EVIDENCE OF GEOTHERMAL POTENTIAL IN KAHAUALE'A

By GERALD NIIMI

THERMASOURCE, INC.

ABSTRACT

Geothermal resources have been discovered in the East Rift Zone of Kilauea Volcano. This is proof that the necessary conditions to have a resource: heat, fluids, and permeable reservoirs are available in the Rift Zone. There is strong evidence indicated by the current eruption of Pu'u O, geophysical, and geological studies, that a potential geothermal resource exists in Kahauale'a. Aeromagnetic surveys and the current eruption of Pu'u O demonstrate that a potent heat source is available. High rainfall and the proximity to seawater provide ample sources of water to the Rift Zone. Geology of the Rift Zone and a high level of earthquake activity indicate faulting and fracturing that is commonly associated with the presence of geothermal reservoirs. The results of a microearthquake survey in Kahauale'a compares very favorably with similar microearthquake studies in the Lower Rift Zone around HGP-A. Extrapolation of drilling results from existing wells to the planned development areas of Kahauale'a are encouraging to the existence of a geothermal resource. An area of 7800 acres within Kahauale'a has been identified has having the necessary characteristics to support a geothermal resource. This report also outlines the steps that are planned to protect the safety of men and equipment while operating in a potentially hazardous area due to the threat of lava flows.

I. BACKGROUND

The East Rift Zone of Kilauea Volcano on the Big Island of Hawaii has been established as a source of geothermal energy. Various investigators have written about the regional potential for geothermal energy based on geophysical, geological, geochemical studies, and the simple fact that vast amounts of heat energy are available from an active volcano. The current eruption amply demonstrates this. High rainfall amounts on the eastern portion of the Big Island provide a large source of meteoric water to supply a geothermal system. In addition, seawater may also provide a source of geothermal fluids.

Exploratory drilling has established that a geothermal resource exists in the Lower East Rift Zone. The HGP-A Project further demonstrates that a geothermal resource in the Kilauea East Rift can be used to generate electricity.

Kahauale'a straddles the East Rift Zone and covers about 25,000 acres in the Puna District, Island of Hawaii (Figure 1). The property is owned by The Estate of James Campbell and is to be developed by the True/Mid-Pacific Geothermal Joint Venture. An area of approximately 7800 acres within Kahauale'a is believed to have geothermal resource potential. The purpose of this report is to present available evidence to indicate why exploratory drilling, which is the ultimate test, can be expected to establish a commercial geothermal resource at Kahauale'a.

II. REGIONAL EVIDENCE

The primary source of geothermal heat at Kahauale'a comes from magma intrusions into the East Rift Zone. Those areas of Kahauale'a within or near the Rift Zone are believed to have the highest probability of encountering a geothermal system. The only exception is a relatively small area on the western edge of Kahauale'a that receives its heat from Kilauea Iki or the Summit magma chamber. Regional evidence of a geothermal resource at Kahauale'a comes from geologic maps, aeromagnetic surveys, and gravity surveys.

Definition of the East Rift Zone has been published by various investigators. Numerous maps have been drawn to define the East Rift Zone. Holcomb's 1980 Kilauea Study has been a good source to define geologic features along the entire East Rift. Holcomb's maps(Figure 2) show that the Rift Zone is about 4 Km wide, although geophysical studies tend to indicate a much wider Rift Zone at depth. Also shown are the locations of vents, spatter cones, faults, and fissures that are evidence of volcanic activity and infer dike formations in the subsurface. Identifying surface expressions such as faults is a useful tool to site geothermal wells. There is little if any change in the geologic character of the Rift Zone from Upper to Lower elevations. Thus it can be presumed that the subsurface character will not be much different between the

Upper or Lower portions of the Rift Zone. Holcomb's maps will be referred to again in the site specific assessment.

Another indicator that is often used in geothermal resource exploration is the presence of earthquakes in a given area. Regional mapping of earthquakes by the USGS Hawaii Volcano Observatory shows the East Rift Zone to be an active earthquake center. Figure 3 shows earthquake activity in a typical year(1976) on the Big Island. Location of the earthquake activity clearly defines the East Rift Zone and a potential geothermal resource area.

An aeromagnetic study of the entire Big Island was conducted by Godson et. al. in 1981. The results of this study show that the Upper portion of the East Rift has reverse magnetism. It can be concluded that the subsurface strata are heated above their Curie Temperature, or in excess of 500 deg. C. (Figure 4).

An apparent zone of extensive diking or intrusions can be seen on the southern portion of the East Rift Zone as a dipolar aeromagnetic anomaly. This could suggest a general subsurface structure that slopes gradually to the north. Because of this structure, heat from the Rift Zone influences a larger area to the north relative to the south.

A gravity survey of the Big Island provides information concerning the basic structure of the East Rift Zone. The

Bouger Map shows gravity highs associated with each of the five major volcanoes and generally reflects topography(Figure 5). Contours along the East Rift of Kilauea are spread out on the north side and closer together on the south side. This again suggests that the dense dike complex diminishes more gradually to the north as compared to the south side. This seems to be consistent with the aeromagnetic data.

It appears that the Kilauea East Rift has a wedge shape. The crest is about 4 Km wide and is defined by a line that follows the most active portion of the Rift (Pu'u Kamoamoa to Cape Kumakahi). The subsurface portion of the Rift Zone may be much wider. The resource area is believed to be wider on the north side of the Rift Zone than to the south. Any wells drilled south of the crest, even though successful may be tapping a limited resource.

With this general structure in mind, a hydrological model was developed to assist in the formulation of drilling plans during the exploratory phase of the Kahauale'a geothermal project. Stearns and McDonald described the general subsurface stratigraphy and structure of Kilauea. Volcanological studies establish that eruptions occur frequently along the East Rift Zone and are expected to continue. Hence the earth's natural heat energy is made available here at relatively shallow depths.

Because of extremely high rainfalls over the entire windward side of the Big Island, abundant water is available to supply underground aquifers essential to the formation of a geothermal reservoir. In the Kilauea/Mauna Loa complex, rainwater percolates through the porous and permeable surface lavas until an impermeable barrier such as volcanic ash or dike system is reached. Then water flows downslope to the east and then Northeast toward Hilo as the East Rift Zone is encountered. With such huge amounts of water (1 billion gallons per day, according to Stearns and McDonald), some of the water migrates into the Rift Zone. In the Rift Zone, diking causes the water to be held up and impounded while the magma intrusions heat the water, creating convection cells. Figure 6 is an idealized hydrothermal model. When the water flashes to steam, mineral deposits form in the pore spaces and fractures of the laval rocks. Eventually the deposits (mainly calcium carbonate) cause the lava to become essentially impermeable. This impermeable layer serves as a cap rock so that flashing no longer occurs beneath it and a hot water or liquid-dominated geothermal reservoir is formed. Because lavas are brittle, they are prone to fracturing when subjected to stresses from magma movement and tectonic events. Toward the Makai side of the Rift Zone, a similar phenomenon occurs, only this time seawater is substituted for fresh rainwater. Since there is 500 times more salt in seawater than in rainwater, the mineralization of pore spaces is accelerated and is more complete. In fact, given sufficient time, the entire reservoir may be plugged with mineralization caused by circulation of hot seawater. This could partly explain why wells drilled along the south portion of the East Rift have heat, but no permeability.

The results of the regional information define the general structure and location of the Kilauea East Rift Zone. Aeromagnetic information and eruptive features indicate that heat is present. The hydrology of the area is favorable to accomodating a geothermal system. Earthquake activity and the surface geology throughout the East Rift Zone are characteristic of geothermal areas.

III. SITE SPECIFIC DATA

Published data on drilling from the Lower Rift Zone were studied. An assessment of the results is reflected in a NW-SE cross-section perpendicular to the Rift Zone axis(Figure 7). In 1976, a deep geothermal test well called HGP-A was drilled to a depth of 6435 feet in the Lower East Rift Zone. The well encountered hot water with temperatures as high as 676 degrees F. and also produced enough energy to justify installation of a 3 MW power plant. In 1980, encouraged by the success of HGP-A, Geothermal Energy Development Company (GEDCO) drilled a well called "Ashida 1" two-and-a-half miles to the Southwest of HGP-A to a depth of about 8,000 feet. Temperatures above 390 deg. F., suitable for a geothermal resource, were measured in the well, and the well produced some measurable, but small, quantity of geothermal fluids. Other information is being held in confidence. GEDCO drilled a second well in 1981, about 2,500 feet south of HGP-A. Complete information about this well is not available; however, it is commonly believed that the well, called "Lani Puna 1," was drilled to a depth of about 8,350 feet and the results were identical to the Ashida 1 well -- good temperature, but non-commercial-producing rates. Immediately following this well, Thermal Power Company, operating for the Puna Geothermal Venture (PGV), drilled two wells, "Kapoho State 1" and "2" about 1,700 feet North of HGP-A. Kapoho State 1 was drilled to 7,290 feet and apparently encountered temperatures above 390 deg. F. and produced geothermal fluids. Kapoho State 2 was drilled to a depth of 8,005 feet and also apparently encountered a geothermal resource.

Based on the qualitative drilling results of four privately financed wells, the published mechanical condition of the wells, and detailed information from HGP-A, a model of the geothermal reservoir can be constructed. When a well is drilled into the East Rift, temperature gradients remain relatively low (4-5 degrees per 100 feet) until a certain depth is reached, then the gradients increase markedly to 10-30 degrees per 100 feet. One of the key decisions that is made during drilling is the setting depth of the 9-5/8" casing string. This must be set prior to entering a producing zone or mechanical problems with the well, such as poor cementing, will occur. Thus, a correlation can be made on the assumption that the 9-5/8" casing is run when temperature gradients start to increase, indicating that the reservoir is close at hand. Records of th HGP-A well indicate that the 9-5/8" casing was set at a rather shallow depth not corresponding to the gradient change occuring in HGP-A at a depth of 3,000 feet.

By contouring the setting depth of the 9-5/8" casing in four wells with the depth of gradient change in HGP-A, a rather smooth curve establishes the depth where the gradient change occurs across the Rift Zone. This surface could also be called the top of the cap rock. The next marker that can be developed corresponds to the top of the reservoir or the bottom of the cap rock. In HGP-A, a section 800 feet thick was essentially isothermal, indicating a convection cell. This convection cell was set up because of a fractured zone where fluids can circulate freely. Since the GEDCO wells had little permeability, there should be only a thin convection zone nearby. On the other hand, the PGV wells were successful and should have a convection zone similar in thickness to HGP-A. Thus, the main geothermal reservoir starts at a uniform thickness and then gradually gets thinner from Northwest to Southeast.

At the bottom of HGP-A, the temperature surveys indicate the start of another conduction zone with temperatures of 625 deg. F. This isotherm probably marks the bottom of the reservoir.

The cross section also shows a pressure profile which is based on data from HGP-A. Pressure gradients of .296 psi/foot are much lower than normal hydrostatic gradient of .433 psi/foot. This is because the water is heated to around 600 deg. F. Published data show that the density of water will be reduced by 68% when heated from 60 deg. F. to 600 deg. F.

It is postulated that the Rift Zone displays similar charcteristics along its axis. If KA-1 is projected down Rift onto this cross-section using sealevel as a datum, the reservoir markers can be extended to estimate the character of the geothermal resource at Kahauale'a. This shows that the main convection zone will occur at depths of 6,000-8,000 feet below sealevel, and reservoir pressures are projected to be 2,200 psi to 2,800 psi. A liquid-dominated reservoir is expected, and because of the structural positon, the resource should be less saline and contain less H2S than HGP-A.

In order to ascertain whether the formations expected at depth have fracture permeability (on the order of magnitude found at HGP-A), a microearthquake study was performed in early 1982. Seismographs were placed at 12 locations in Kahauale'a(Figure 8). A total of 1,500 events were recorded by the instruments. Of that total, 100 were locatable with some degree of accuracy within the 1-3 Km depth range. An average of 5-7 events per day were monitored, compared to an average of 1.6 events per day recorded during a microearthquake survey in Lower Puna near HGP-A in 1976(Suyenaga,1978). Thus there is an excellent probability that the degree of fracturing at Kahauale'a is at least as good as the area around HGP-A. This was one of the important reasons (the other being proximity to heat) that prompted the selection of KA-1 in the middle of the prospect area as the initial drill site.

To supplement the vertical picture of the geothermal resource at Kahauale'a, an areal dimension may be obtained by a detailed examination of the geologic maps. The area shows numerous cracks and fissures that infer dike emplacements. The surface geology at Kahauale'a is compared in Figure 9 to the geology in the Lower Rift Zone where successful wells have been drilled. Since the two areas look similar, there is a good reason to believe that resource potentials are similar.

Potential geothermal areas in Kahauale'a are generally within the surface expression of the East Rift Zone as defined by Holcomb. The only area that does not fit into this category is located on the western edge of the property where the influence of Kilauea Iki is predominant.

IV. HAZARDS

The Rift Zone can be a hazardous area. However, with planning and mitigating measures, most of the hazards due to lava flows can be avoided. Activities that are planned for the Kahauale'a Project are:

1. Locate wells, pipeline, and power plants as far north and at as high an elevation as the resource will permit. The initial exploratory phase will attempt to delineate the northern extent of the resource;

2. Strongly consider the use of smaller power plants to provide areal diversification to prevent a single event from knocking out a large power plant;

3. Automatic pipeline shut-downs in case of rupture. Interties between plants to provide contingency routes for the well production;

4. When an eruption is occurring nearby, such as Pu'u O,

a series of trip wires will be installed in order to alert drilling crews that a lava flow is coming and at what speed. Contact with HVO should provide information when an eruption is imminent;

5. Barriers consisting of a trench, elevated pad, and berms should divert most flows away from the wells;

6. If a well is drilling and a lava flow was impending, the well would be suspended with a subsurface (below 300') plug. All surface valves would be closed and the drilling location cleared of as much equipment as possible. All valves, wellheads are tested at the factory to hold pressure at 2000 degees F. and designed to withstand temperatures in excess of 2500 degrees F. compared to 2,000 deg. F. lava temperature. In the event that the entire wellhead assembly is destroyed by a massive flow, the subsurface plug would provide a backup to isolate the well from the lava;

7. A proposed drill site already covered by a recent lava flow and directly in the path of another lava flow will not be occupied until the eruption subsides.

V. CONCLUSIONS

0. Kahauale'a Geothermal Project Area is located in the Kilauea East Rift Zone, an area with a known heat source and

existing geothermal wells. At present an area of 7800 acres is potentially productive of a geothermal resource.

2. Regional aeromagnetic and gravity surveys indicate the structure and location of the Rift Zone. In addition, the aeromagnetic maps show that the deep strata at Kahauale'a are above the Curie Temperature. The Rift Zone is a wedge-shaped structure 4 Km wide at the surface and much wider at depth.

3. Holcomb's Geologic Maps define the surface limits of the Rift Zone. The surface geology at Kahauale'a is identical to the surface geology in the Lower East rift where geothermal resources have been discovered.

4. A regional hydrological model of the Kilauea East Rift has been developed. The north side of the Rift Zone has greatest potential because it has less of an impact from possible seawater intrusion.

5. A Resource Model of the East Rift indicates that good wells are generally located north of the crest. This is where the primary Kahauale'a prospect area is located. The structure of the Rift Zone suggests that a larger resource area exists north of the Rift Zone axis compared to the area south of the Rift axis.

6. Safety of personnel is of the utmost concern. Hazards due to lava flows have been anticipated and plans to deal with the hazards have been made.

REFERENCES

(1). Broyles, M. L., 1977, The Structure of the East Rift Zone of Kilauea, Hawaii, From Seismic Refraction, Gravity and Magnetic Surveys, M.Sc. Thesis No. 1505, University of Hawaii, Honolulu.

(2). Broyles, M. L., Sugenaga, W., Furumoto, A. S., 1979, Structure of the Lower East Rift Zone of Kilauea Volcano, Hawaii, From Seismic and Gravity Data, J. Volcanol. Geotherm. Res., vol. 5, pp. 317-336.

(3). Chen, B. H., et. al., Well Test Results from HGP-A, Geothermal Resources Council Transactions, Vol. 2, July, 1978.

(4). Cox, M.E. and Thomas, D.M., Chloride/Magnesium Ratio of Shallow Ground Waters as a Regional Geothermal Indicator in Hawaii, Assessment of Geothermal Resources in Hawaii: Number 3, Hawaii of Geophysics, HIG 79-9, November, 1979.

(5). Edmiston, R.C., A Review and Analysis of Geothermal Exploratory Drilling Results in the Northern Basin and Range Geologic Province of the USA from 1974 Through 1981. GRC Annual Meeting Transaction, San Diego, 1982, pp. 11-15.

(6). Epp, D., and Halunen, A. J. Jr., Temperature Profiles in Wells on the Island of Hawaii, Hawaii Institute of Geophysics, HIG-79-7, 1979.

(7). Godson, R.H., et. al., Aeromagnetic Map of the Island of Hawaii, USGS Geophysics Investigation, Map GP-946, 1981.

(8). Hawaiian Volcano Observatory - U.S. Geological Survey, Bi-Monthly Report - August and September, 1983.

(9). Holcomb, R.T., Geology of the Kilauea East Rift Zone, USGS Open File Report - 80-796, 1980.

(10). Kauahikaua, J., and Mattice, M., Geophysical Reconnaissance of Prospective Geothermal Areas on the Island of Hawaii Using Electrical Methods, Hawaii Institute of Geophysics, HIG-81-4.

(11). Keller, G.V., Skokan, C.K., et. al., Geoelectric Studies on the East Rift, Kilauea Volcano, Hawaii Island, Hawaii Institute of Geophysics, HIG-77-15, December 1977.

(12). Kingston, Reynolds, Thom and Allardice Ltd. Hawaii Geothermal Project Well Completion Report, HGP-A, September 1976.

(13). Kinoshita, W. T., 1965, A Gravity Survey of the Island of Hawaii, Pacific Science, vol. 19, no. 3, p. 339.

(14). Koyanagi, R. T., Meagher, K., Klein, F. W., Puniwai, G. S., and Lipman, P. W., 1978, Hawaiian Volcano Observatory Summary 76: January to December 1976, U. S. Geological Survey preliminary report.

(15). Kroopnick, P.M. et. al., Hydrology and Geochemistry of Hawaiian Geothermal System: HGP-A, Hawaii Institute of Geophysics, HIG-78-6, May 1978.

(16). Marks, S.M. and Bufe, C.G., Preliminary Hypocenters of Earthquakes in the Healdsburg (1:100,000) Quadrangle, Lake

Berryessa to Clearlake, California: USGS Open File Report 78-953, 1978.

(17). Microgeophysics Corporation, Seismicity Report on the Pahoa Prospect, Hawaii County, Hawaii, 1975.

(18). Petroleum Information National Geothermal Well Report, Various Issues.

(19). Revised Environmental Impact Statement of Kahauale'a Geothermal Project, June, 1982.

(20). Stearns, H.T. and MacDonald, G.A. Geology and Ground-Water Resources of the Island of Hawaii, Bulletin 9, Hawaii Division of Hydrography, 1946.

(21). Summary Report for Phase I, the Hawaii Geothermal Project, May, 1975.

(22). Suyenaga, W., et. al., Seismic Studies of Kilauea Volcano, Hawaii Island, Geothermal Resources Exploration in Hawaii: Number 5 September, 1978.

(23). Yuen, P.C., et. al., Hawaii Geothermal Project, HGP-A Reservoir Engineering, University of Hawaii, September, 1978.

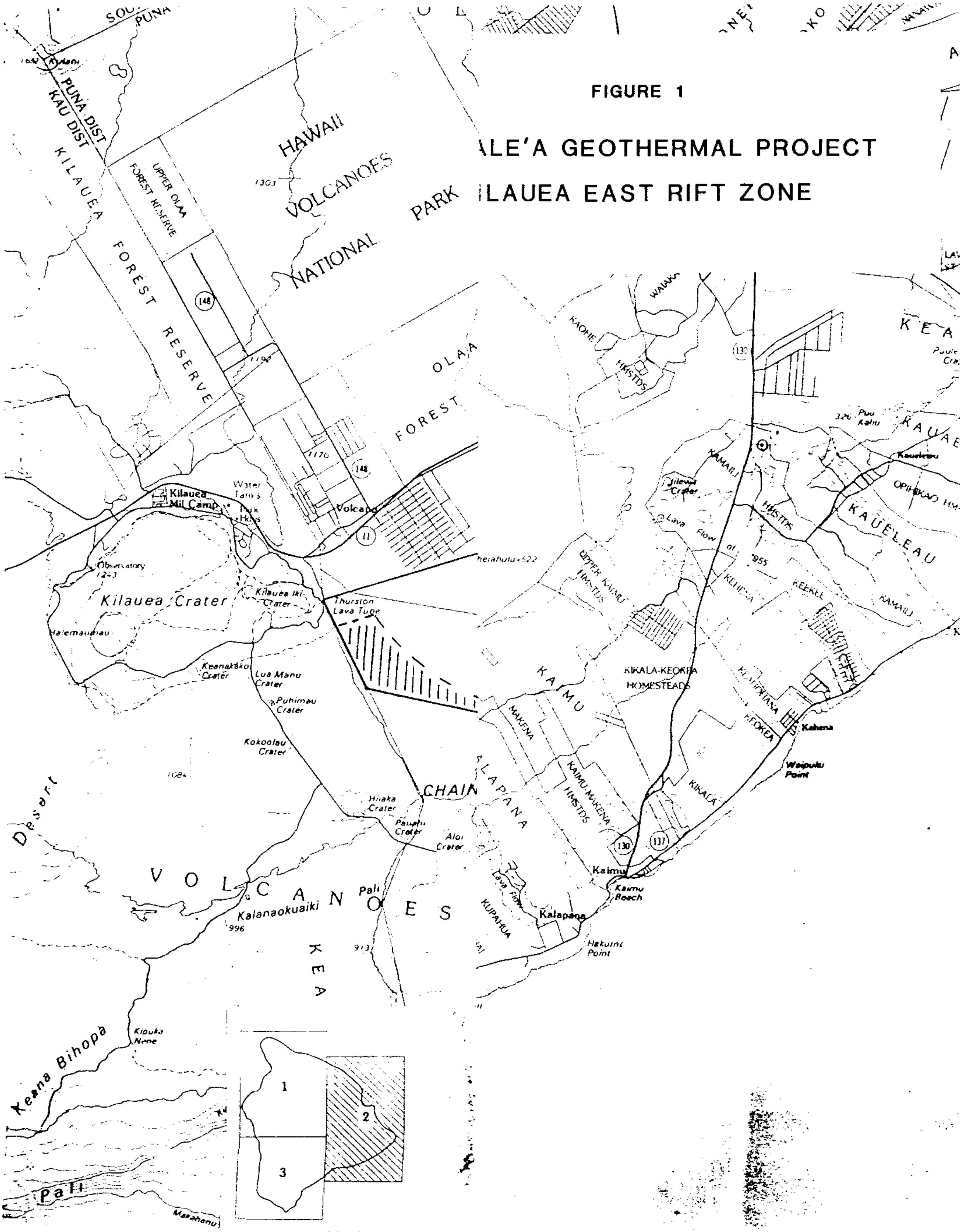


FIGURE 1

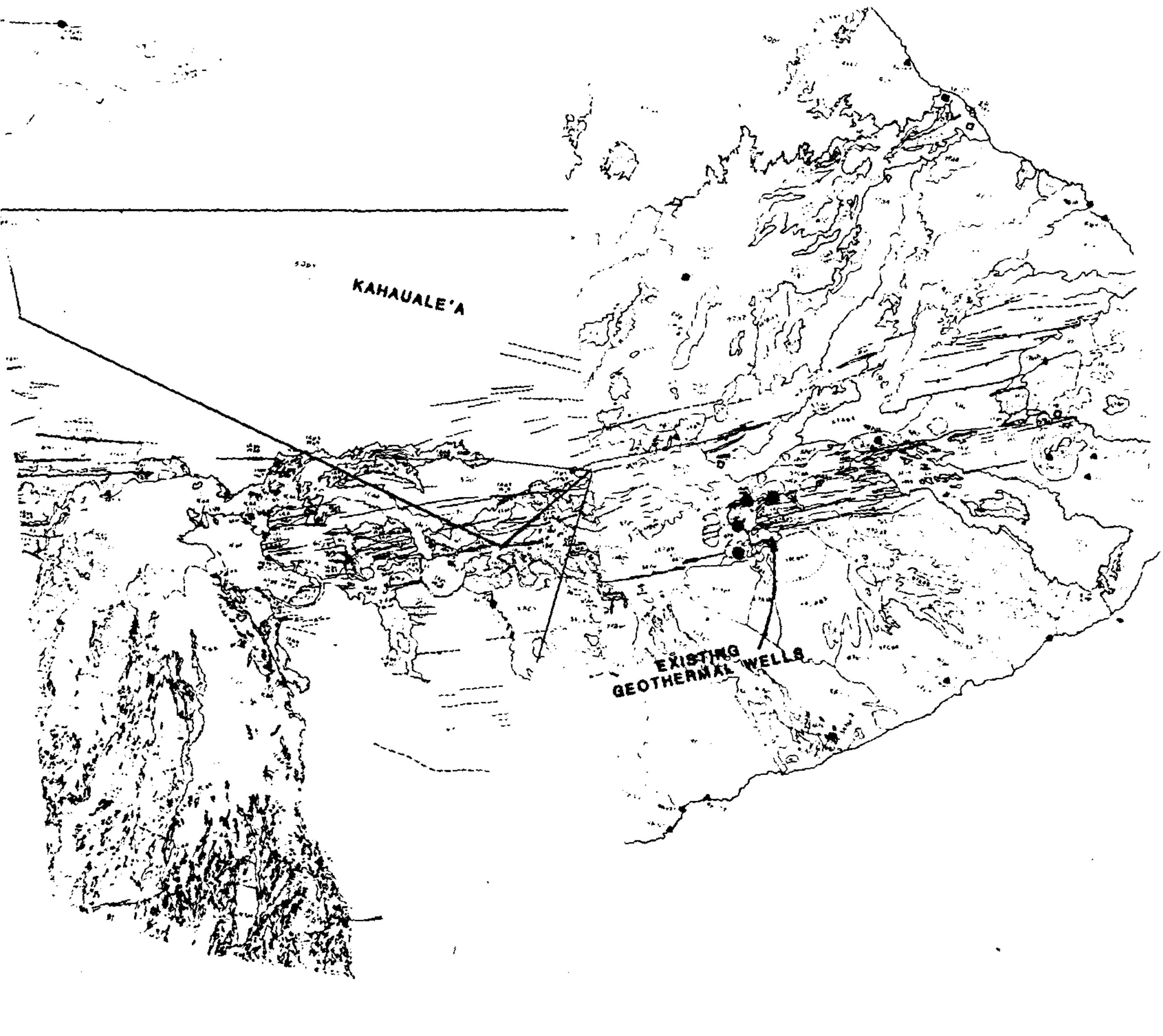
ALE'A GEOTHERMAL PROJECT

ILAUEA EAST RIFT ZONE

FIGURE 2

MAP OF KILAUEA VOLCANO

ROM HOLCOMB, 1980



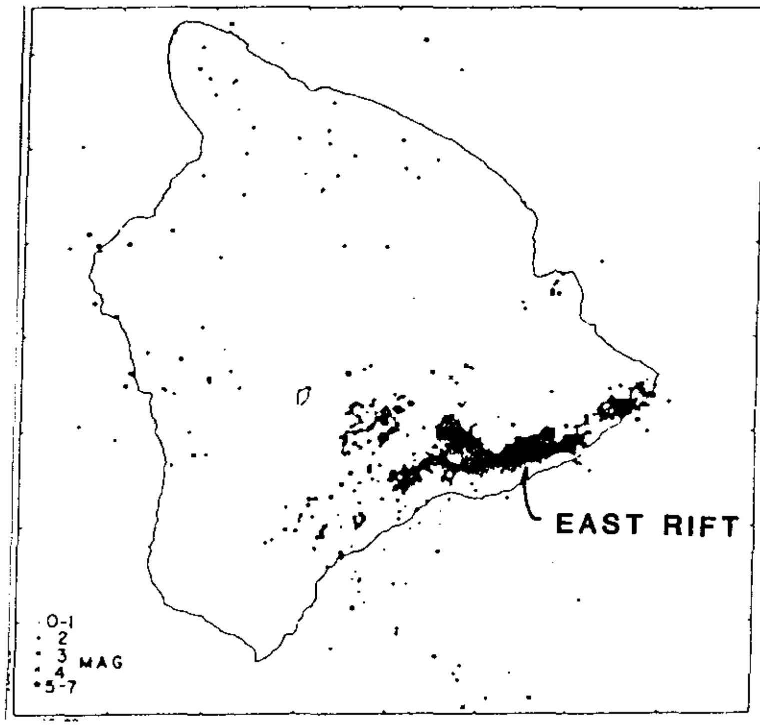


FIGURE 3

EARTHQUAKE EPICENTERS-1976

FROM KOYANAGI, 1978

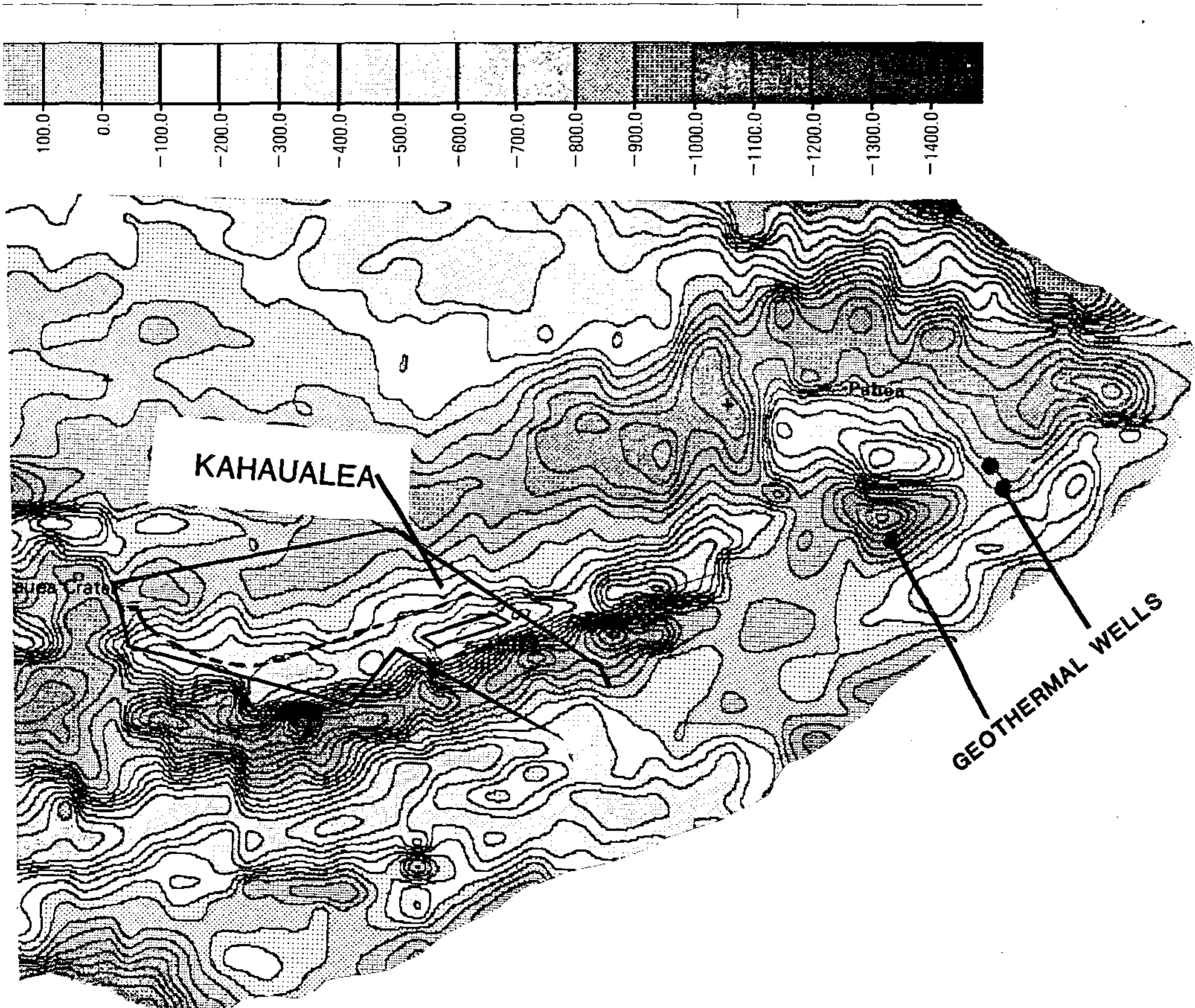


FIGURE 4

AEROMAGNETIC MAP OF HAWAII
From Godson et al, 1981

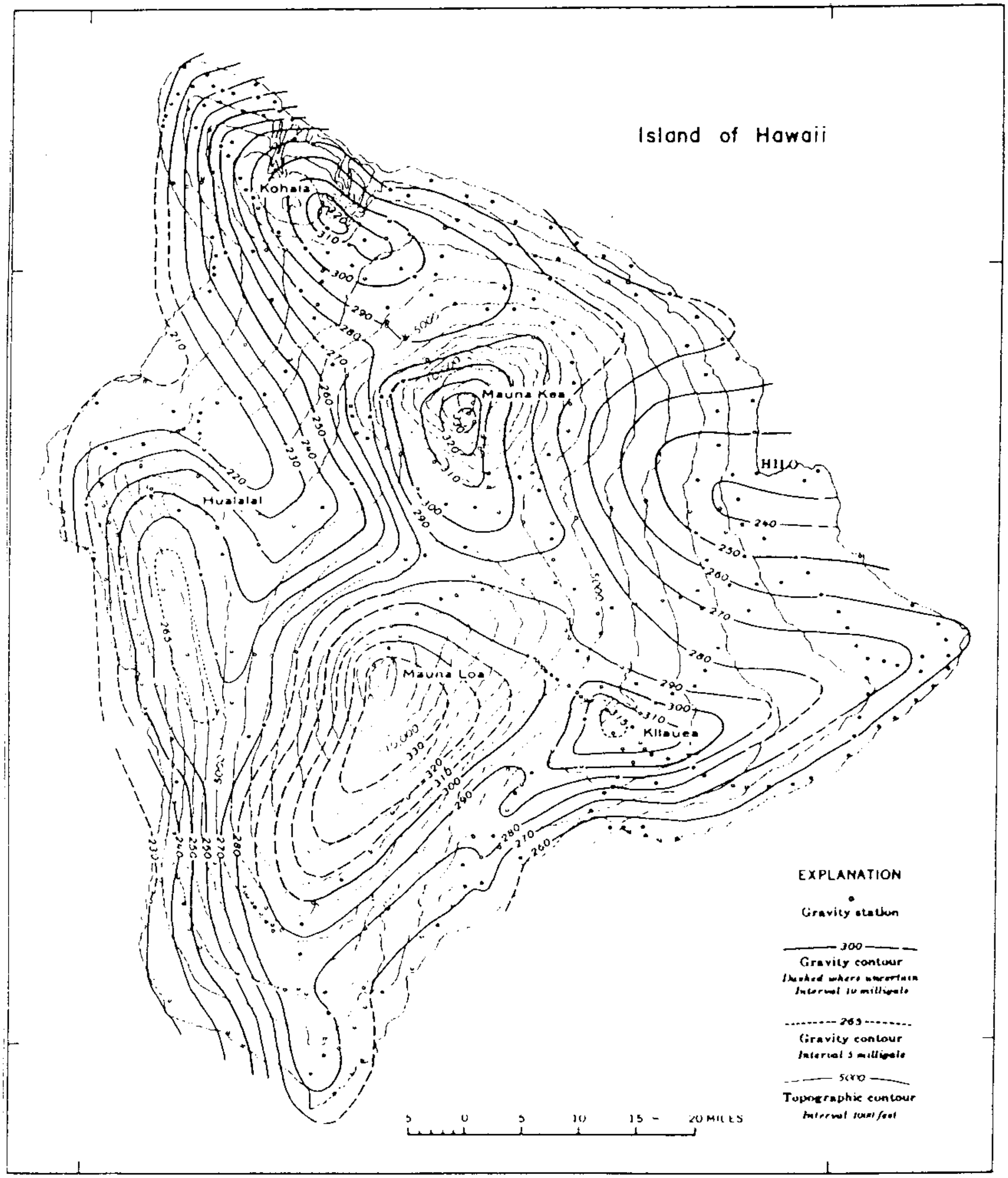


FIGURE 5

BOUGER GRAVITY ANOMALY MAP

FROM KINOSHITA, 1965

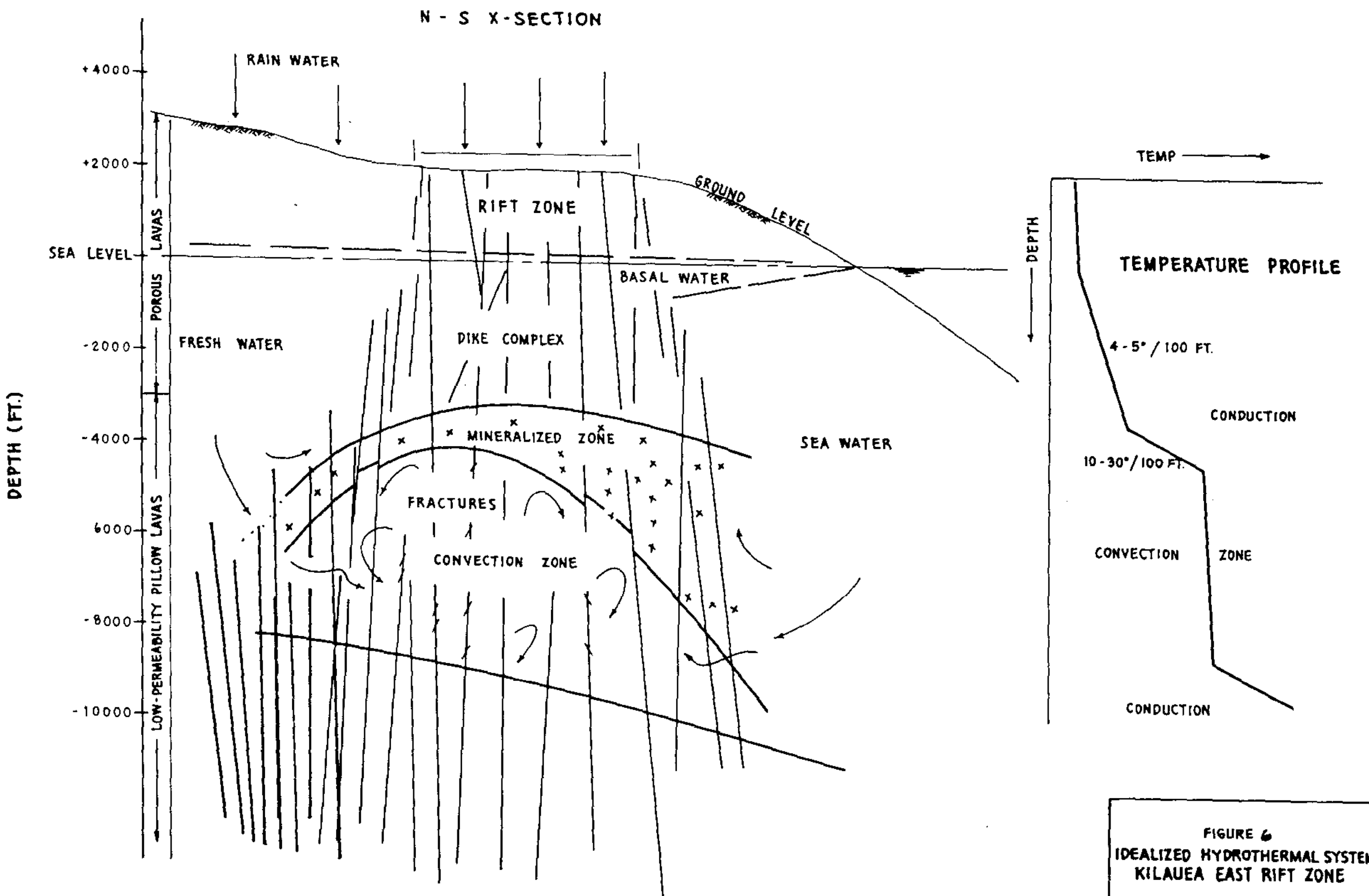


FIGURE 6
IDEALIZED HYDROTHERMAL SYSTEM
KILAUEA EAST RIFT ZONE

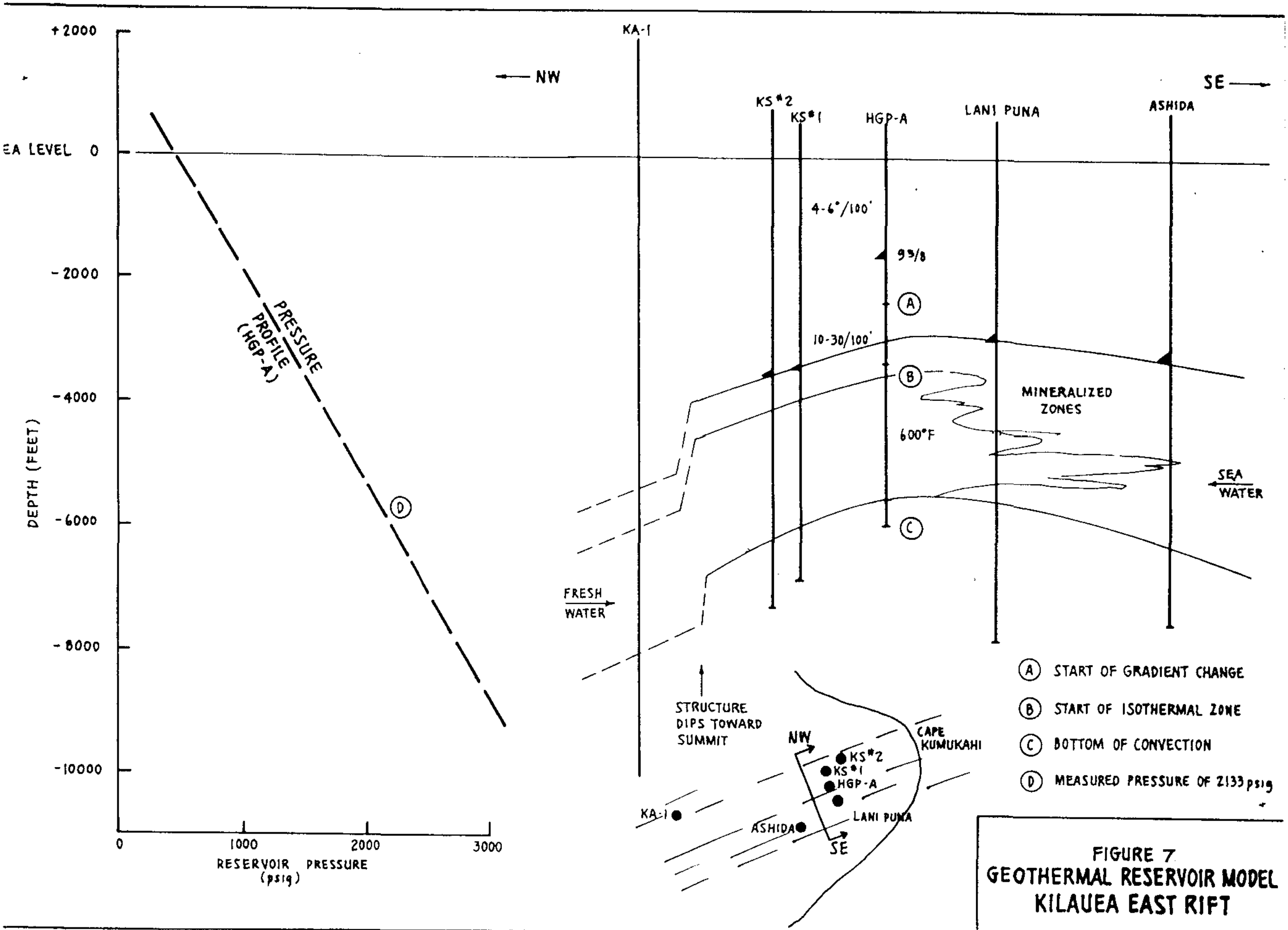


FIGURE 7
GEOTHERMAL RESERVOIR MODEL
KILAUEA EAST RIFT

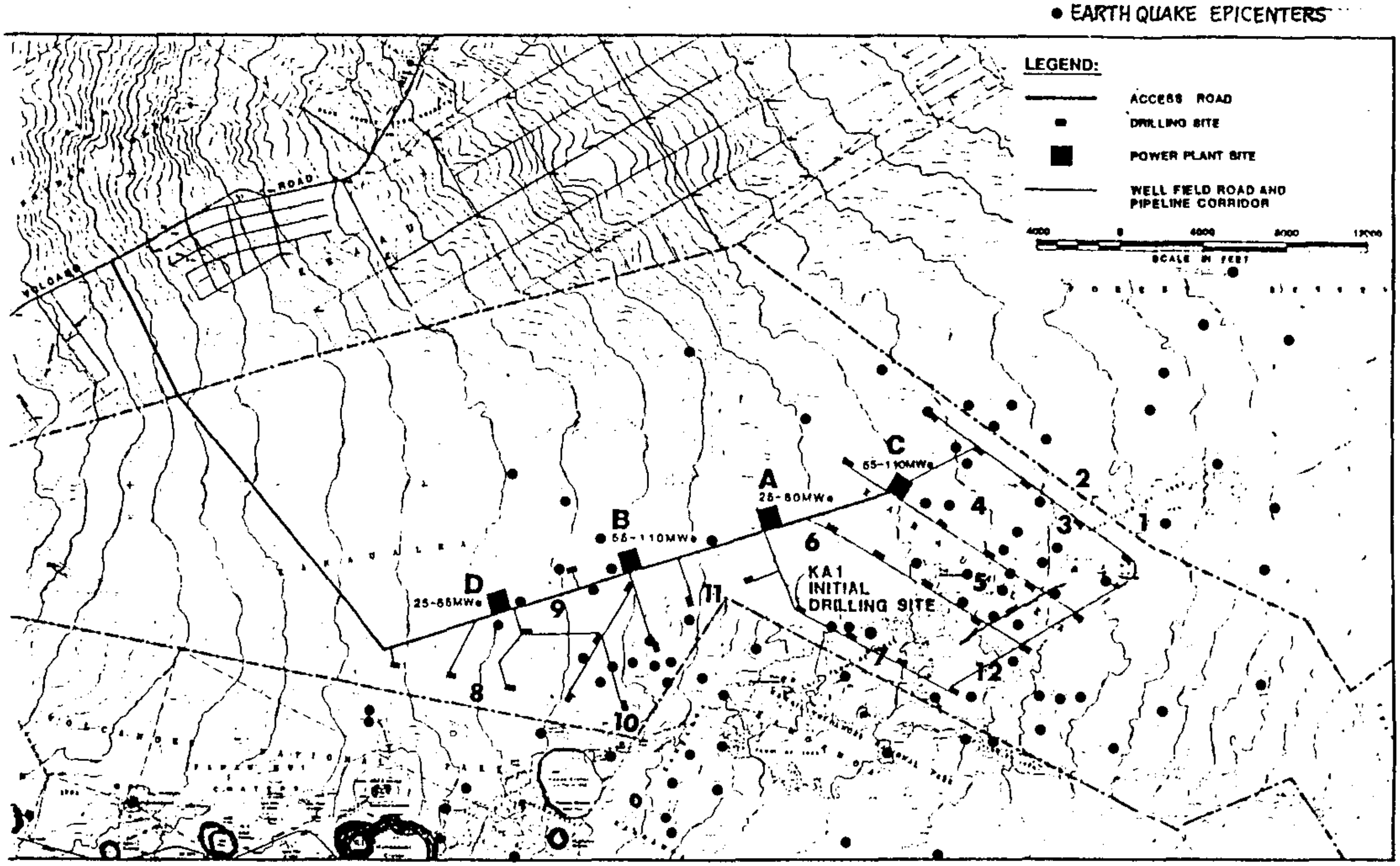
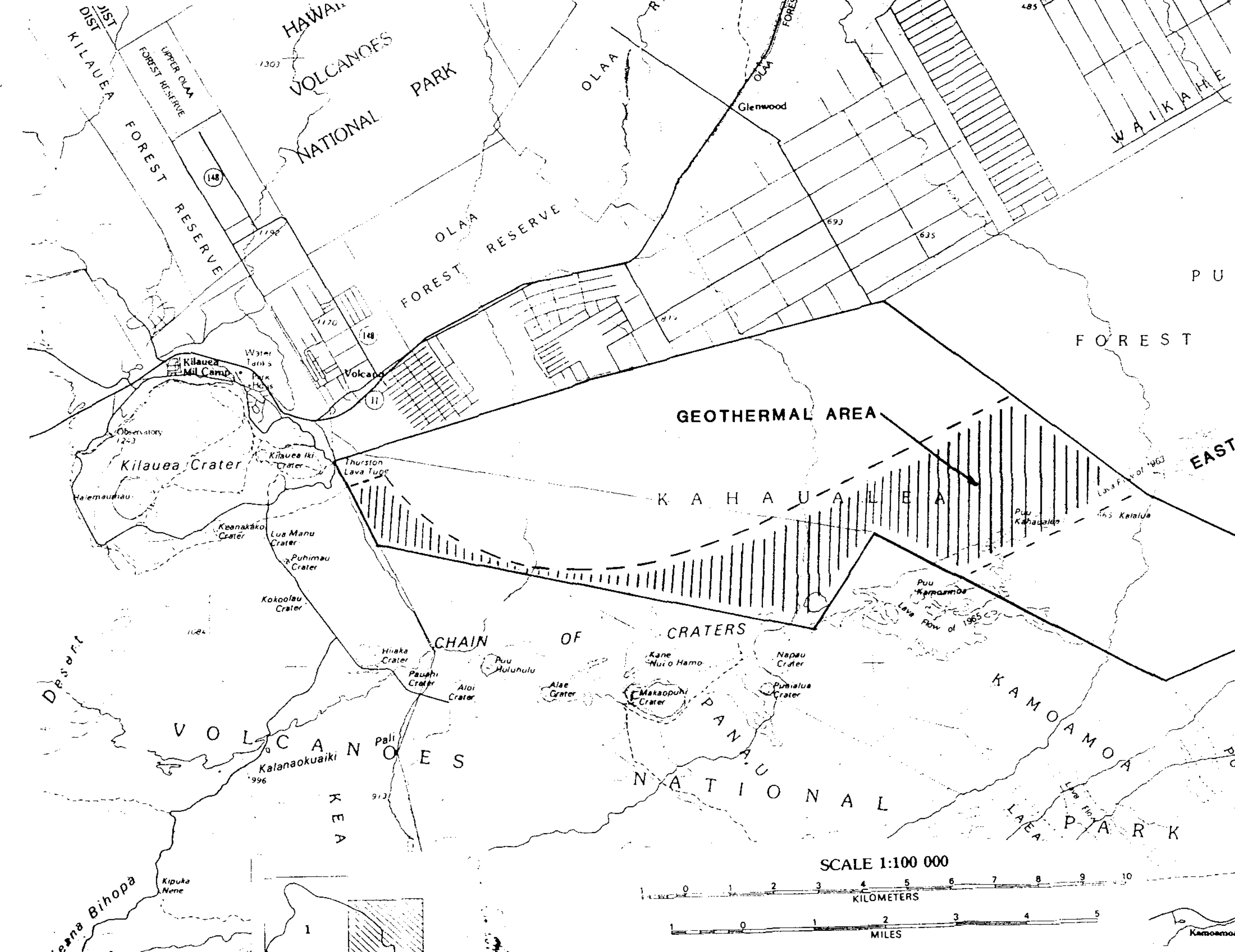
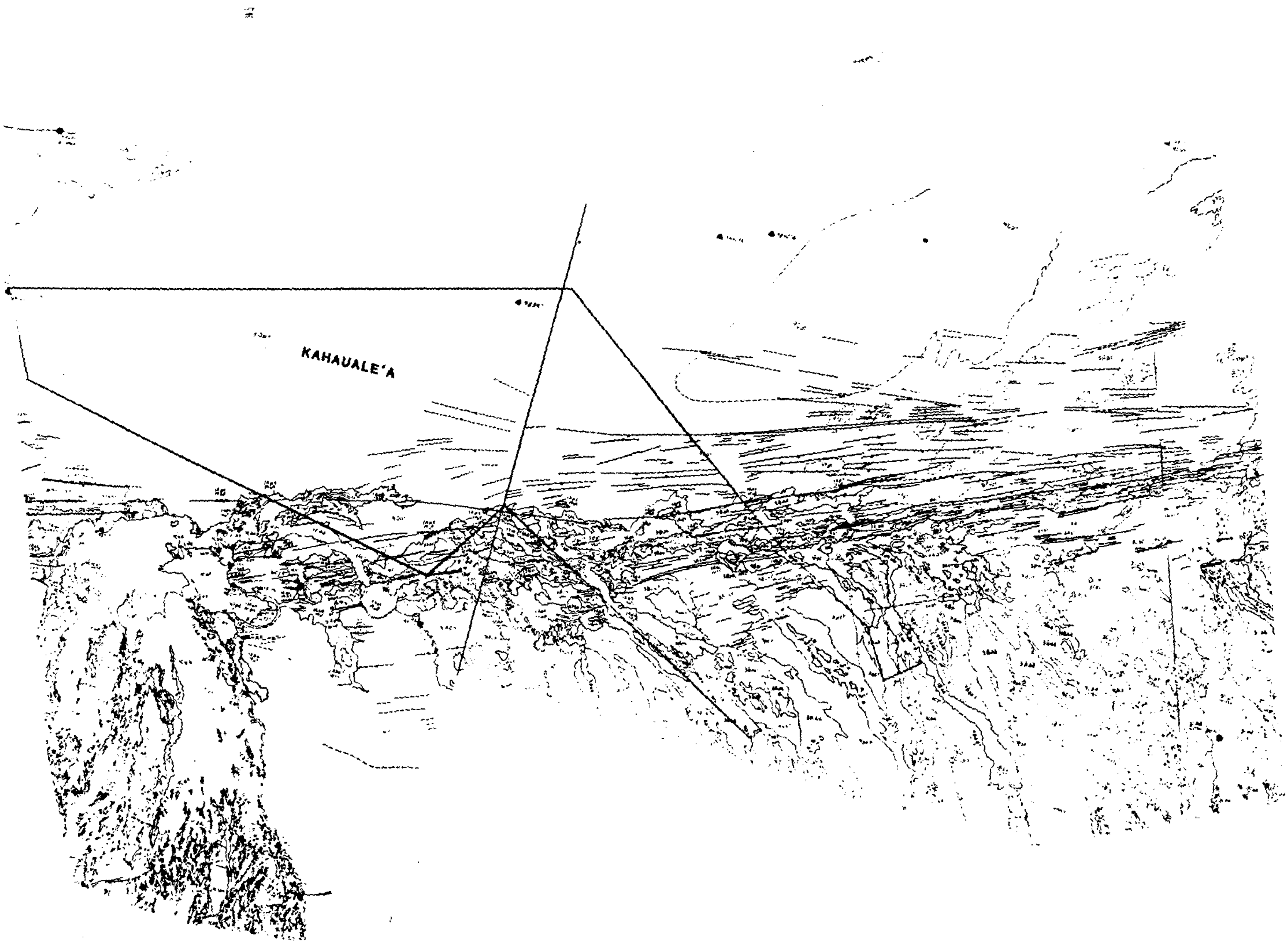


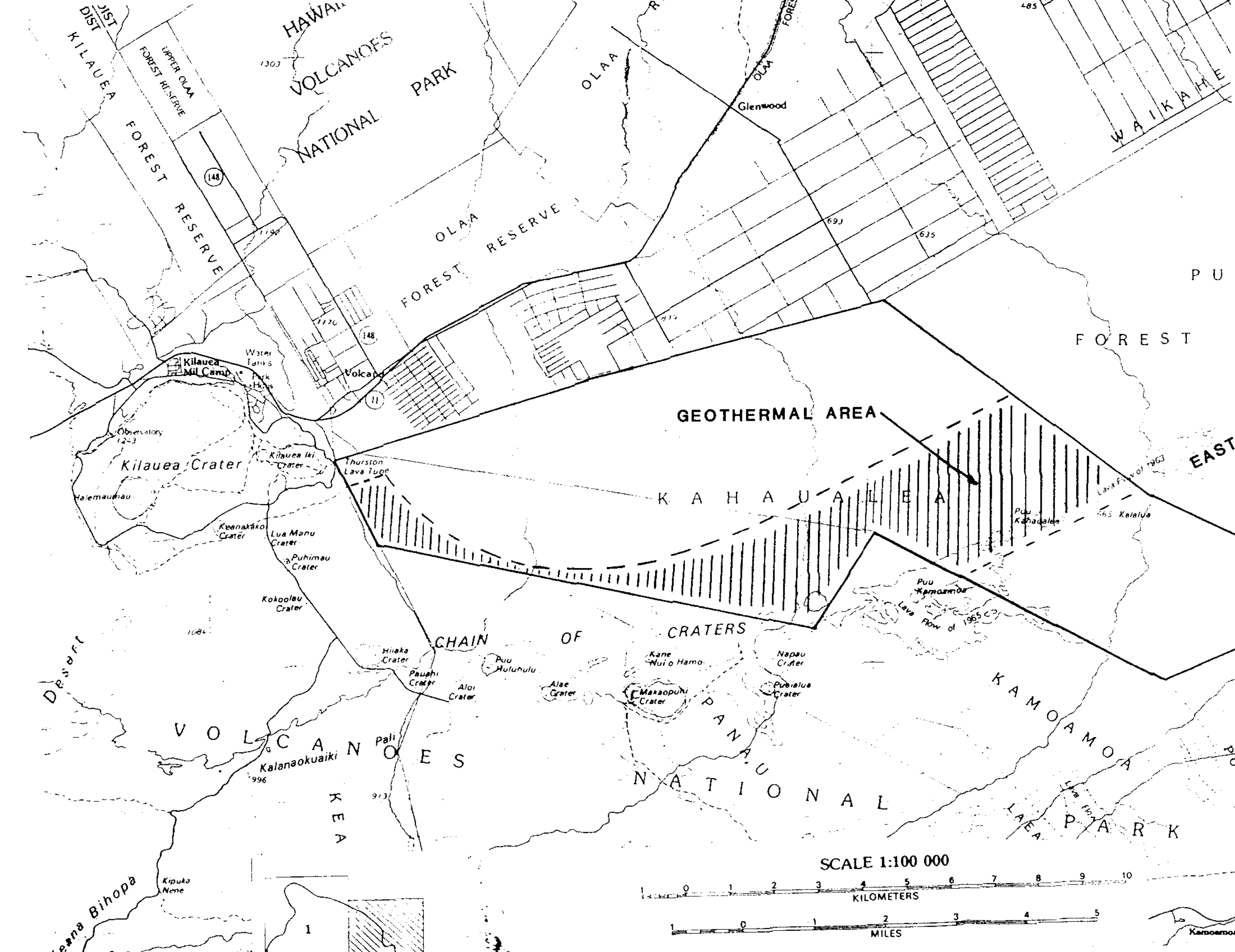
FIGURE 8

EPICENTER MAP
KAHAUALE'A MICROEARTHQUAKE STUDY

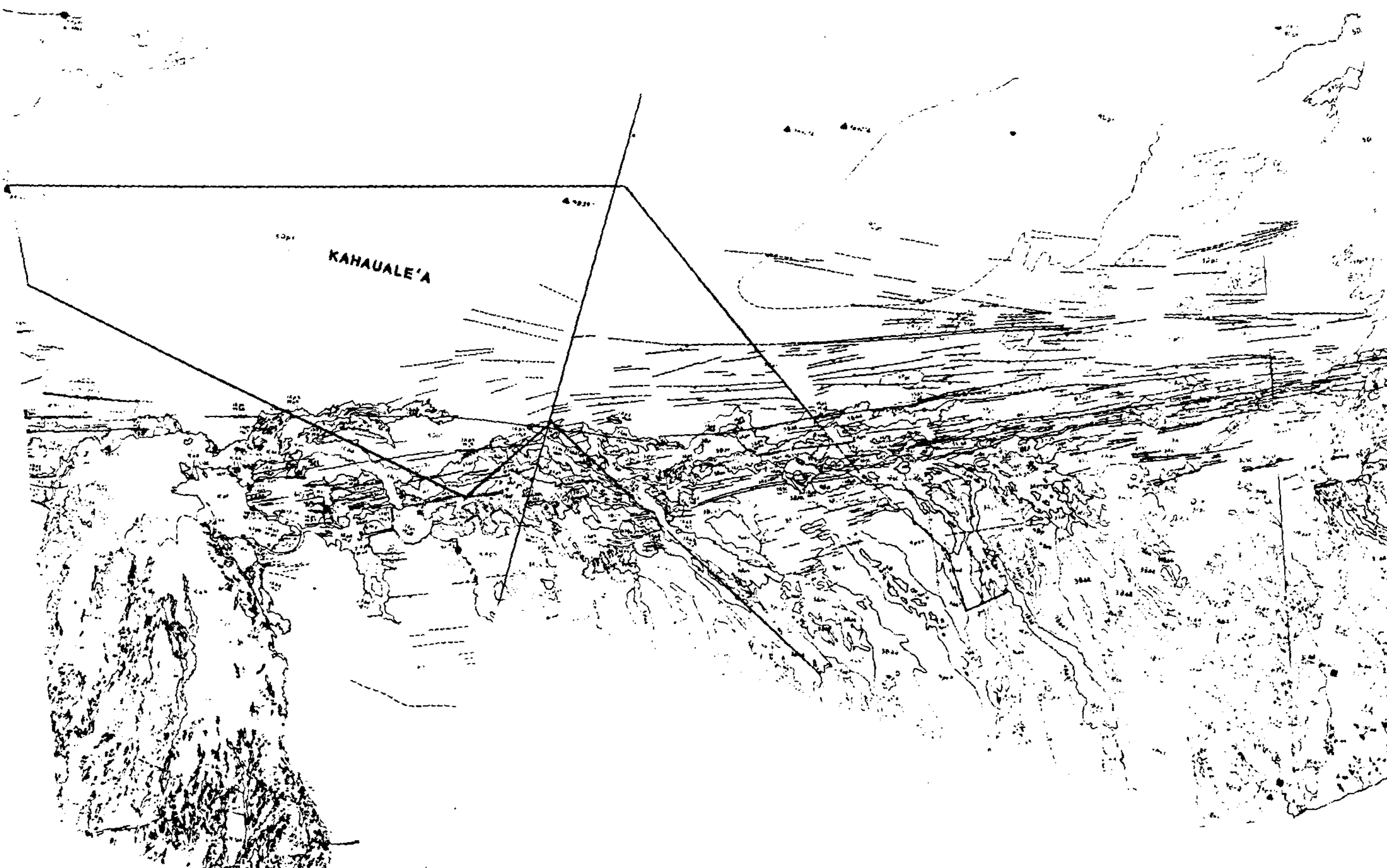

GEOTHERMAL AREA
HAWAII VOLCANOES NATIONAL PARK
KILAUEA FOREST RESERVE
UPPER OLAA FOREST RESERVE
OLAA FOREST RESERVE
OLAA
WAIKAHE
Glenwood
Volcano
Kilauea Mil Camp
Water Tanks
Park Hq
Observatory 1243
Kilauea Crater
Halemaumau
Kilauea Iki Crater
Thurston Lava Tube
KAHAUALEA
Puu Kahaualea
Kalalua
Lava Flow of 1963
EAST
FOREST
Keanakakoi Crater
Lua Manu Crater
Puhimau Crater
Kokoolau Crater
CHAIN OF CRATERS
Hiiaka Crater
Pauahi Crater
Aloi Crater
Puu Huluhulu
Alae Crater
Kane Nui o Hamo
Makaopuhi Crater
Napau Crater
Puu Kamoamoa
Lava Flow of 1965
Pulualua Crater
KAMOAMOA
PANAU
VOLCANOES NATIONAL PARK
Kalanaokuaiki Pali
Desert
Kipuka Nene
Bihopa
SCALE 1:100 000
KILOMETERS
MILES
Kamoamoa

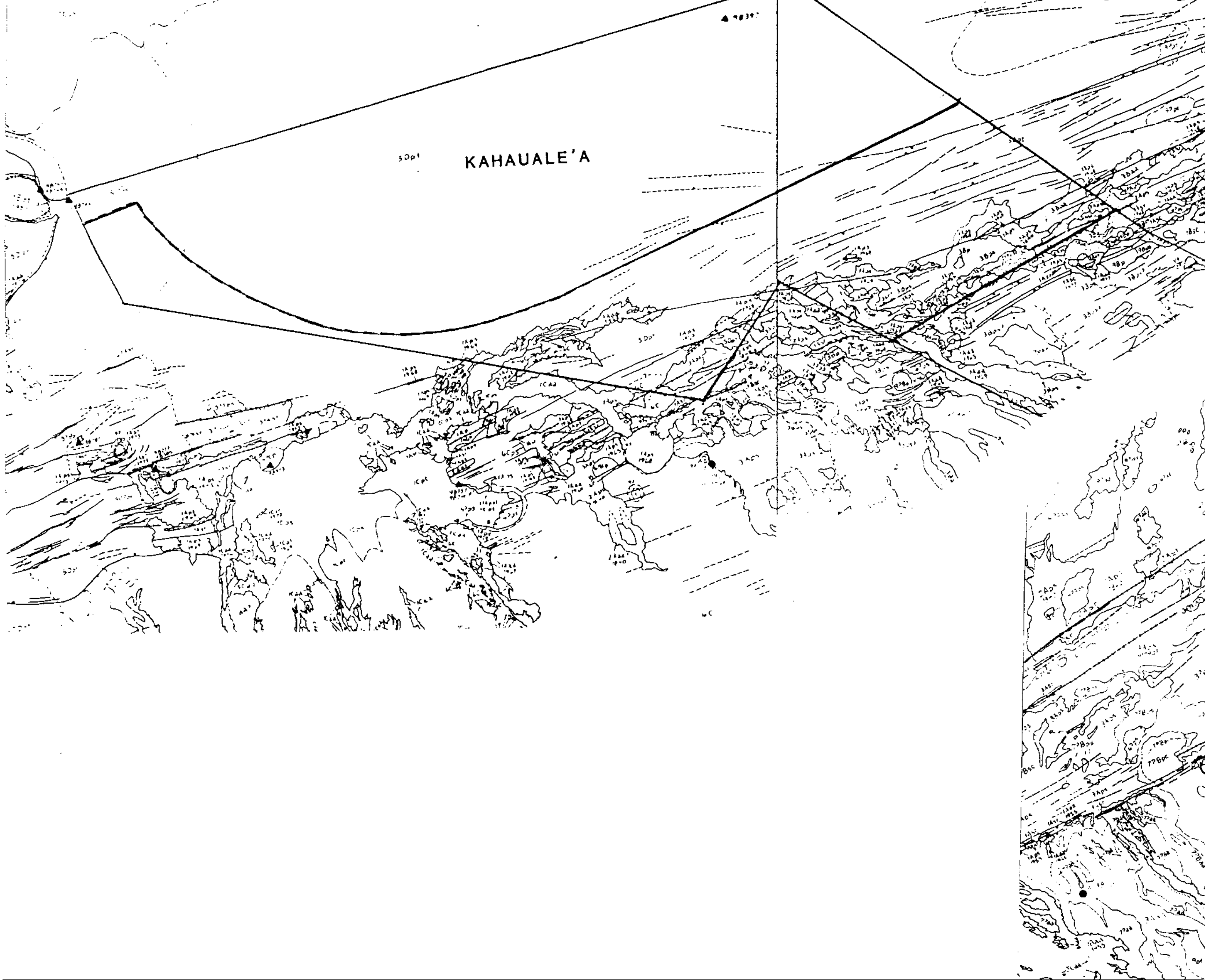

KAHAUALE'A


KAHAUALE'A



HAWAII VOLCANOES NATIONAL PARK
KILAUEA FOREST RESERVE
UPPER OLAA FOREST RESERVE
OLAA FOREST RESERVE
OLAA
Glenwood
WAIKAHE
PU
FOREST
EAST
GEOTHERMAL AREA
KAHAUALEA
Kilauea Mil Camp
Water Tanks
Park Hq
Volcano
Observatory 1243
Kilauea Crater
Kilauea Iki Crater
Thurston Lava Tube
Halemaumau
Keanakakoi Crater
Lua Manu Crater
Puhimau Crater
Kokoolau Crater
Lava Flow of 1963
Puu Kahaualea
Kalalua
Puu Kamoamoa
Lava Flow of 1965
CHAIN OF CRATERS
Hiiaka Crater
Pauahi Crater
Aloi Crater
Puu Huluhulu
Alae Crater
Kane Nui o Hamo
Makaopuhi Crater
Napau Crater
Puialua Crater
PANAUNUI
KAMOAMOA
LAEA
VOLCANOES NATIONAL PARK
Desert
Kalanaokuaiki Pali
KEA
Kipuka Nene
Keana Bihopa
SCALE 1:100 000
KILOMETERS
MILES


KAHAUALE'A


KAHAUALE'A