line of vents to illustrate the geographical relationship of the rift with the areas of low resistivity. Of these area E is considered the result of cultural sources such as water pipes, sewer pipes and cables. The low resistivity zone in area B, which was outlined by Keller (1973), was estimated to exist from a depth of 700 m to 2100 m. As outlined by Keller the original area for B was larger; in the map it has been trimmed to exclude those portions thought to be caused by salt water intrusions from the sea. Even so, area B is still much larger than area A.

Attempts have been made to interpret the resistivity data in terms of Archie's Law. The conclusion, although admittedly hazardous, is that the upper limit of the temperature of hot water in the areas under consideration is about 140°C.

Gravity Survey

The available Bouguer gravity map of the island published by Kinoshita (1965) was not particularly useful to the geothermal project because the gravity stations were confined to highways and were spaced at 2 km intervals; for this reason, a more detailed survey was carried out in April 1974 over a stretch of Highway 13 in the Puna district (Figure 4). For analysis of the data, Bouguer corrections were added and the values were projected along a line that ran perpendicular to the line of vents along the Puna east rift. On incorporating Kinoshita's data, a gravity profile crossing the east rift was obtained as shown in Figure 5.

To analyse the data, we assumed that the subsurface feature causing the gravity profile was a two-dimensional body. Also, in order to use simplified methods of analysis, we considered the body to cause a symmetrical profile around the maximum value which is shown as 275.3 mgals in Figure 7. We assumed the high gravity values to the right of that point to be caused by a separate body. Upon using the simplified methods as proposed by Skeels (1963) we obtained the following values for the gravity anomaly.

Table. Dimensions of an Assumed Rectangular Prism Anomaly

Density Contrast	Depth to top of Anomaly	Depth to Bottom of Anomaly	Width of Anomaly	Depth to Center of Anomaly
0.6 g/cm^3	1.0 km	3.4 km	3.2 km	2.2 km
0.5	.87	3.6	3.2	2.2
0.4	.69	4.0	3.2	2.3

central recording station, three of them by hard wire and the other four by radio. The survey covered a period of two weeks and the number of earthquakes detected was not large. Figure 11 shows epicenteral locations and Figure 12, focal depths projected onto line AA'. On the left side of the figure is given the velocity structure which we have used to obtain epicenters and focal depths. Notice in Figure 12 that there is a cluster of earthquakes concentrated in the shallow depth between the surface to 5 km. Below the depth of 5 km the earthquakes are few. One interpretation from these data is that the dike complex or the active part of the dike complex is limited to a depth of 5 km. This inference is in accord with our gravity survey which determined that the dike complex bottoms out at about 4 km.

Ground Noise Survey

A ground noise survey using a 1-Hz geophone was carried out in August 1974. Recording was done on an FM tape recorder. After taking into consideration such things as diurnal variation, meteorological factors, etc., a ground-noise intensity map centering on 4 Hz was obtained as shown in Figure 13. Other frequency ranges were analysed with similar results.

Geochemical Surveys

Water samples from the wells throughout the Puna area were collected and analysed for oxygen isotope content. Chemical analysis showed that silica content in some of the wells was rather high although the basaltic rock is undersaturated as mapped by Malahoff and Woollard (1968). These lineaments are disturbed by hot intrusives, a good example of which is the summit area of Kilauea (Figure 19). The hot area which we have found by surface surveys also disturbs the lineaments.

Let us consider first the hot area of Figure 14 and 15 which also corresponds to area B of low electrical resistivity. Keller (1973) calculated that the low resistivity zone here extends from a depth of 700 m to a depth of 2100 m. Keller (personal communication) also found from earthquake data that rocks in this area have high Poisson's ratio, about 0.4, and also that small earthquakes here have fault plane solutions which dip southward at angles from 45° to 70°. High Poisson's ratio is indicative of fractured rocks. Another bit of geophysical data for this area is that of Hill (1969) who, using seismic refraction methods, found a layer with seismic velocity 3.1 km/sec at a depth of 700 m, coinciding with the low resistivity layer of Keller.

We shall now attempt to assemble these seemingly disparate bits of geophysical parameters into a coherent model, which is shown in Figure 16. The source of heat for the rift zone is the dike complex, but hot material whether magma or hot water leaks off into the southern flank of the rift zone. The fractured rocks have cracks dipping south 45° to 70°, as the fault plane solutions indicate. The hot material heats up brine seeping in from the sea, in the manner of the Ghyben-Herzberg hypothesis. Now if the brine is heated, how are we to account for the low resistivity at 700 m depth?

Area A has the following favorable geophysical data: a self-potential anomaly, a low resistivity area, ground noise high, and hot water (92°C) in a nearby well. But the drawbacks are several: aeromagnetic and surface magnetic surveys do not indicate hot intrusions; the low resistivity occupies relatively a small area so that even if a hot water or vapor system were present, the volume would not be commercially viable; the hot water in the nearby well is limited to a thin layer of about 7 m, and below that the water temperature drops off considerably. The motivation of the site selection committee seems to be the hope of hitting hot rock or magma, but even this hope may turn out to be in vain, as magnetic data would appear to forecast.

CONCLUSIONS

Electrical methods are generally considered the most powerful tool for geothermal exploration. But for basaltic rocks with high permeability, the nature of low resistivity areas found by electrical methods cannot be determined unless the ultimate source of heat is found. Usually the source is a dike complex or plug, which can be clearly outlined by gravity and seismic methods. The dike complex is not uniformly hot; hot areas occur in patches which can be found by magnetic methods. Surface magnetic surveys are more effective than aeromagnetic surveys.

We are still assessing the value of geochemical data for resource location.

Gratitude is hereby expressed to the project participants P.F. Fan, D.P. Klein, J. Kauahikaua, W. Suyenaga, R. Norris and

G. McMurtry, who made their data available for this paper. All of the illustrations used in this paper, except Figure 15, have appeared in a final report to the National Science Foundation under Grant GI 38319. The support by this grant is gratefully acknowledged. This paper constitutes Hawaii Institute of Geophysics Contribution No. 673.

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EXPLORATION SCHEME

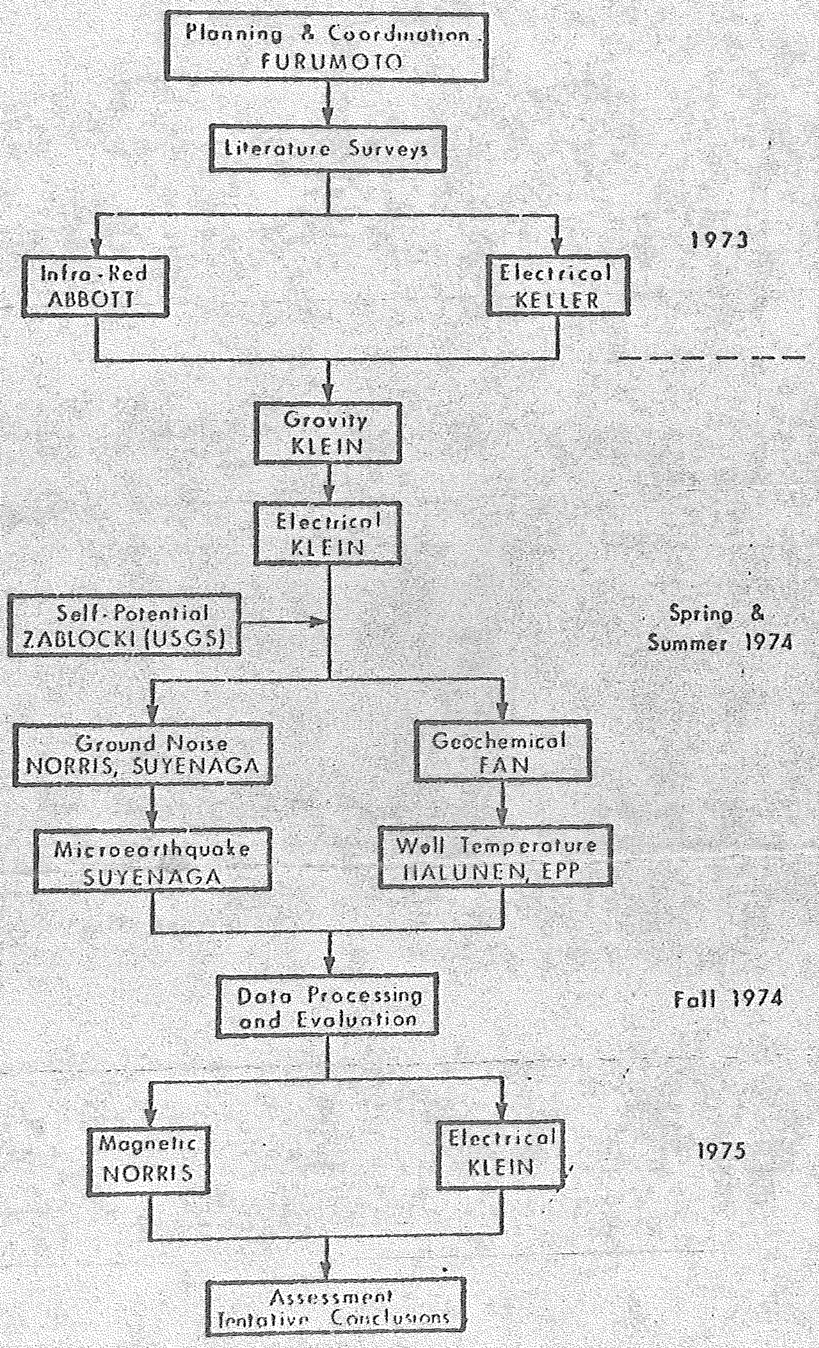


Fig. 1 Furumoto

FIG. 1

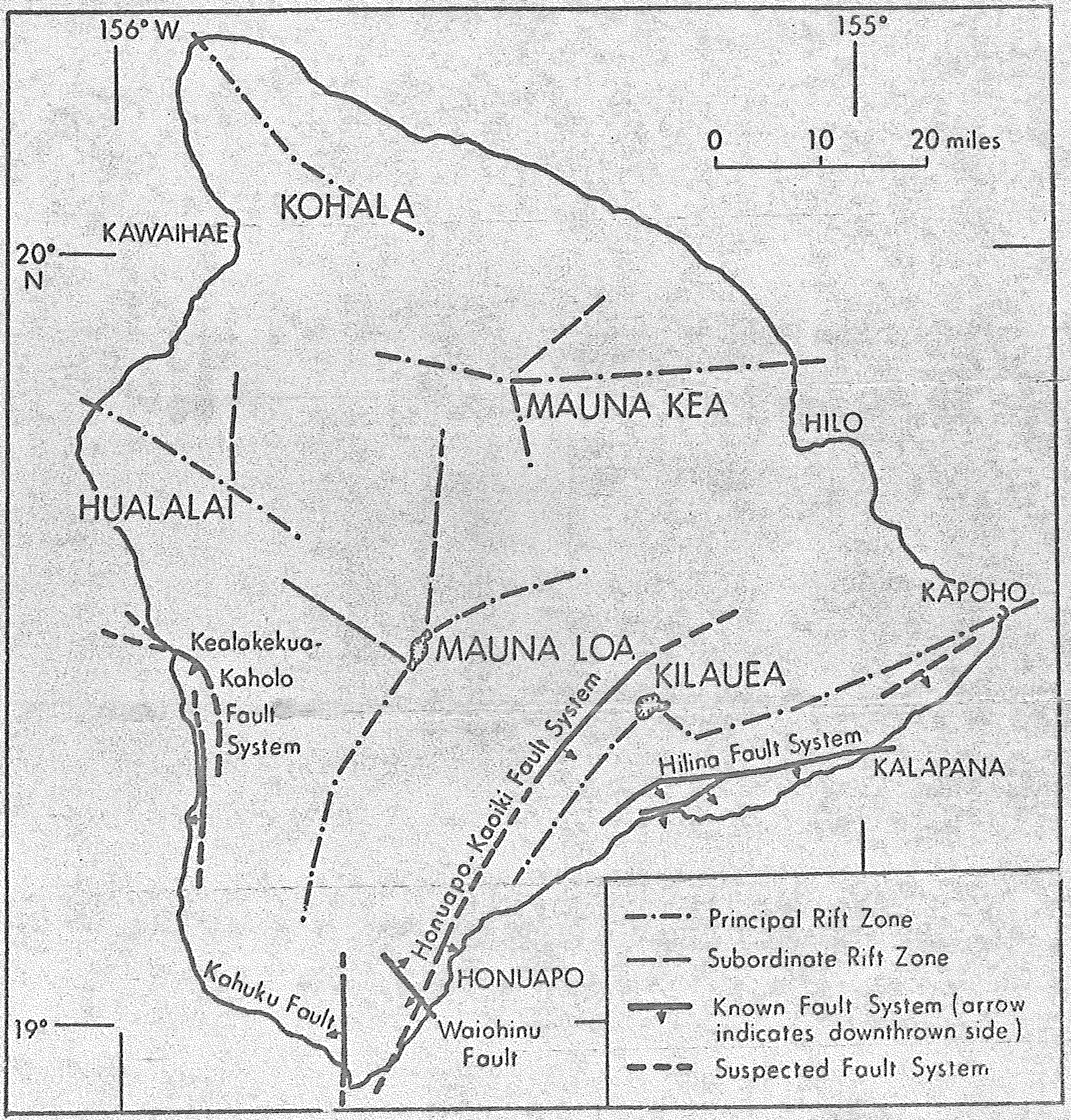

156° W
155°
0
10
20 miles
KOHALA
KAWAIHAE
20°
N
MAUNA KEA
HILO
HUALALAI
MAUNA LOA
KILAUEA
KAPOHO
Kealakekua-Kaholo Fault System
Honuapo-Kaoiki Fault System
Hilina Fault System
KALAPANA
HONUAPO
Kahuku Fault
Waiohinu Fault
19°
Principal Rift Zone
Subordinate Rift Zone
Known Fault System (arrow indicates downthrown side)
Suspected Fault System

FIG. 2

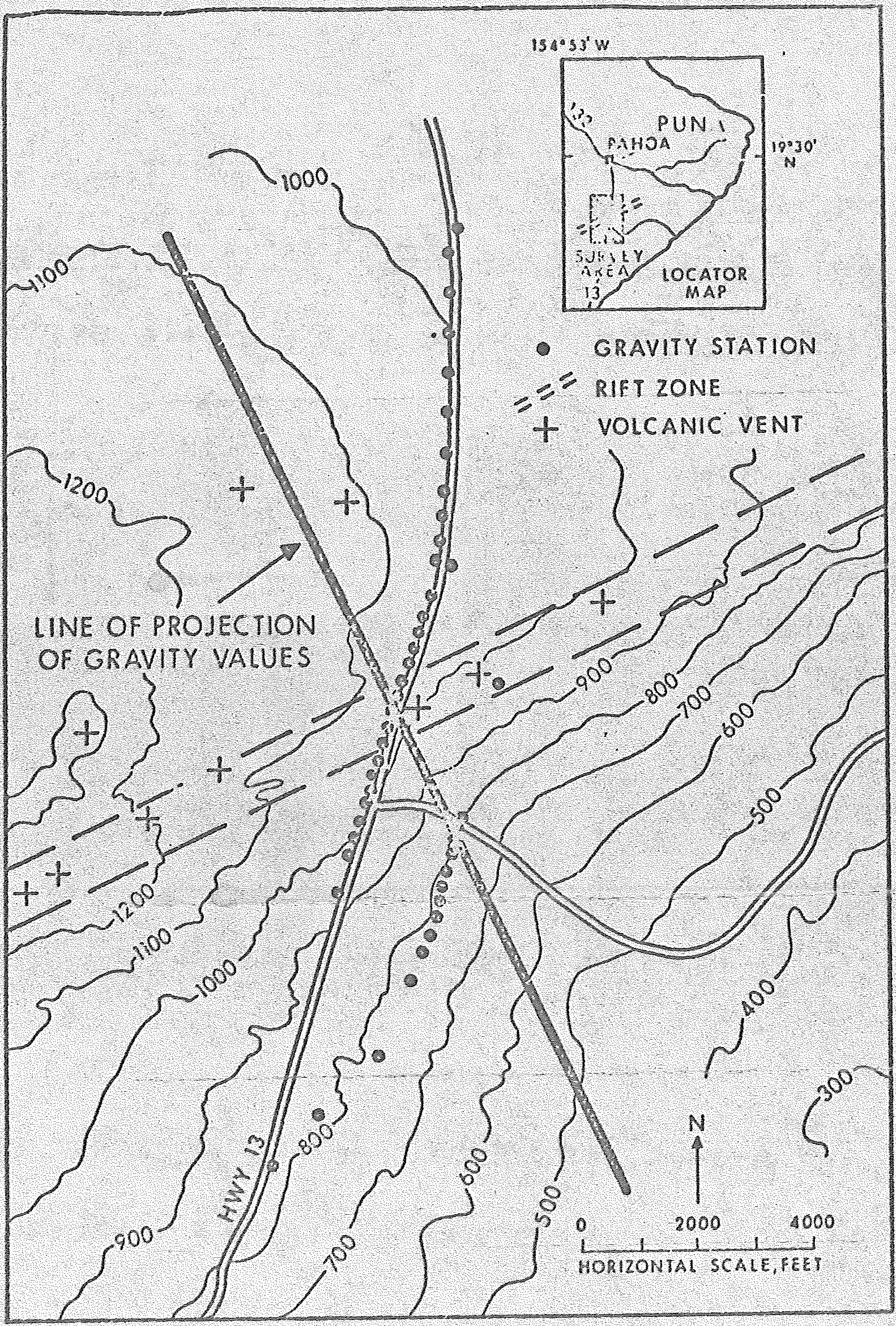
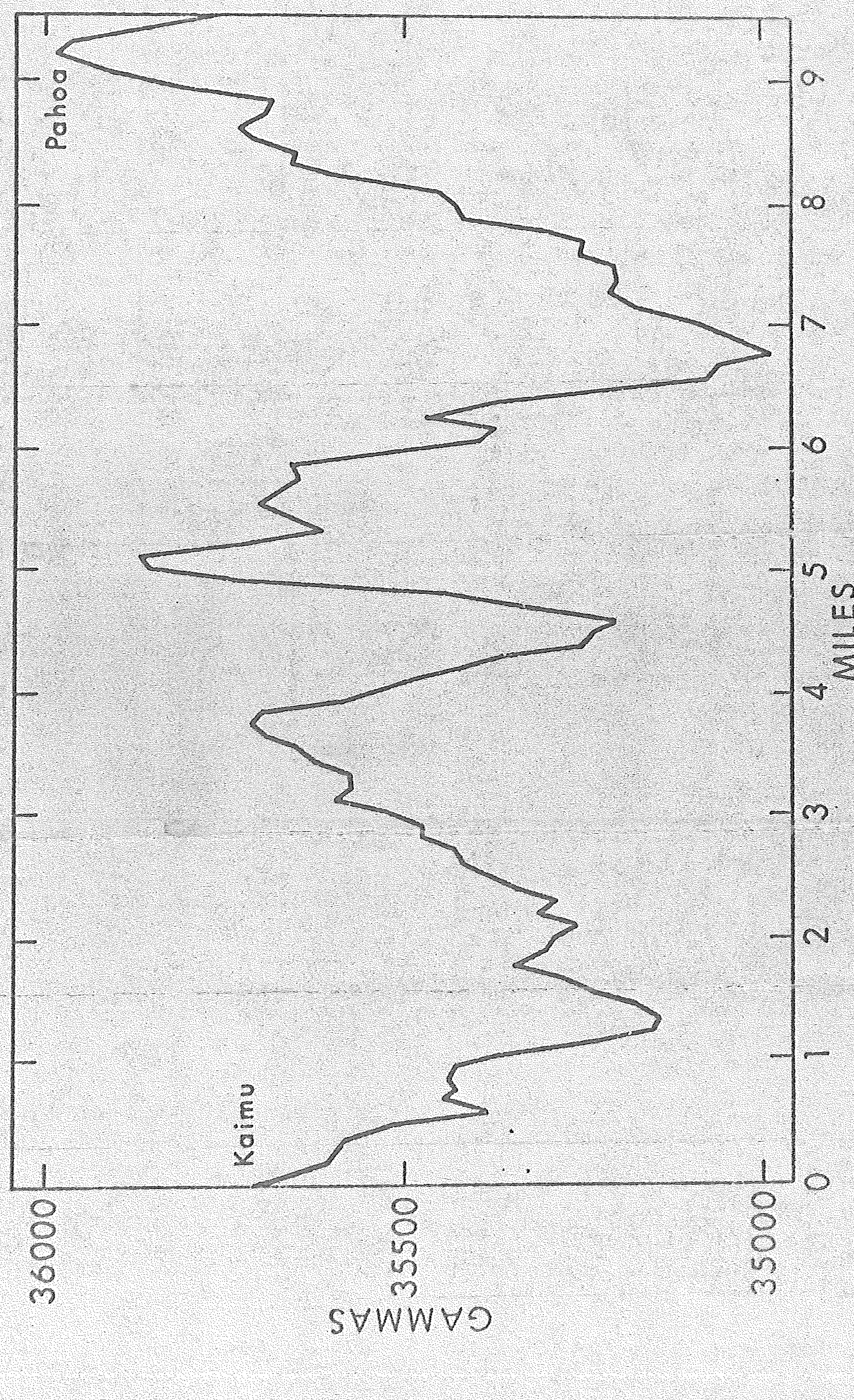


Figure ~~10A~~ 4. Survey Area and Gravity Stations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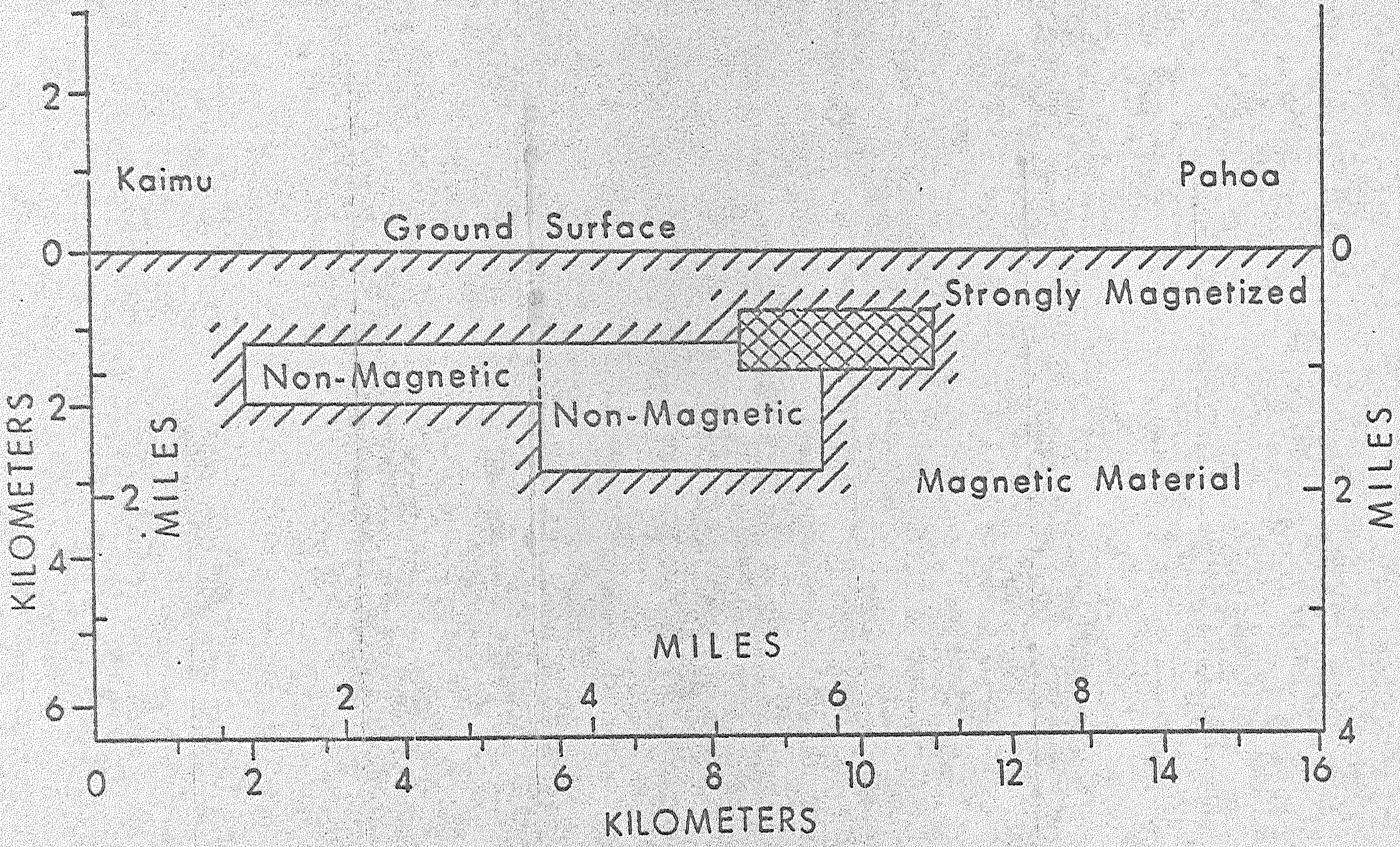
35500
35000
MILES
0
1
2
3
4
5
6
7
8
9
Kaimu
Pahoa


Kaimu
Pahoa
Ground Surface
Strongly Magnetized
Non-Magnetic
Non-Magnetic
Magnetic Material
KILOMETERS
MILES
MILES
MILES
KILOMETERS
2
0
2
4
6
2
0
2
4
2
4
6
8
0
2
4
6
8
10
12
14
16

Furumoto

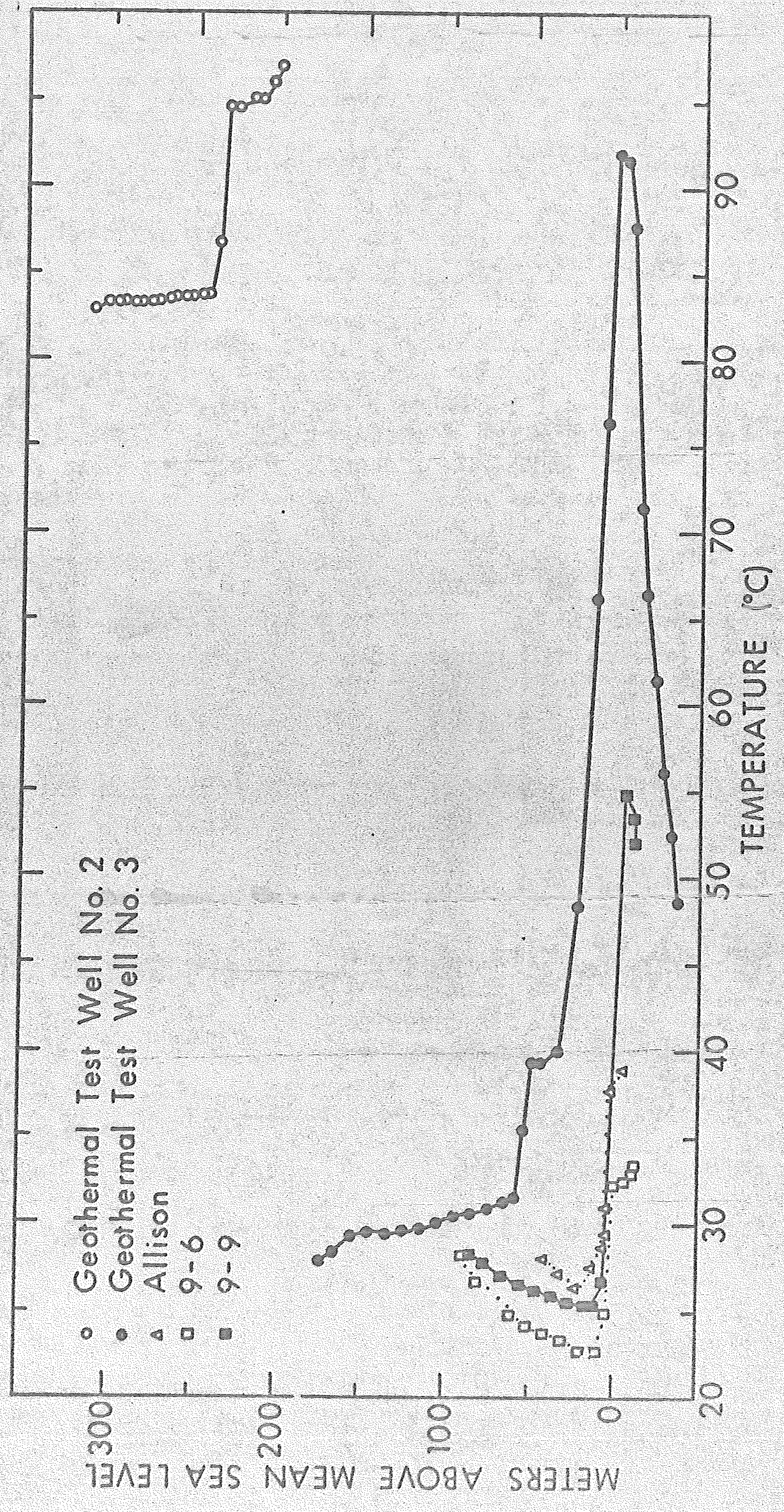
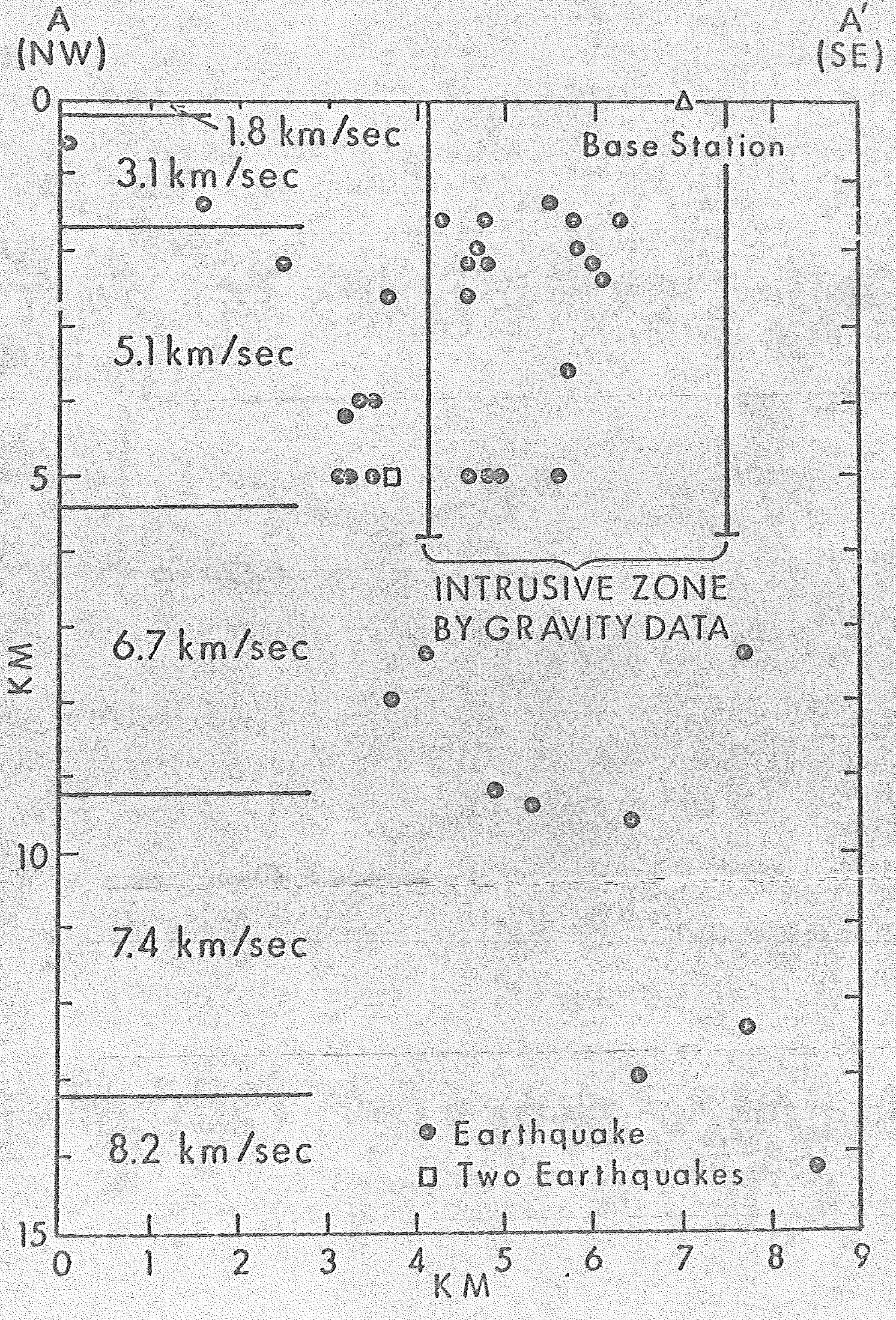

Geothermal Test Well No. 2
Geothermal Test Well No. 3
Allison
9-6
9-9
METERS ABOVE MEAN SEA LEVEL
300
200
100
0
TEMPERATURE (°C)
20
30
40
50
60
70
80
90

Fig 10



Focal depths projected to A-A′

Fig. 12. Furumoto

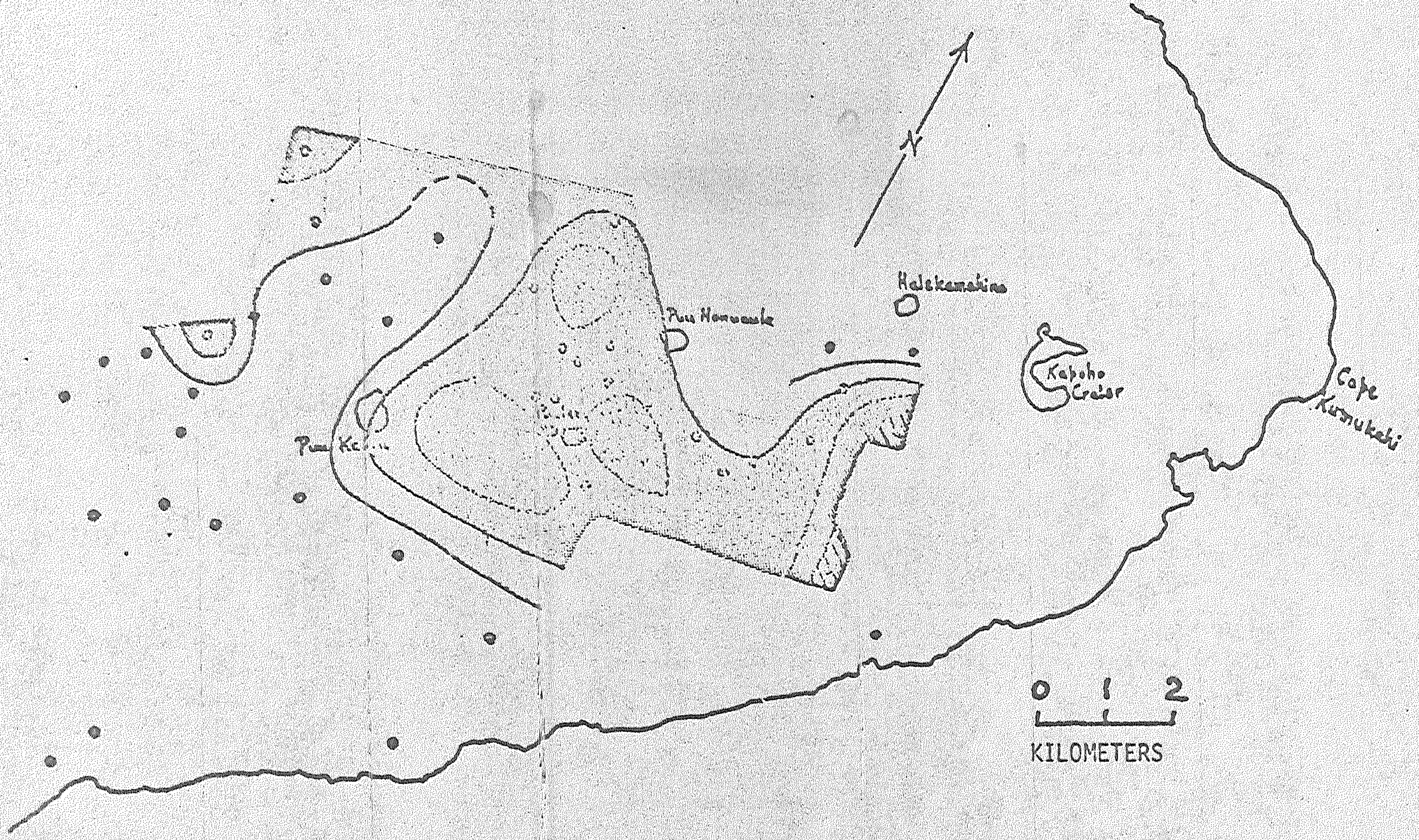


Fig. 13 Furumoto

Ground noise intensity contered on 4 Hz band.

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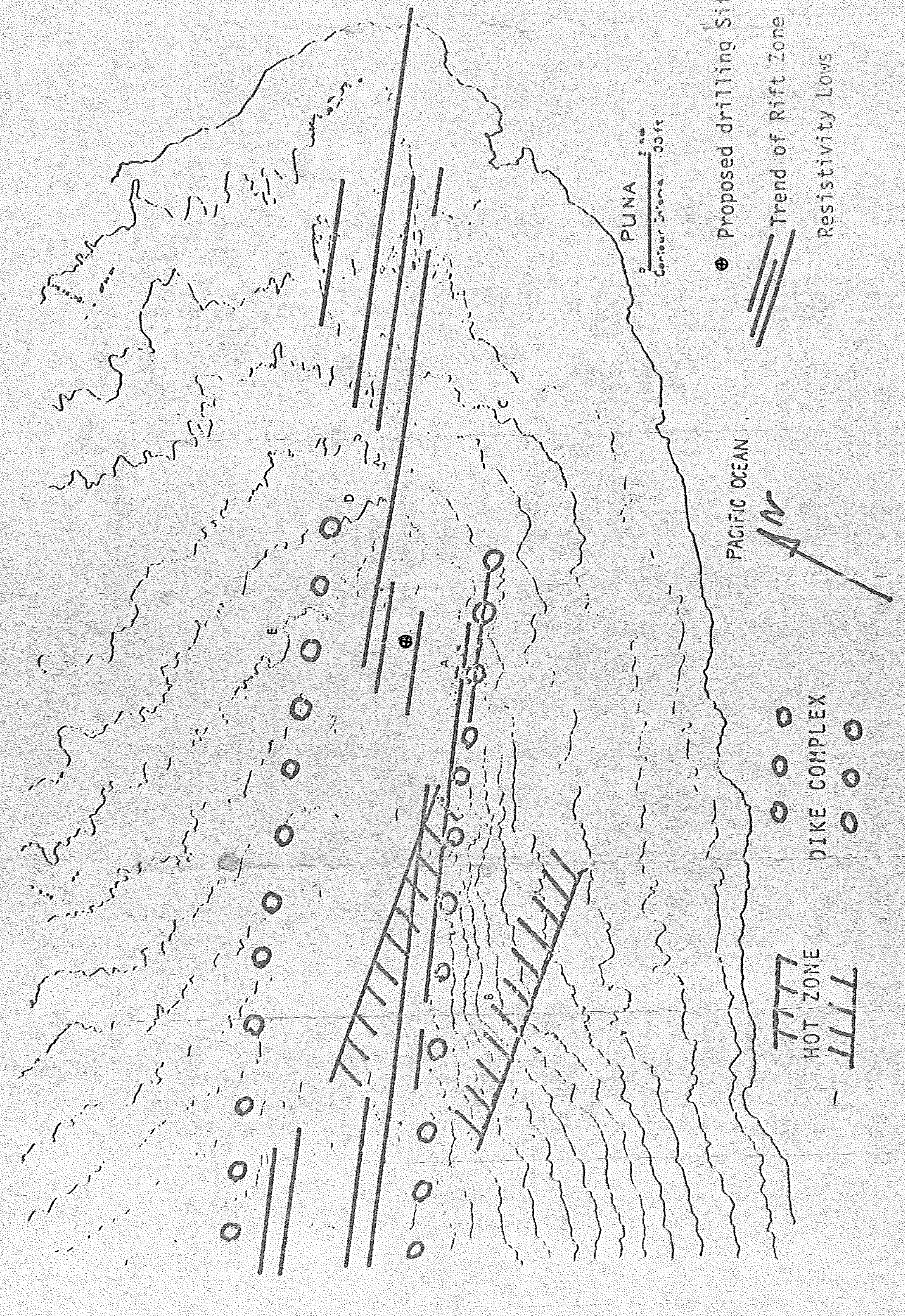
PUNA
0 1 mi
Contour Interval 50 ft
⊕ Proposed drilling Site
Trend of Rift Zone
Resistivity Lows
PACIFIC OCEAN
N
A
B
D
E
DIKE COMPLEX
HOT ZONE

Figure 3

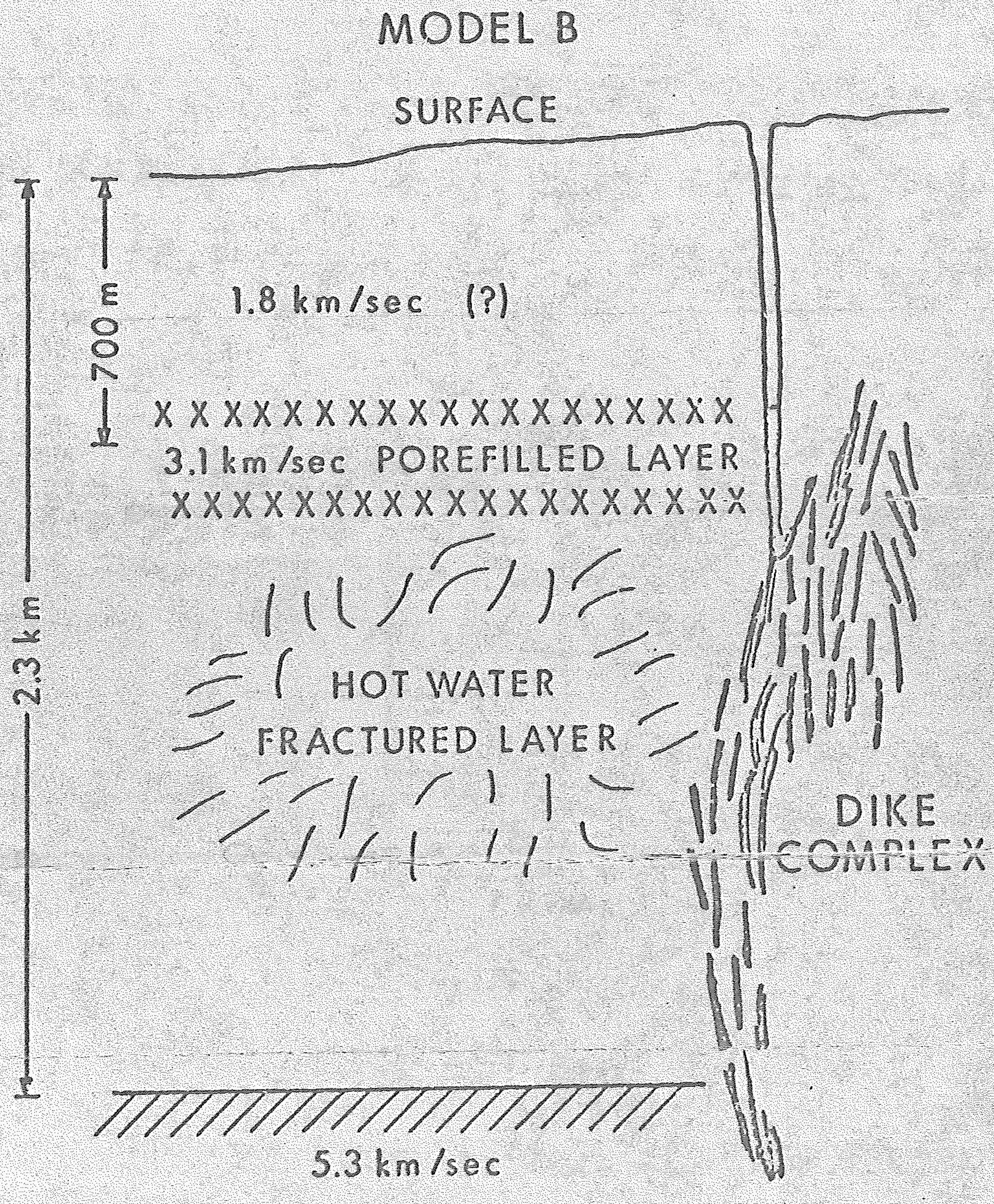

Fig. 16 Furumoto