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COLORADO SCHOOL OF MINES
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Department of Geophysics

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FINAL REPORT:

EXPLORATION FOR GEOTHERMAL ENERGY ON OAHU, HAWAII

by

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for

OFFICE OF NAVAL RESEARCH
Contract N00014-76-C-0824

EXPLORATION FOR GEOTHERMAL ENERGY ON OAHU, HAWAII

Most interest in geothermal development in Hawaii up to the present time has centered on the development of thermal energy at Kilauea Volcano on the Island of Hawaii. Several test wells have yielded encouraging results with respect to further development of geothermal energy (Keller, et al, 1974). However, nearly 80% of the population of Hawaii reside on the Island of Oahu. In view of the larger market for energy there, it is reasonable to review the potential for the occurrence of commercial geothermal resources on Oahu, (Furumoto, 1976).

The Hawaiian chain is entirely volcanic (Macdonald and Abbott, 1970). At least two volcanoes on the Island of Hawaii, Kilauea and Mauna Loa, have been highly active in modern times. The age of principal volcanism appears to decrease as one travels northwestward along the Hawaiian chain. Development of the volcanoes appears to have been episodic, with episodes of volcanism persisting for a half million years or more at one location.

The Island of Oahu represents the remnants of two major volcanic centers in which the principle volcanism took place between two and three million years before the present. Erosional remnants of these two volcanoes are represented today by the Waianae Mountains along the west coast of Oahu and the Koolau Range along the southeastern coast (see Figure 1). The presence of dense rock in a stock-like mass under each of these mountain ranges is clearly expressed on the gravity map of the Island of Oahu (Figure 2; Strange, Machevsky, and Woolard, 1965).

It is reasonable to expect that if any subsurface heat remains in these two dormant volcanoes, the major part of it should be concentrated in these volcanic stocks. The amount of heat persisting until the present time will depend on how effective the cooling has been. That the central stock of Koolau Volcano may still be warm is indicated by resurgent activity which occured as recently as 31,000 to 33,000 years before the present, based on the ages of the most recent lavas of the Honolulu Volcanic Series as determined by the potassium argon method by Cox (1969). The locations of these recent flows are shown on the map in Figure 3 (Gramlich, et al, 1971).

Exploration for geothermal energy on Oahu has been limited. Tasci (1975) has described the results of geophysical surveys carried out in the Lualualei Valley as part of a project funded by the Office of Naval Research. The Lualualei Valley lies within the Waianae Range on the west coast of Oahu, and is situated approximately in the center of the Waianae Caldera. In this study, anomalously low values of electrical resistivity were mapped in part of the Lualualei Valley. In addition, shallow (1 meter) subsurface temperature measurements showed that the area with low resistivity was also characterized by a subsurface temperature about 2° C above the normal temperature in the surrounding area. Several water wells drilled in the 1950's also produced surface waters at temperatures of 5° to 10° C above normal from depths of about 100 meters. While these data do not demonstrate conclusively that commercial geothermal energy is present in the Lualualei Valley, they are sufficiently encouraging that further work was recommended to the Office of Naval Research in 1975.

As proposed to the Office of Naval Research, extensive resistivity and seismic surveys were to be carried out over the two calderas to determine the most likely locations for potential geothermal reservoirs. These exploration surveys were to be followed by the drilling of a number of shallow boreholes to test subsurface temperatures at depths ranging from 100 to 200 meters, and to obtain water samples from beneath the fresh water layer for geochemical studies. The cost of the program as proposed was $130,000. The proposed survey was not funded, and in place of the comprehensive study, a reconnaissance study was funded at $25,000, later increased to $28,000. This report describes the results of the preliminary studies. The work carried out included a resistivity survey of the Koolau area, some additional resistivity measurements along the east side of the Waianae Range, a study of microseismicity on the Island of Oahu, several magnetotelluric soundings in the Lualualei area, and a study of the concentration of mercury in soil in the Koolau Caldera area.

<u>Mercury in Soil</u>

A primary concern in evaluating the geothermal prospects of an area is the temperature at which groundwaters exist at drillable d[illegible]. The principle method used in determining subsurface temperatures is geochemistry. Some elements are taken into solution in diagnostic amounts as the temperature of a rock is raised; these elements can be used as geothermometers. For example, when groundwater is in contact with quartz at temperatures of 200^{o} to 300^{o} C, the solubility of silica in the groundwater is from 250 to 600 parts per million (Ellis and Mahon, 1964). Silica does not precipitate immediately when water from a geothermal reservoir leaks to the surface in a warm spring, even though the temperature of the warm spring may be markedly less than that of the reservoir. Therefore, detection of high amounts of silica in a warm spring is a means for determining the temperature of a subsurface geothermal reservoir. Similarly, the ratio of alkali ions taken into solution from feldspars is sometimes characteristic of reservoir temperature (Fournier and Truesdell, 1973). By analyzing the concentrations of potassium, sodium and calcium, an estimate of subsurface temperature can be made.

The silica and alkali geothermometers work best if there is direct leakage from a geothermal reservoir to surface springs. Unfortunately, geochemistry of spring waters is often complicated by mixing of leakage from subsurface geothermal reservoirs with surface waters. This problem is particularly pronounced in Hawaii where the rainfall is heavy, and the surface waters move rapidly through the soil to the sea. There is very little opportunity for deep subsurface waters to leak to the surface to form warm springs. These occasionally occur along the coastline but sampling is difficult.

Another method for geochemical evaluation of geothermal reservoirs is the detection of mercury in soil or mercury or helium in soil gas. These elements are not easily trapped in rocks, and tend to diffuse continuously to the surface of the earth. If subsurface temperatures are unusually high, the rate of diffusion is accelerated and anomalously high concentrations of mercury and helium will occur in the soil. For example, the normal concentration of mercury in soil is 10 to 100 ppb (parts per billion). It has been observed that in known geothermal areas, the concentration of mercury is 100 to 1000 times greater. At The Geysers in California, at Roosevelt Hot Springs in Utah, and at the Hawaii Geothermal Test Well No. 1 in Puna, the concentration of mercury in the soil reaches levels of 1,000 to 10,000 ppb (Matlick and Buseck, 1975; White, et al, 1976). These three geothermal areas are characterized by relatively high reservoir temperatures, in the range from 500° to 600° F. At Heber, in the Imperial Valley of California, the soil mercury content reaches 300 to 500 ppb where the reservoir temperature is approximately 350° to 400° F. While these data are yet inconclusive, they indicate that a correlation exists between the concentration of mercury in soil and geothermal reservoir temperature.

As part of the study on Oahu, 34 soil samples were analyzed for mercury. Thirty-two of these soil samples were taken within the area of the Koolau Caldera as indicated on the map in Figure 4. The other two soil samples were taken near the entrance of the Lualualei Naval Magazine in the Waianae Caldera area. Unfortunately, permission to sample within the Magazine area could not be obtained. Samples amounting to 30 to 50 grams were taken from the soil at a depth of 6 to 12 inches. These samples were sieved to separate the fine sand sizes for analysis. The fine sand separate was heated in a small oven to volatilize any metallic mercury which might be present. The fumes derived from the sample were passed through a silver thimble to separate the mercury from organic compounds volatilized along with them. After heating for three minutes, the thimble was removed and it in turn was placed in the oven. On heating, the thimble released the amalgamated mercury which was then passed through a dual atomic absorption cell. The accuracy of mercury determinations with this device is probably ±20%. The range of concentrations to be expected is from 10 or 20 ppb in a barren materials to 10,000 ppb in material rich in metallic mercury.

The mercury analyzed in this manner is in the metallic state, either in soil gas, or absorbed on soil particles. The residence time is not known, but is probably short, ranging from a few days to a few weeks. It is believed that the presence of metallic mercury in the soil is indicative of high temperatures in the subsurface at the present time.

All of the values except for a few measured in the northern part of the Koolau area were anomalously high. Many values were in the range from 100 to 500 ppb and two samples showed mercury concentrations of more than a 1,000 ppb. Station locations and mercury concentrations are shown on the map in Figure 4.

All the soil samples shown on Figure 4 were taken at locations within the Koolau Caldera. The normal values for soil mercury content determined on the Island of Hawaii are in the range from 40 to 100 ppb (Anderson, James: personal communication, 1976). Whether or not such normal values would be observed at locations outside the Koolau Caldera cannot be determined on the basis of the data presented here. The relatively high mercury contents on Oahu may possibly be attributed to a relatively high concentration of mercury in the basalt generated by the two volcanoes on Oahu. A more likely explanation, particularly in view of the fact that the highest mercury concentrations are aligned with the Diamond Head Fracture Line along which eruptive activity has occured within the last 300,000 years, is that the mercury is being mobilized by residual heat.

The mercury concentrations determined for the two samples taken in the Lualualei area are 250 and 235 ppb, or roughly the same as the general level in the Koolau Caldera.

Seismicity Surveys

Studies of local seismicity are widely used in geothermal prospecting. In some cases, geothermal systems are characterized by unusually high levels of weak earthquake activity (Ward, 1972). Many earthquakes with magnitudes ranging from -2 to 0 can be observed around cooling intrusions; such is the case at Kilauea Volcano on the Island of Hawaii. It is suspected that this seismic activity is associated with the breakage of rock under thermal stresses because the rate of heating in a newly developed geothermal system is very high. In other geothermal systems, the level of microseismic activity may be quite low.

Even in such cases, travel times for earthquake waves through the crust and upper part of the mantle can be used to locate zones with unusually high temperatures. Elevation of temperature along with fracturing of the crustal rock will reduce the velocity of transmission for both P and S waves. In an area where the rocks at depth are unusually hot, P waves arriving from distant earthquakes will be slow. This method has been used very effectively at Yellowstone National Park for mapping the magma chamber beneath the caldera area (Eaton and others, 1975).

A microseismicity survey of the Island of Oahu was carried out jointly by Microgeophysics Corporation of Golden, Colorado, and the Hawaii Institute of Geophysics during the interval from July 16 to August 5, 1976. Microearthquake recording systems were operated at 10 locations as indicated in Figure 5. For most of the survey, records were obtained continuously from seven or eight stations. The intervals during which each of the stations were operative is indicated on the operations log in Table 1.

Because of the high population density on the Island of Oahu and because of the relatively small size of the island, extraneous noise from human activity and from wave action on the coast made detection of small events difficult. Four of the twenty days during which at least part of this network was operating, no events could be identified as occuring within either the Waianae or Koolau Calderas. While it is possible that the recording period was one of unusual quiet, it appears that microseismic activity in the two calderas is at a lower level than is normally encountered in volcanic areas with recent intrusives.

P wave velocities across the Koolau Caldera were determined for five clearly recorded but more distant events as listed in Table 2. These events originated at distances ranging from 89 to 320 km, so that the first arrival should be a P wave refracted along the top of the mantle. The apparent travel time for the P wave across the array was determined by plotting arrival times as a function of distance from the epicenter. It should be noted that the epicentral distance need not be known in order to determine the incremental velocity. The travel time curves for the five events are presented in Figures 6 through 10. The incremental velocities determined for the five events range from 5.2 km per second to 8.5 km per second. The higher interval velocities were not associated with the greater epicentral distances, as may be seen by the combined travel time plot in Figure 11. This assures us that the difference in velocity does not reflect a change in velocity with depth for the waves arriving from a greater distance. It seems more likely that the differences in interval velocity reflect changes in the velocity structure of the crust and upper mantle, some of which may be caused by temperature. A plot of the interval velocities for each of the stations used in the determinations with a vector showing the direction of arrival for the waves indicates that there could be an area of relatively low interval velocity in the vicinity of Olomana Peak (see Figure 5).

While the evidence for an anomaly in wavespeed within the caldera is minimal, it is suggestive enough that further effort should be expended in defining the velocity structure within the caldera.

Direct Current Resistivity Survey

A direct current resistivity survey was carried out in two areas on Oahu as part of this program. The dipole mapping method (Keller, et al, 1975) was used. Two sets of measurements were made about two source locations, one in the vicinity of Kailua Village on the Koolau side of Oahu, and the other along the east face of the Waianae Range.

In each of these surveys, a crossed bipole source was used. That is, at a source location, two bipole sources oriented roughly at right angles to each other were installed. These bipole sources were approximately one km in length each, consisting of AWG No. 8 wire grounded through sheets of metal buried in the soil. Each of the two sources was powered sequentially with an asymmetric square wave current wave form. The current wave form had a periodicity of 20 seconds, but current flow in one direction of the square wave lasted for about 50% longer than the current flow in the opposite direction. The asymmetry of the current wave form was used to identify the polarity of received signals.

Electric field measurements were made at many locations around each of these pairs of bipole sources. The electric field was detected using short grounded dipoles oriented approximately at right angles to one another, with an interior spacing of 10 to 30 meters. The signals from the electrode pairs were recorded on an analog recorder, and later scaled to yield the voltage between receiver electrodes caused by current flow from the source bipole.

As a first step, the signals from each of the two bipole sources were treated independently to yield values of apparent resistivity using the formula based on the magnitude of the electric field at a receiver station;

$$\rho_T = \frac{2\pi R_1{}^2}{\left[1 + \left(\frac{R_1}{R_2}\right)^4 - \left(\frac{R_1}{R_2}\right)^2 \cos\delta\right]^{\frac{1}{2}}} \frac{|E|}{I}$$

where R_1 and R_2 are the distances from the ends of the source bipole and a receiver station, δ is the angle between R_1 and R_2, $|E|$ is the magnitude of the observed electric field vector, and I is the amplitude of the current step supplied to the ground. Contour maps of the single-source apparent resistivity are shown for the four sources in Figures 12 through 15. As may be seen, anomalously low resistivities were observed over a small area along the Diamond Head fracture zone adjacent to Olomana Peak. The resistivities in this area are as low as one ohm-m. Quite high resistivities are observed at Olomana Peak (see Figures 12-15).

Resistivities measured along the east side of the Waianae Range show no anomalous behavior.

<u>Magnetotelluric Soundings</u>

With the dipole mapping method described above, no information is provided about the variation of resistivity with pairs were recorded on an analog recorder, and later scaled to yield the voltage between receiver electrodes caused by current flow from the source bipole.

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Resistivities measured along the east side of the Waianae Range show no anomalous behavior.

<u>Magnetotelluric Soundings</u>

With the dipole mapping method described above, no information is provided about the variation of resistivity with depth in the earth. An attempt was made to use the magnetotelluric sounding method to study resistivity variations at depths of several kilometers.

In the magnetotelluric method, natural variations in both the magnetic and the electric field are measured simultaneously (Cagniard, 1953). Apparent resistivity values can be computed by comparing the simultaneous amplitudes of the electric and magnetic field components. Because natural field variations contain very low frequencies, and because very low frequencies can penetrate to great depths in the earth, the magnetotelluric method is best used to study resistivities at depths ranging from kilometers to tens of kilometers.

In the magnetotelluric soundings carried out on Oahu, a SQUID magnetometer was used to detect the two horizontal and one vertical component of the natural field. A SQUID (Superconducting Quantum Interference Device) magnetometer employs a Josephson Junction which senses magnetic field changes with a high degree of resolution. A Josephson Junction consists of a semiconducting film which breaks the continuity of a superconducting ring. Because the metal forming the ring is superconducting only at very low temperatures, it is necessary to keep the Josephson Junction immersed in liquid helium.

The electric field was detected using electrode pairs separated by a distance of one-half kilometer with two electrode pairs being oriented at right angles to one another. Signals from the three magnetometer components and from the two electric field components were recorded simultaneously on a five pen recorder. Records were made for relatively short intervals at each station location, from

10 to 30 minutes. This is a sufficiently long recording period to provide information at frequencies down to approximately one cycle per minute. It was felt that the longer period information would be of no great value because the wave lengths would be such as to detect the presence of the ocean around the edge of the island. At frequencies of 2 or 3 cycles per minute, wave lengths are such that the effect of the nearby ocean is probably not significant.

In processing the magnetotelluric data, the analog records obtained in the field were digitized at an interval of two seconds. The data were then filtered using a zero-phase filter with relatively flat response between two cycles per minute and ten cycles per minute. The filtered information from the five recorded channels was then plotted out. An example of a filtered record is shown in Figure 16.

Apparent resistivity values were computed using single events recorded on all five traces. A single oscillation on the record would be selected. The amplitudes of the two components of the electric field and of the magnetic field were then read from the record. A plot of the directions of the electric field vector and the magnetic field vector was then prepared, as shown in Figure 17. Normally, the two electric field vectors were only roughly perpendicular to one another, reflecting the effect of anisotropy. An apparent resistivity value was computed for each event using the magnitudes of the two vectors, and neglecting the fact that the two vectors are not mutually orthogonal. The conventional Cagniard formula was applied;

$$\rho_a = .2T \left(\frac{E}{H_\perp}\right)^2$$

This process was repeated for several dozen clearly defined signals on each record. The values for apparent resistivity so obtained were not all the same, inasmuch as apparent resistivity values are normally a function of the direction of the inducing field in the magnetotelluric method. A histogram of values determined from one of the stations is shown in Figure 18. The most likely apparent resistivity value had a frequency of approximately 2½ cycles per minute, is 6.39 ohm-m. In a uniform medium, the skin depth at this frequency and this resistivity is approximately 6 km. If the resistivity is uniform beneath the Lualualei Valley, the resistivity is as low as approximately 6 ohm-m to a depth of 6 km.

Summary and Conclusions

The geophysical and geochemical surveys carried out on the Island of Oahu to evaluate the potential for occurrence of geothermal energy have not been extensive enough to provide any conclusive results. However, each of the surveys provides a weak indication that the potential for the occurrence of geothermal energy at either the Lualualei Valley or the Olomana Peak area is reasonable. Both areas are characterized by regions of anomalously low resistivity, though in each case higher resistivities such as might be associated with an intrusive are also present. At the Koolau Caldera area, extremely high values for the concentration of mercury in soil are present. Also in the Koolau area computations of compressional wave velocities from distant earthquakes permit the existence of a crustal and upper mantle zone of anomalously low seismic wavespeed to be present beneath Olomana Peak. Because of the potential need for alternate energy sources on Oahu, these incomplete but suggestive data should lead to a more comprehensive evaluation study.

It is particularly important to do a much more thorough soil geochemistry survey to determine the extent and magnitudes of the areas with high mercury. Likewise it is important to carry on a resistivity survey which has the capacity to map zones of relatively low resistivity at depths ranging up to several kilometers. Further studies should be carried out to determine whether or not low velocity regions exist beneath the two calderas. This might be done either by continued operation of earthquake recording stations in and around the two calderas, or by active seismic exploration. Providing that the potential for the occurrence of geothermal energy is still apparent after more definitive exploration, it is clear that heat flow should be studied using drill holes to moderate depths, ranging from 100 to 300 meters. These drill holes would also provide the opportunity to obtain water samples from beneath the active groundwater layer.

While no effort was made to evaluate any potential environmental impact of geothermal development on the Island of Oahu, some aspects of the environmental impact are obvious to the casual observer. In the two areas where geophysical studies indicate that subsurface heat may exist, the land which would have to be taken out of other usage is not now being used for any conflicting purposes. In Lualualei Valley, the most promising areas lie within the Lualualei Naval Magazine. In the Koolau area, the most promising areas lie in the vicinity of Olomana Peak, which is virtually a wilderness. It appears that the potential lack of environmental impact for development of geothermal energies in these two areas would be highly fortuitous, since most areas on the Island of Oahu are highly developed at the present time.

Acknowledgment

This research was supported by the Earth Physics program of the Office of Naval Research.

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LIST OF FIGURES

Figure 15 Contour map of apparent resistivity measured in the vicinity of Kailua, Oahu. The value contoured is the apparent resistivity calculated for one leg (shown as B) of a rotating dipole source.

Figure 16 Example of two components (one electric and one magnetic) of a magnetotelluric record obtained on Oahu.

Figure 17 Vector diagram illustrating the computation of apparent resistivity from magnetotelluric data.

Figure 18 Histogram showing the distribution of apparent resistivity values computed for successive signals on a magnetotelluric record.

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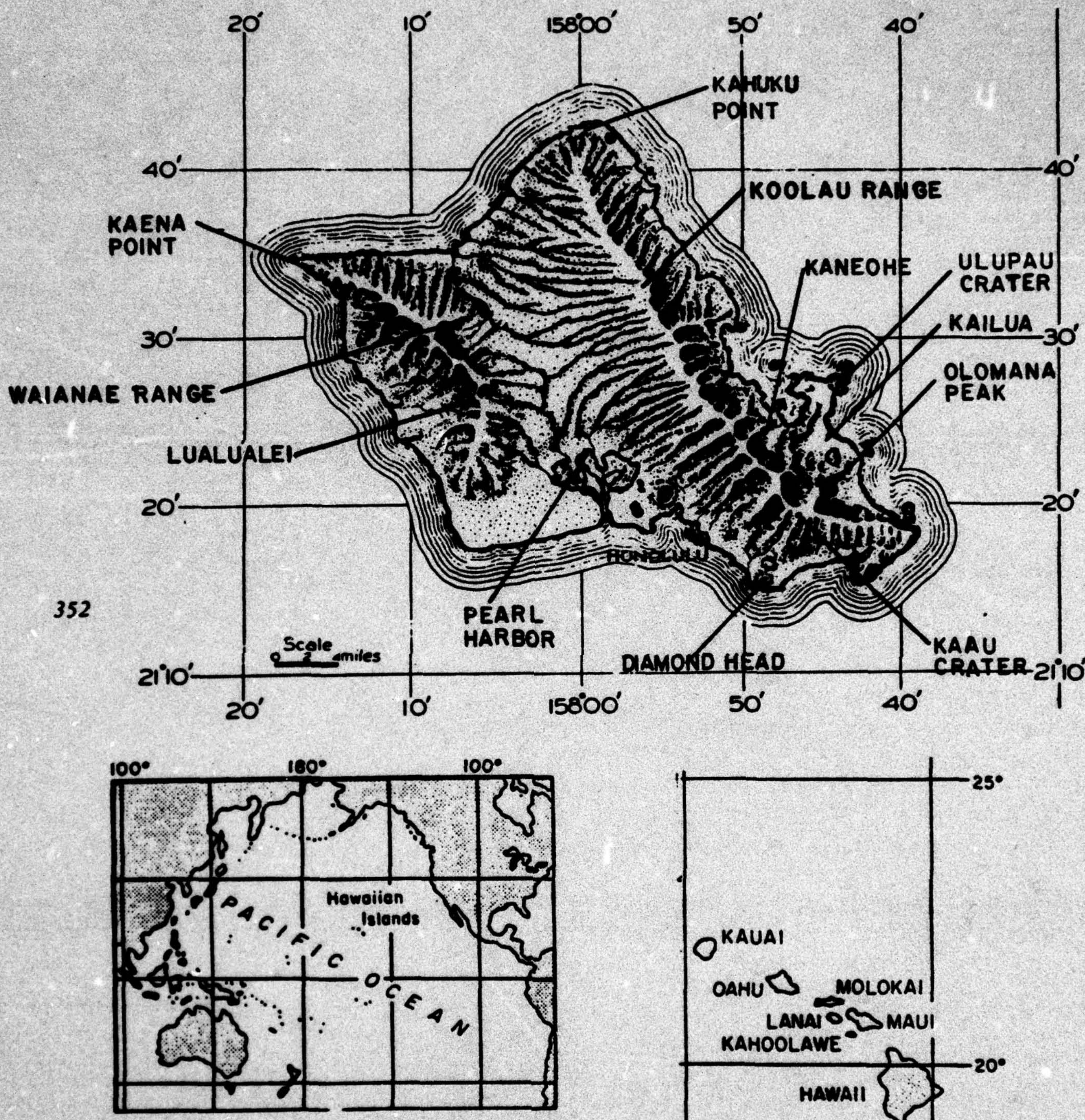


FIGURE 1

MAP OF OAHU

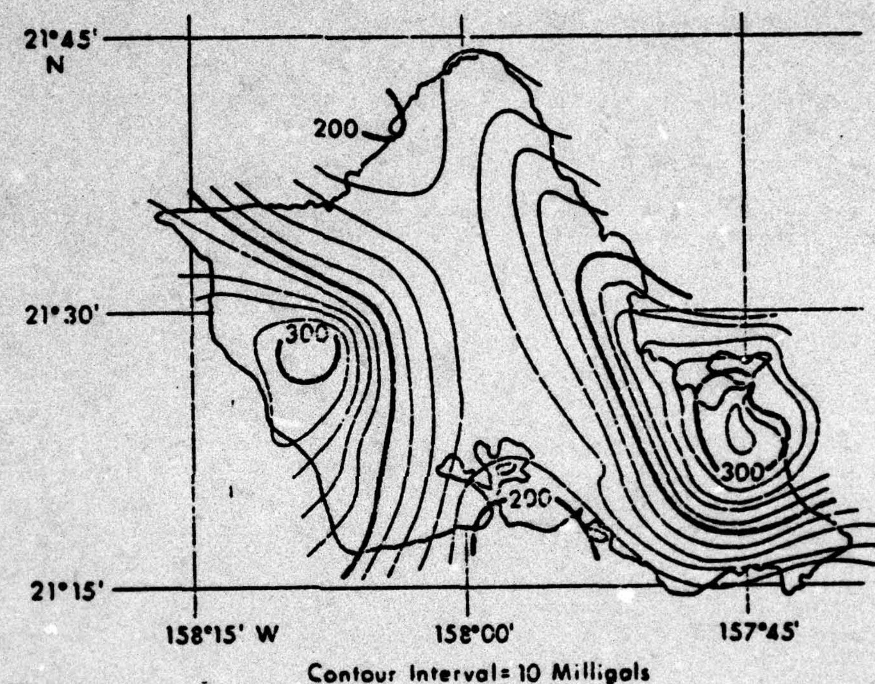
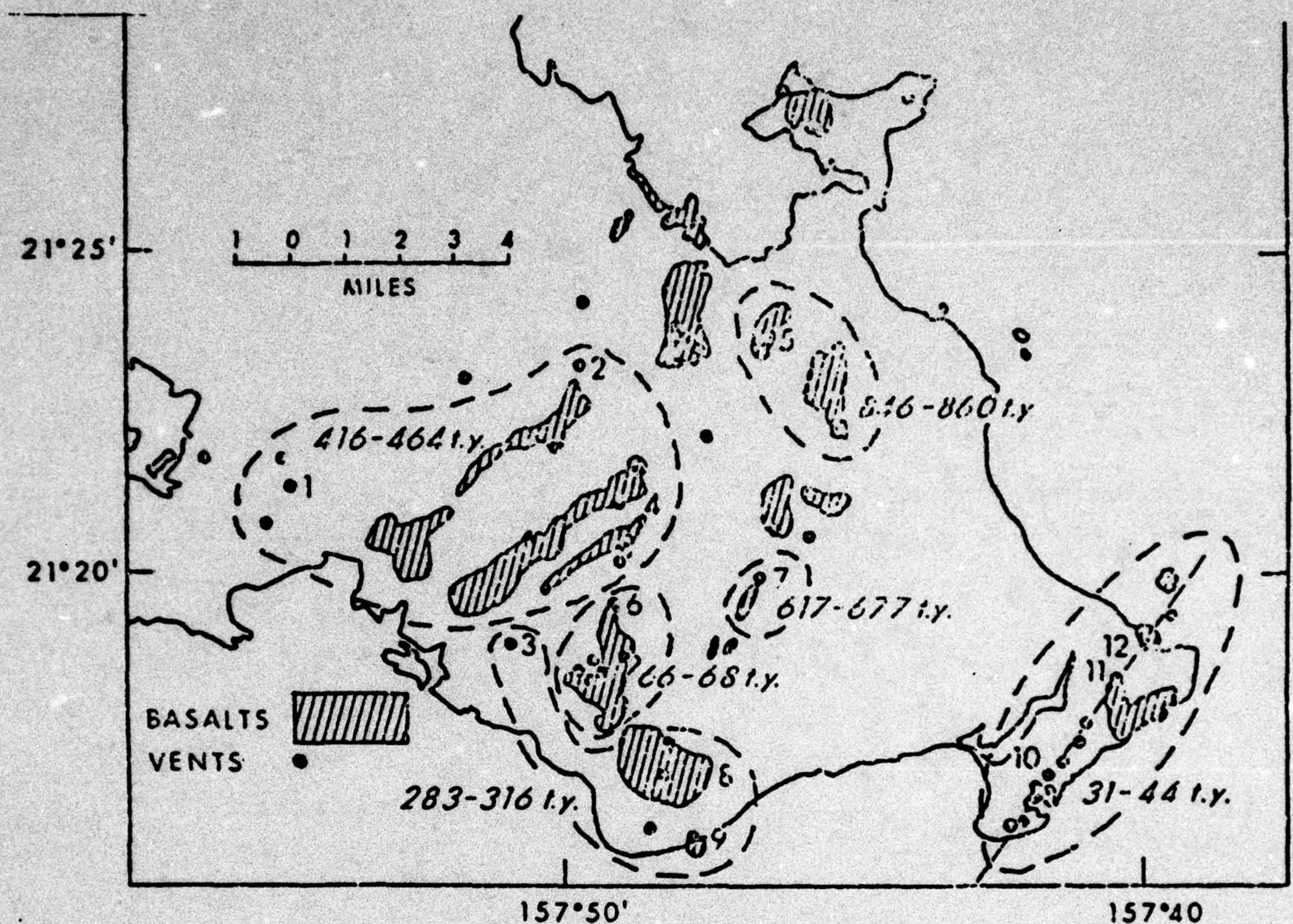


FIGURE 2

Bouguer gravity map of Oahu, modified from Strange, Machevsky, and Wollard (1965).



AGES OF LAVAS OF HONOLULU VOLCANIC SERIES, OAHU, HAWAII BY POTASSIUM-ARGON METHOD. (Gramlich, et al, 1971)

Vent Number	Location	Calculated Ages (Thousand years)
1	Salt Lake	418--430
2	Kaliki	457—464
3	Punchbowl	296--297
4	Nuuanu	416—422
5	Castle	846—860
6	Sugar Loaf	66—68
7	Kaau	617—677
8	Kaimuki	283—286
9	Black Point	297—316
10	Koko	35—44
11	Kalama	36—33
12	Kaupo	31—33

FIGURE 3

Location maps of vents and flows of Honolulu Series. The vents and flows have been grouped according to age in thousands of years (t.y.).

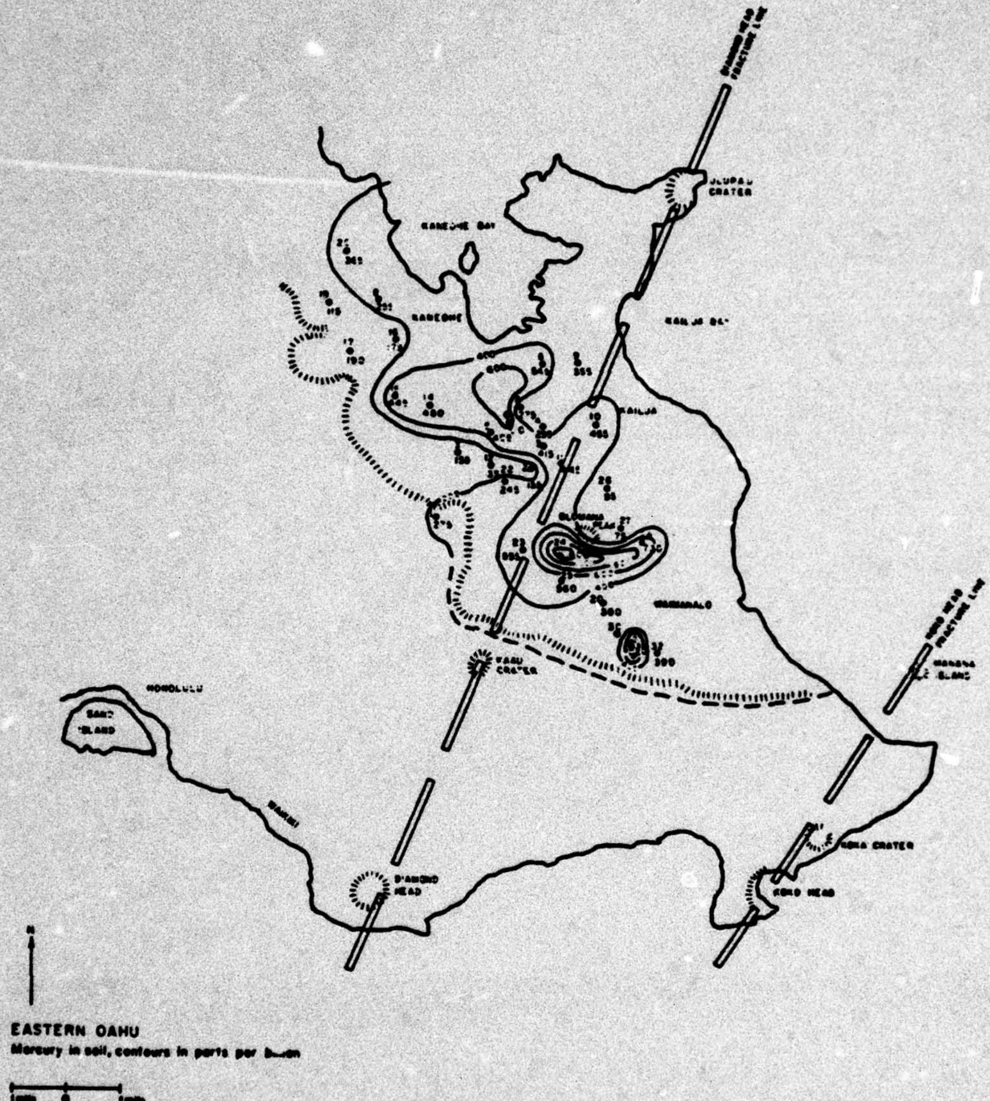


FIGURE 4

MAPS OF EASTERN OAHU SHOWING LOCATIONS WHERE MERCURY CONTENT IN SOIL WAS ANALYZED. CONTOUR INTERVAL IS 200 PPB.

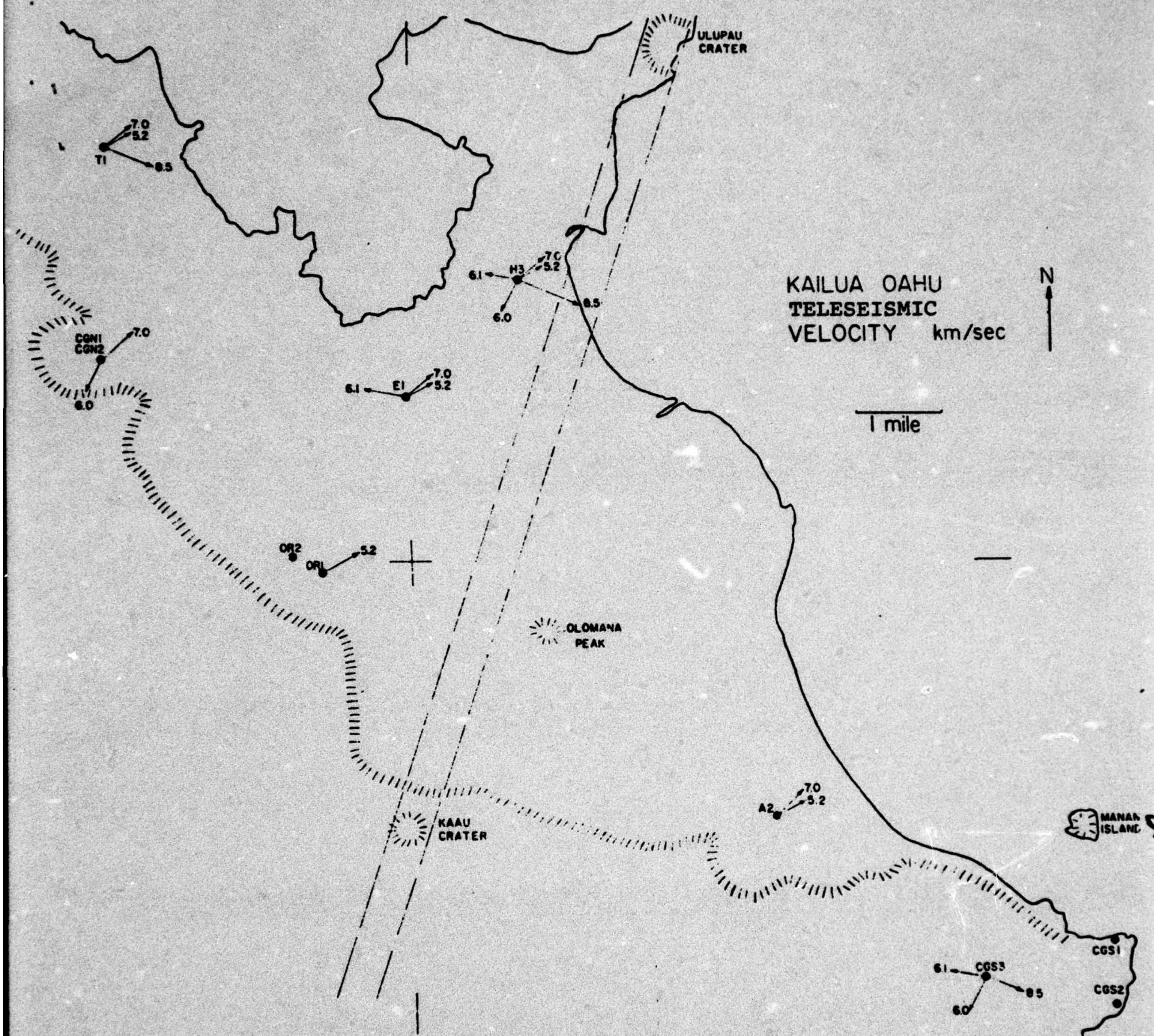


FIGURE 5

LOCATIONS OF SEISMIC RECORDING STATIONS IN EASTERN OAHU. ARROWS ABOUT EACH STATION INDICATE DIRECTIONS OF ARRIVAL FOR 5 EVENTS RECORDED, ALONG WITH THE VELOCITY ACROSS THE ARRAY FOR EACH EVENT.

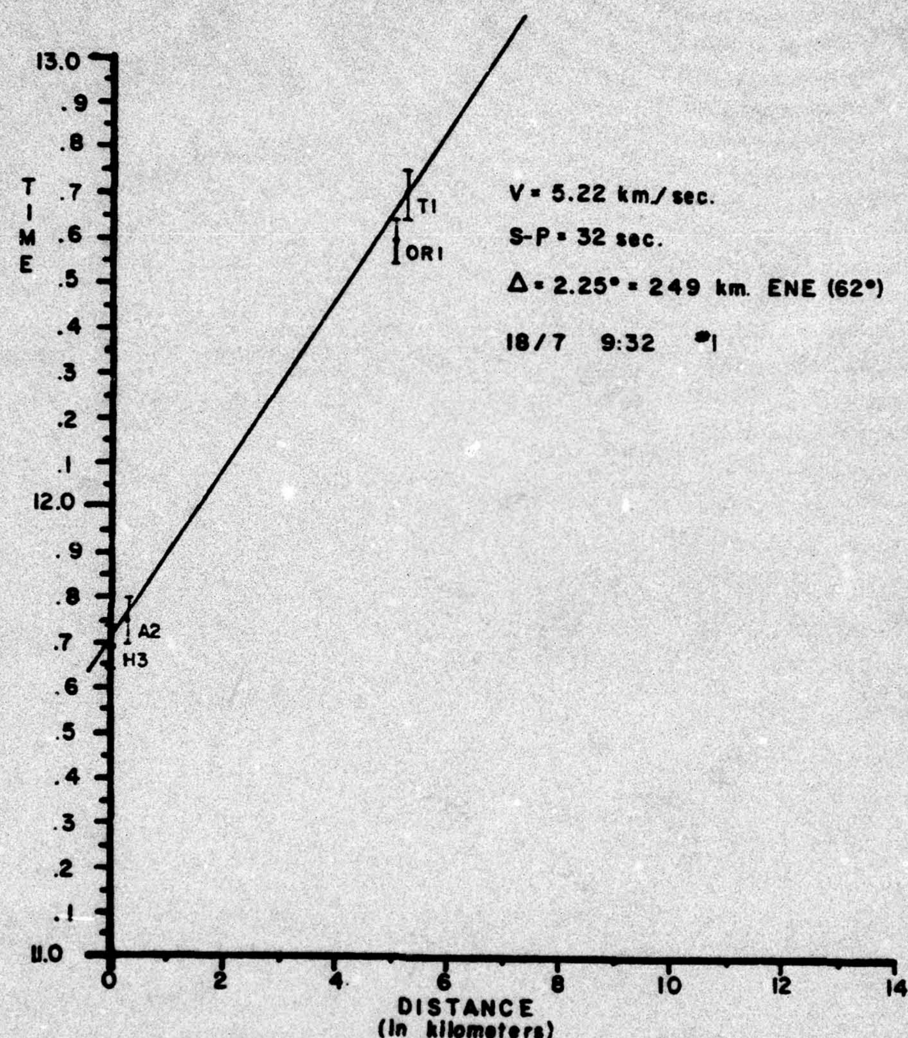


FIGURE 6

TRAVEL-TIME CURVE ACROSS THE EASTERN OAHU ARRAY FOR A TELESEISMIC EVENT RECORDED AT 9032, July 18, 1976. STATION DESIGNATORS ARE KEYED TO FIGURE 5.

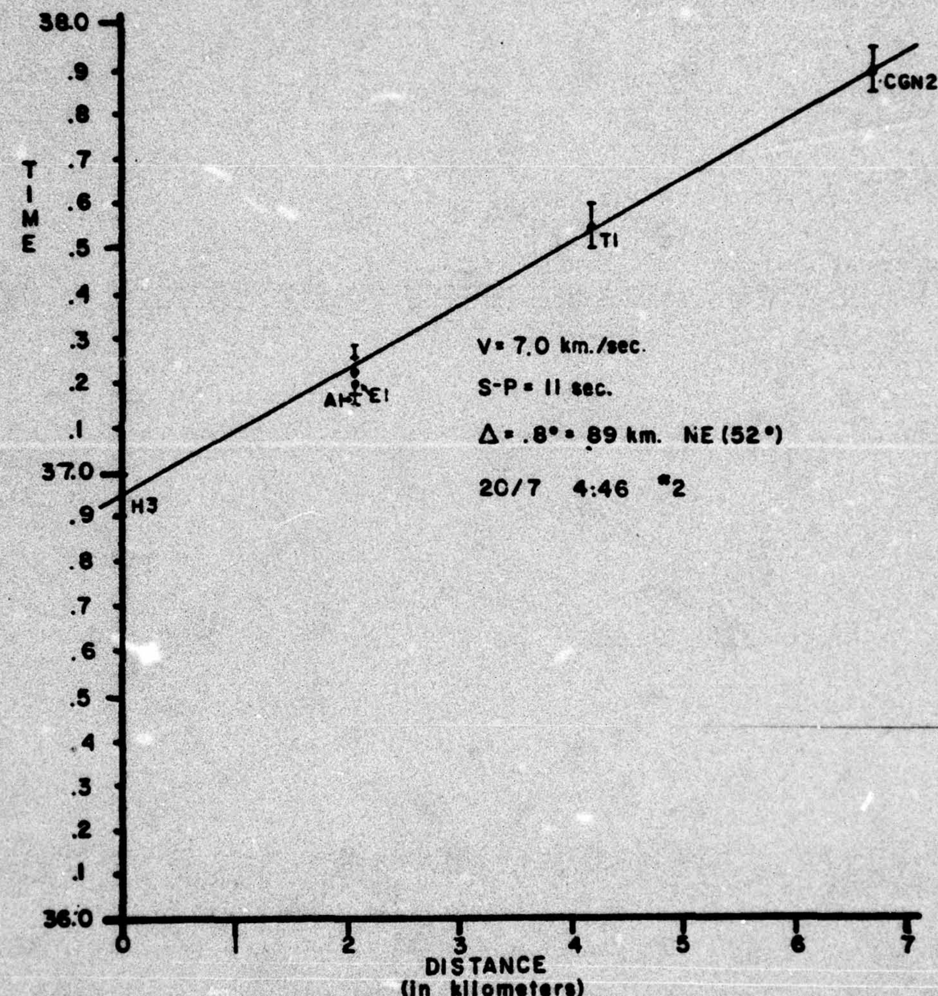


FIGURE 7

TRAVEL-TIME CURVE ACROSS THE EASTERN OAHU ARRAY FOR A TELESEISMIC EVENT RECORDED AT 0446, JULY 20, 1976. STATION DESIGNATORS ARE KEYED TO FIGURE 5.

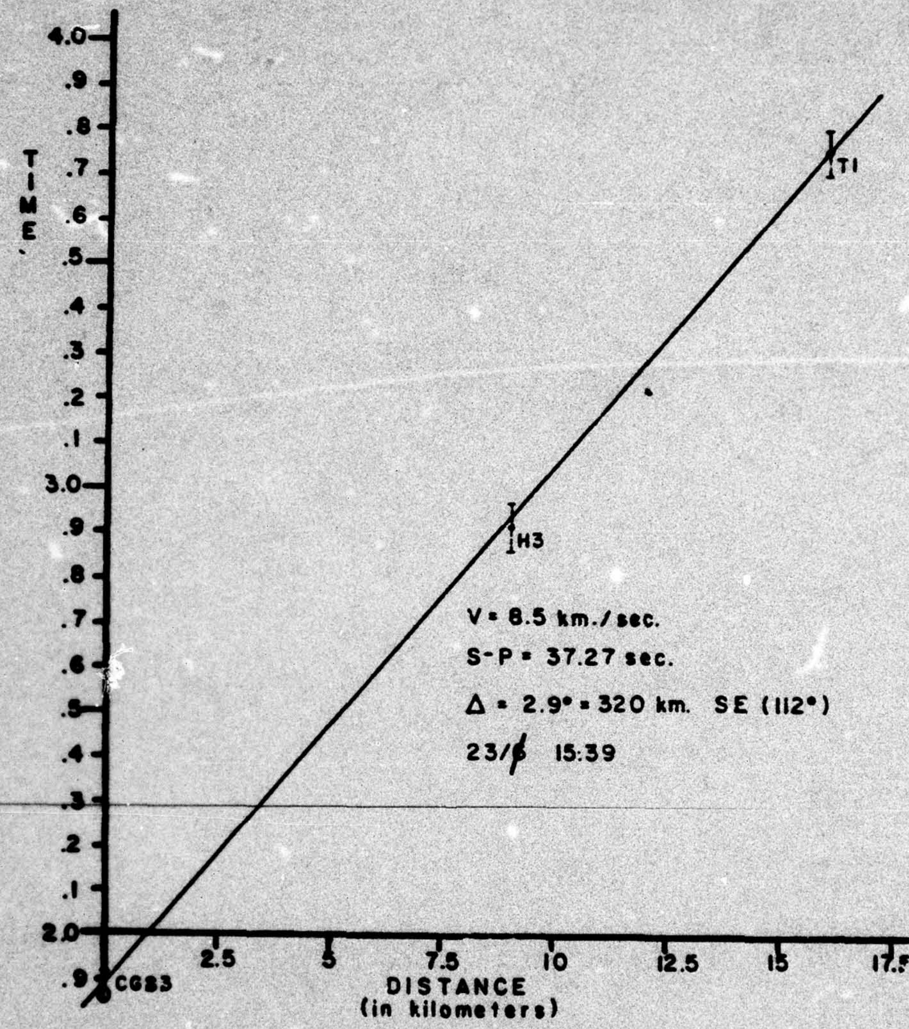


FIGURE 8

TRAVEL-TIME CURVE ACROSS THE EASTERN OAHU ARRAY FOR A TELESEISMIC EVENT RECORDED AT 1539, JULY 23, 1976. STATION DESIGNATORS ARE KEYED TO FIGURE 5.

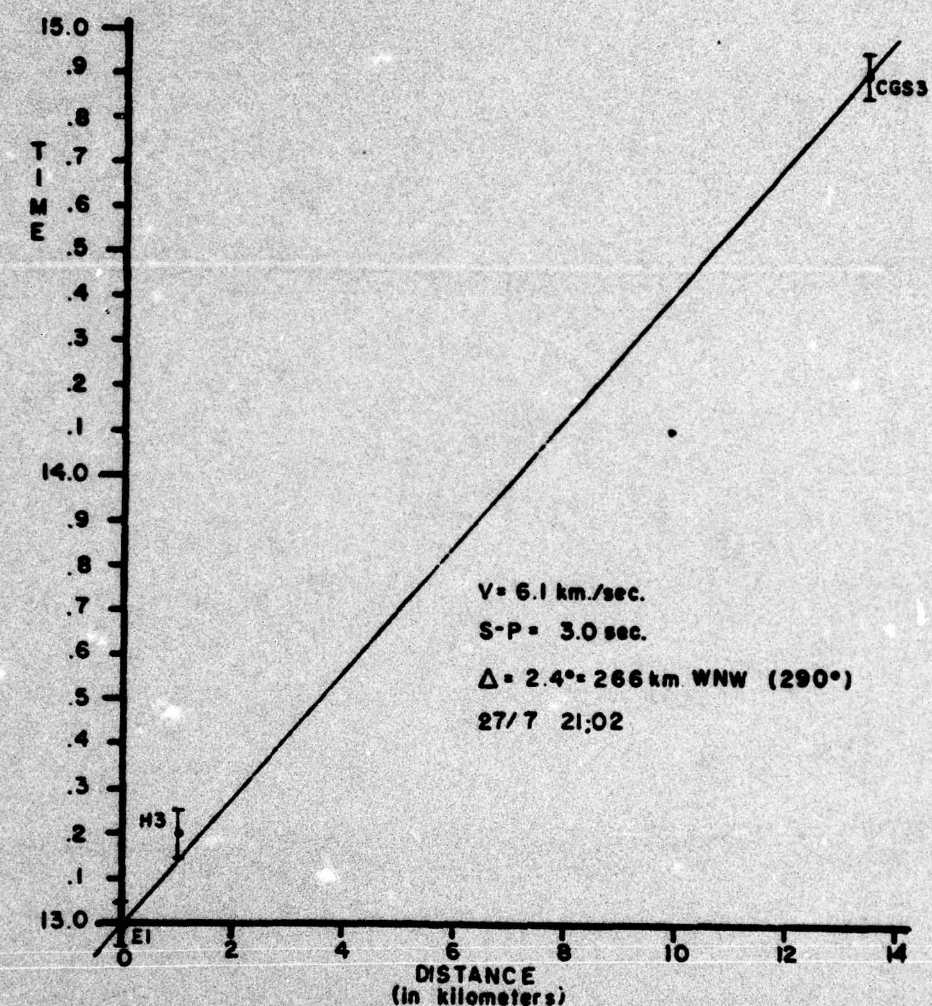


FIGURE 9

TRAVEL-TIME CURVE ACROSS THE EASTERN OAHU ARRAY FOR A TELESEISMIC EVENT RECORDED AT 2102, JULY 27, 1976. STATION DESIGNATORS ARE KEYED TO FIGURE 5.

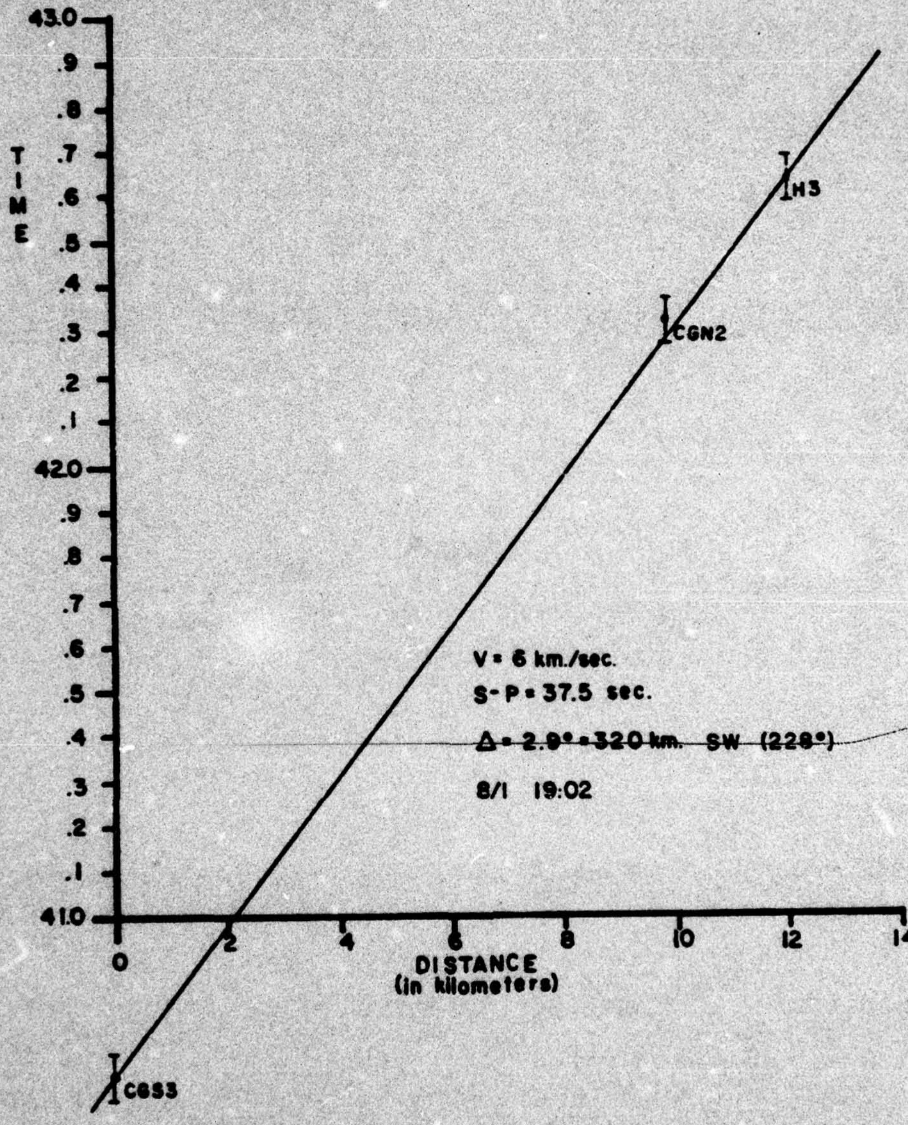


FIGURE 10

TRAVEL-TIME CURVE ACROSS THE EASTERN OAHU ARRAY FOR A TELESEISMIC EVENT RECORDED AT 1902, AUGUST, 1976. STATION DESIGNATORS ARE KEYED TO FIGURE 5.

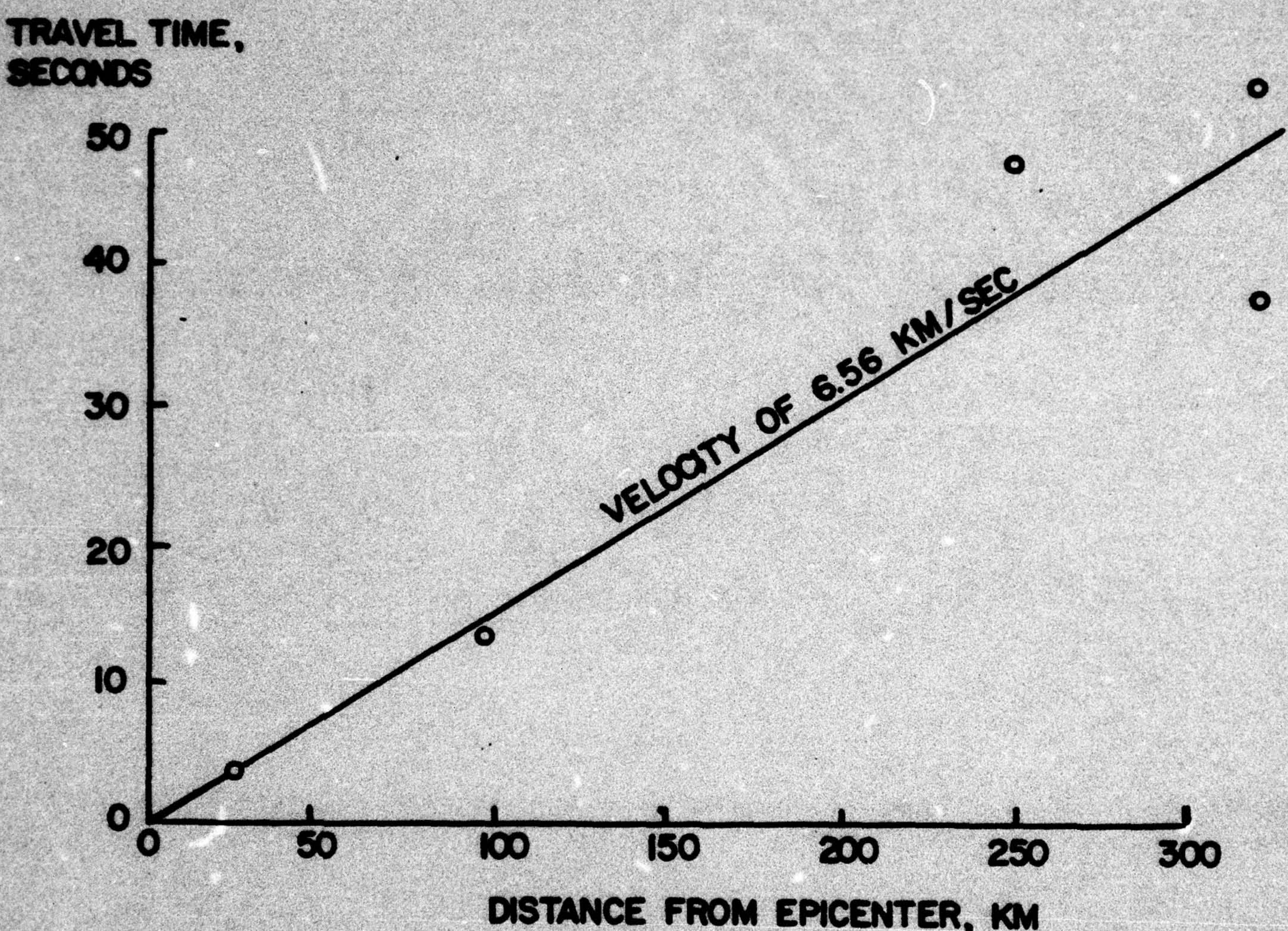


FIGURE 11

COMPOSITE TRAVEL-TIME CURVE FOR THE 5 EVENTS SHOWN ON FIGURES 6 TO 10.

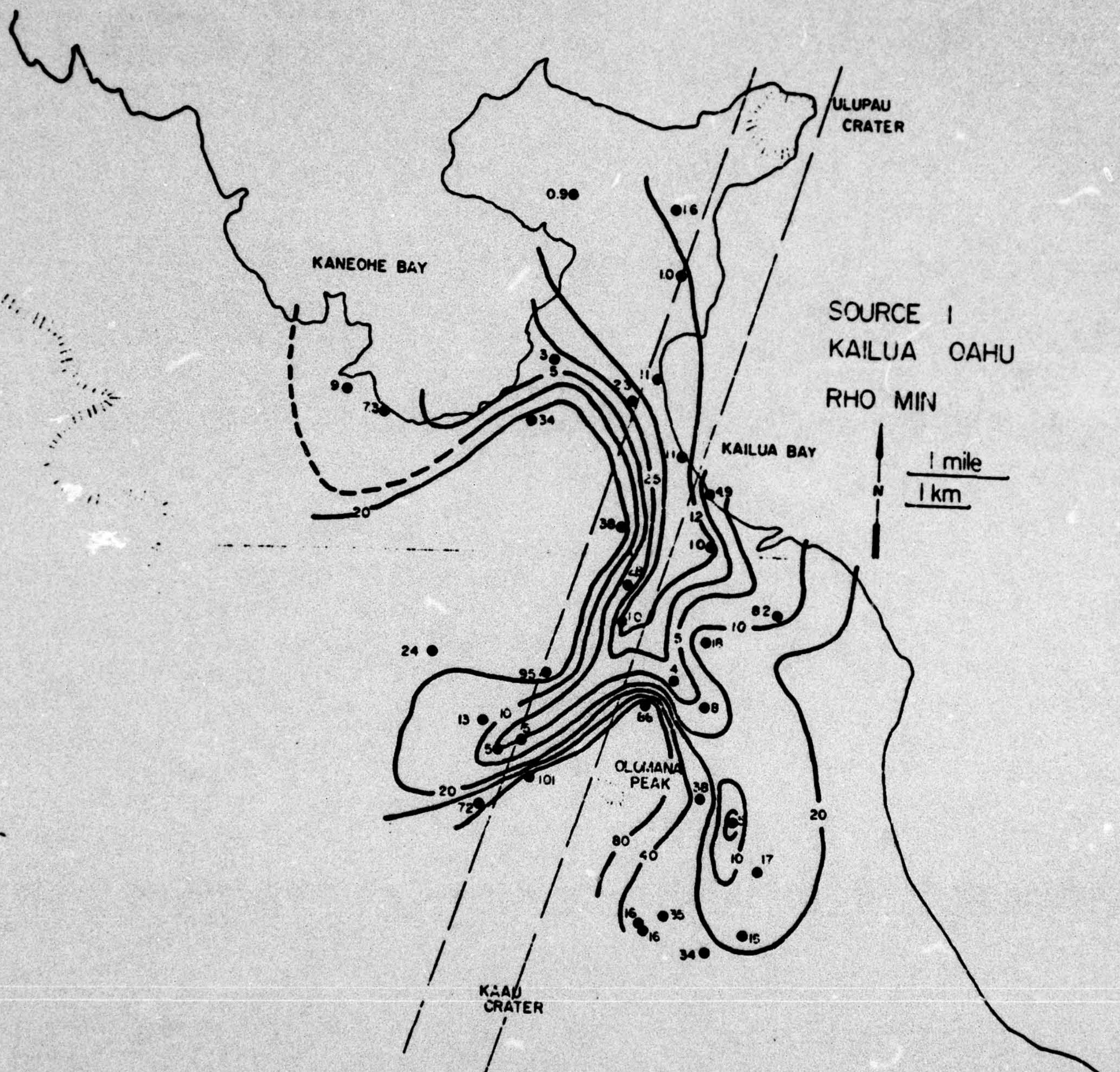


FIGURE 12

CONTOUR MAP OF APPARENT RESISTIVITY MEASURED IN THE VICINITY OF KAILUA, OAHU. THE VALUE CONTOURED IS THE MINIMUM VALUE OBTAINED ON ROTATION OF A DIPOLE SOURCE.

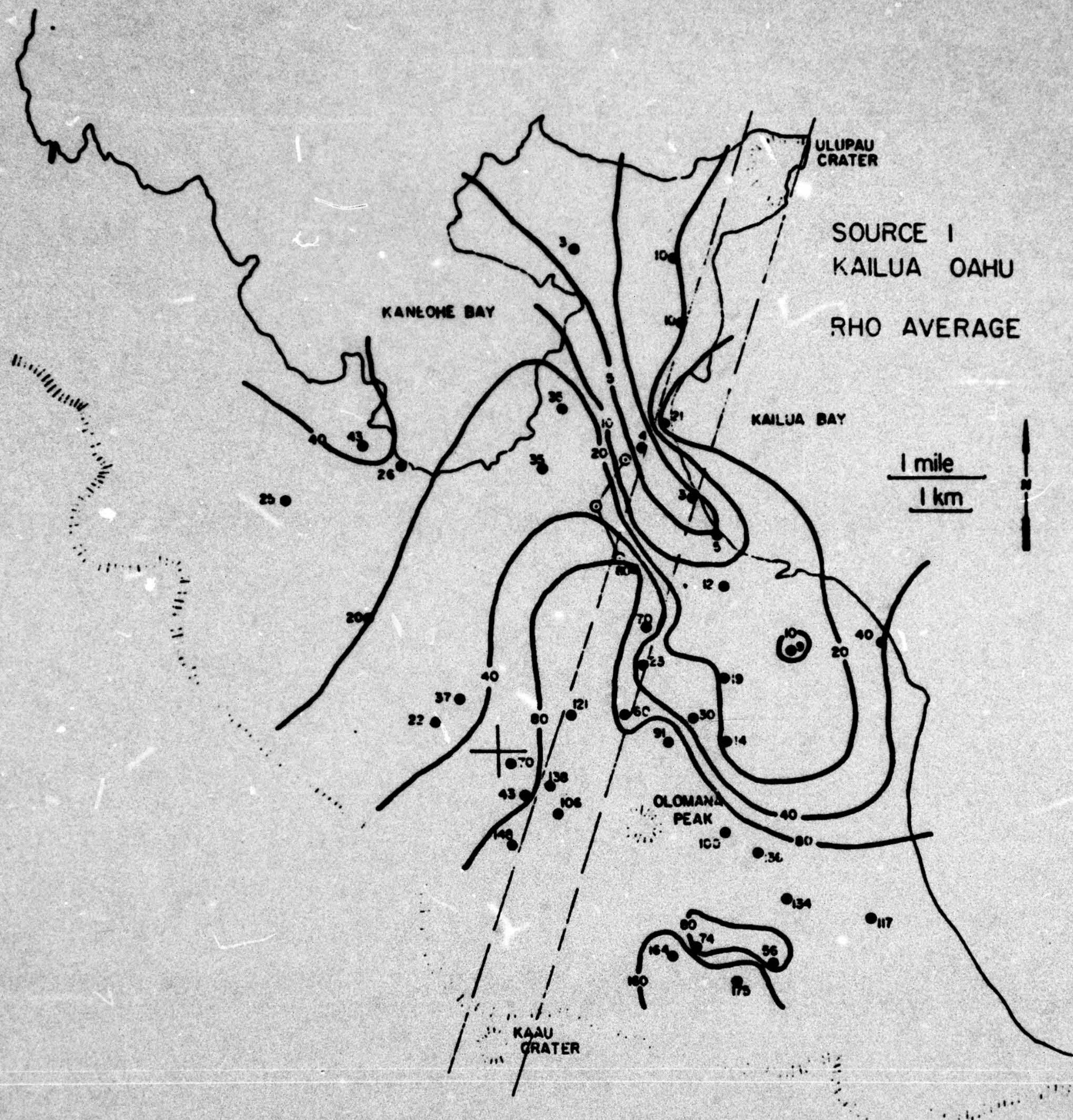


FIGURE 13

CONTOUR MAP OF APPARENT RESISTIVITY MEASURED IN THE VICINITY OF KAILUA, OAHU. THE VALUE CONTOURED IS THE AVERAGE OF THE MAXIMUM AND MINIMUM VALUES OBTAINED ON ROTATION OF A DIPOLE SOURCE.

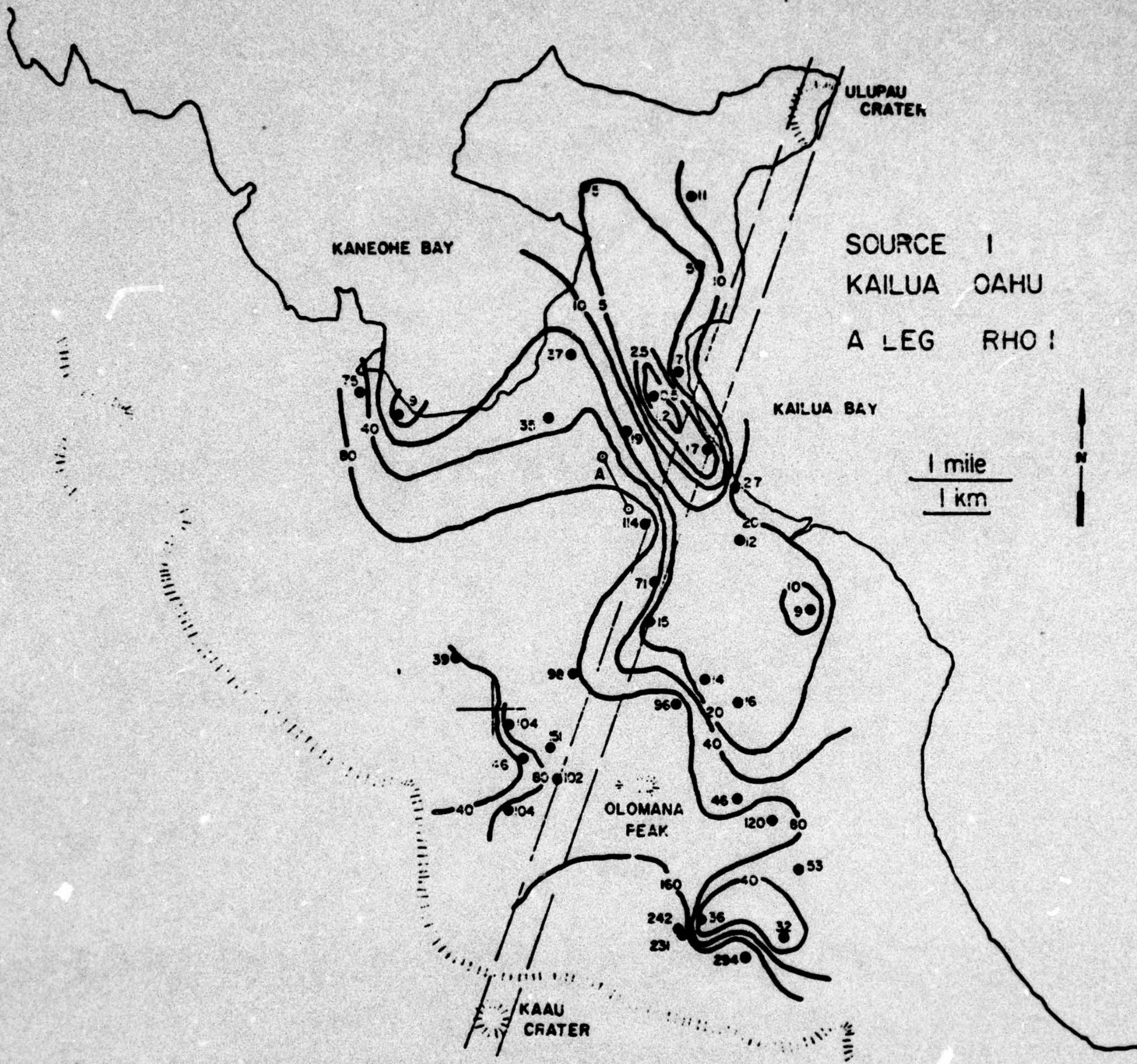


FIGURE 14

CONTOUR MAP OF APPARENT RESISTIVITY MEASURED IN THE VICINITY OF KAILUA, OAHU. THE VALUE CONTOURED IS THE APPARENT RESISTIVITY CALCULATED FOR ONE LEG (SHOWN AS A) OF A ROTATING DIPOLE SOURCE.

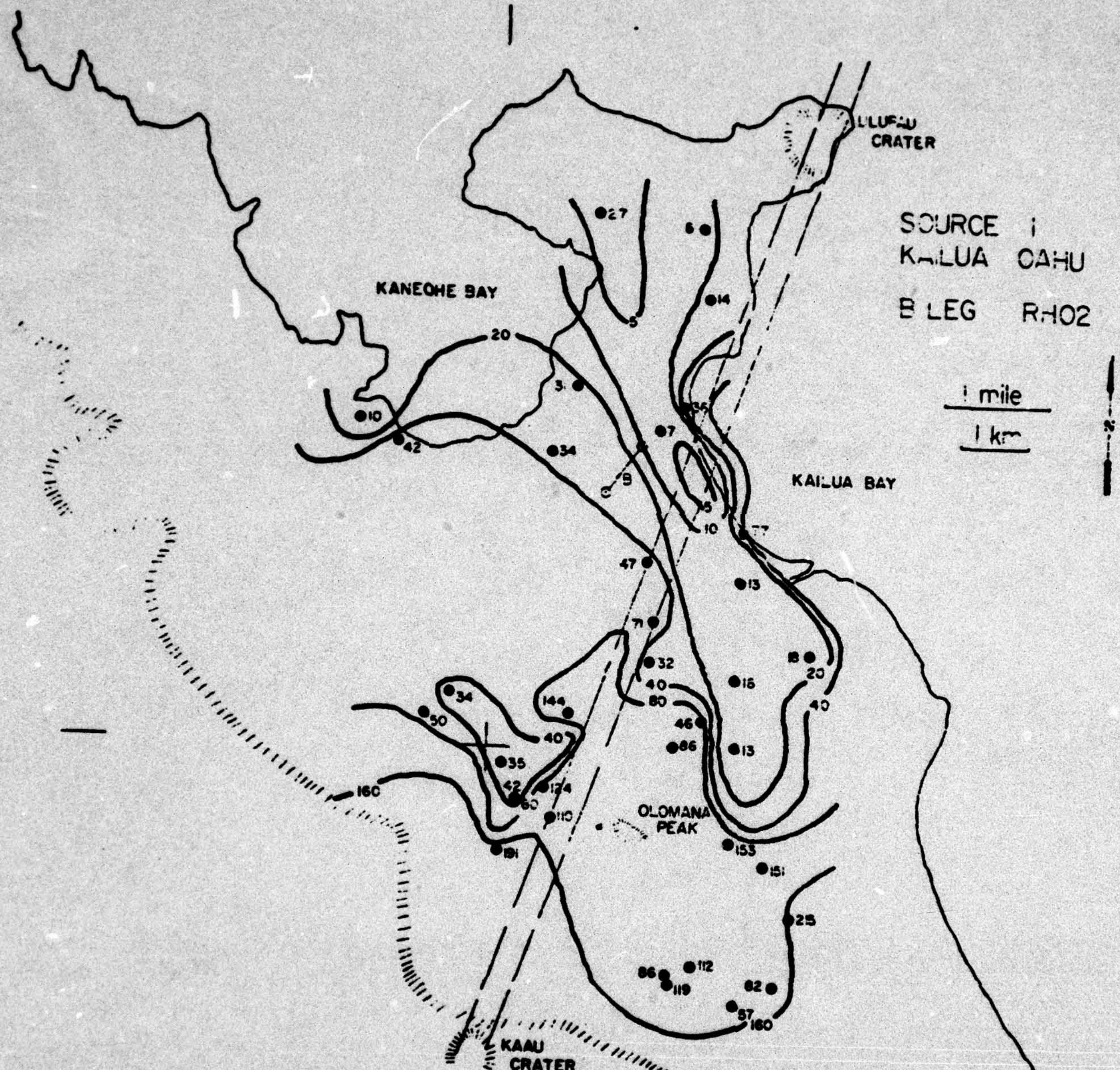


FIGURE 15

CONTOUR MAP OF APPARENT RESISTIVITY MEASURED IN THE VICINITY OF KAILUA, OAHU. THE VALUE CONTOURED IS THE APPARENT RESISTIVITY CALCULATED FOR ONE LEG (SHOWN AS B) OF A ROTATING DIPOLE SOURCE.

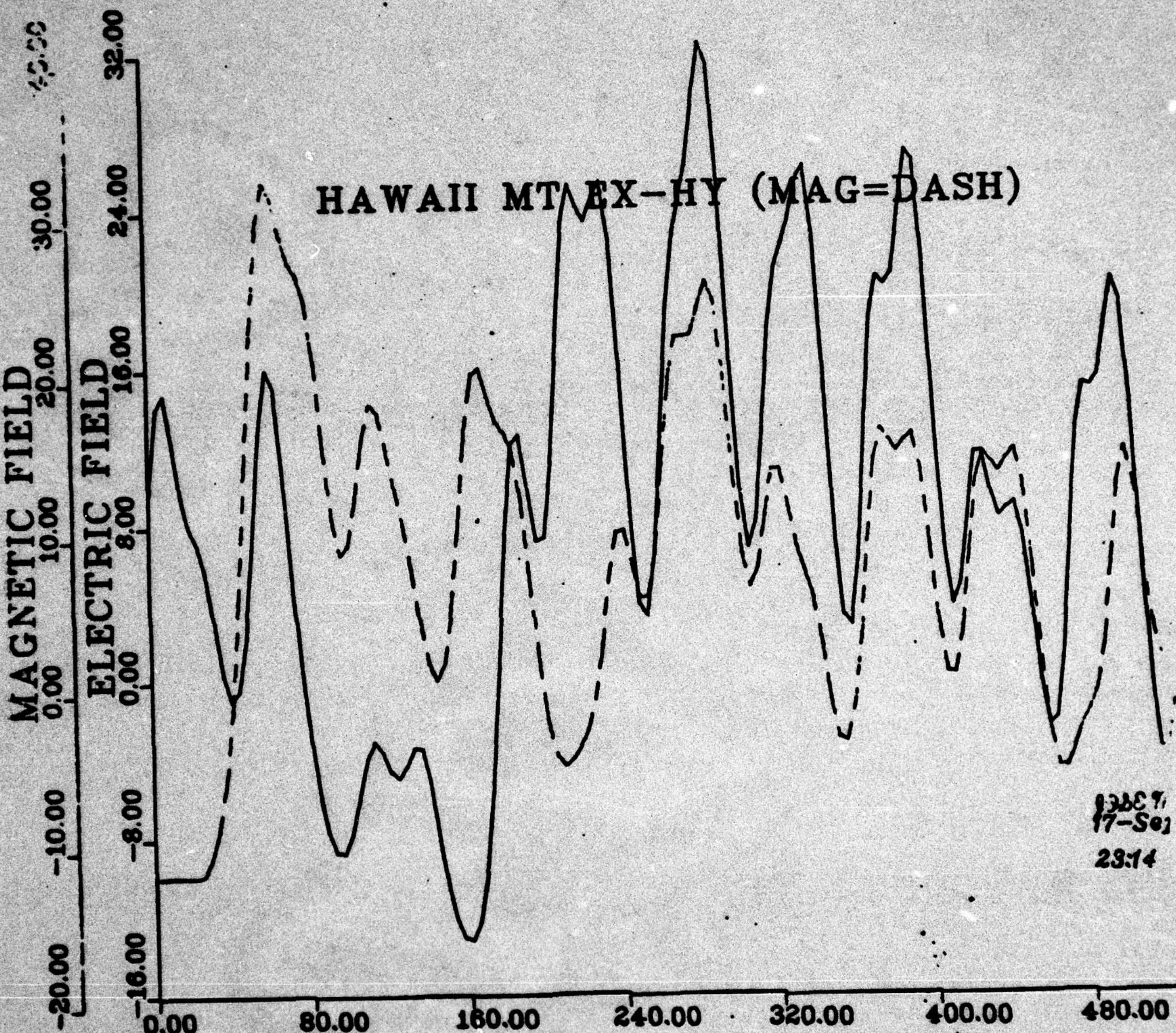


FIGURE 16

EXAMPLE OF TWO COMPONENTS (ONE ELECTRIC AND ONE MAGNETIC) OF A MAGNETOTELLURIC RECORD OBTAINED ON OAHU.

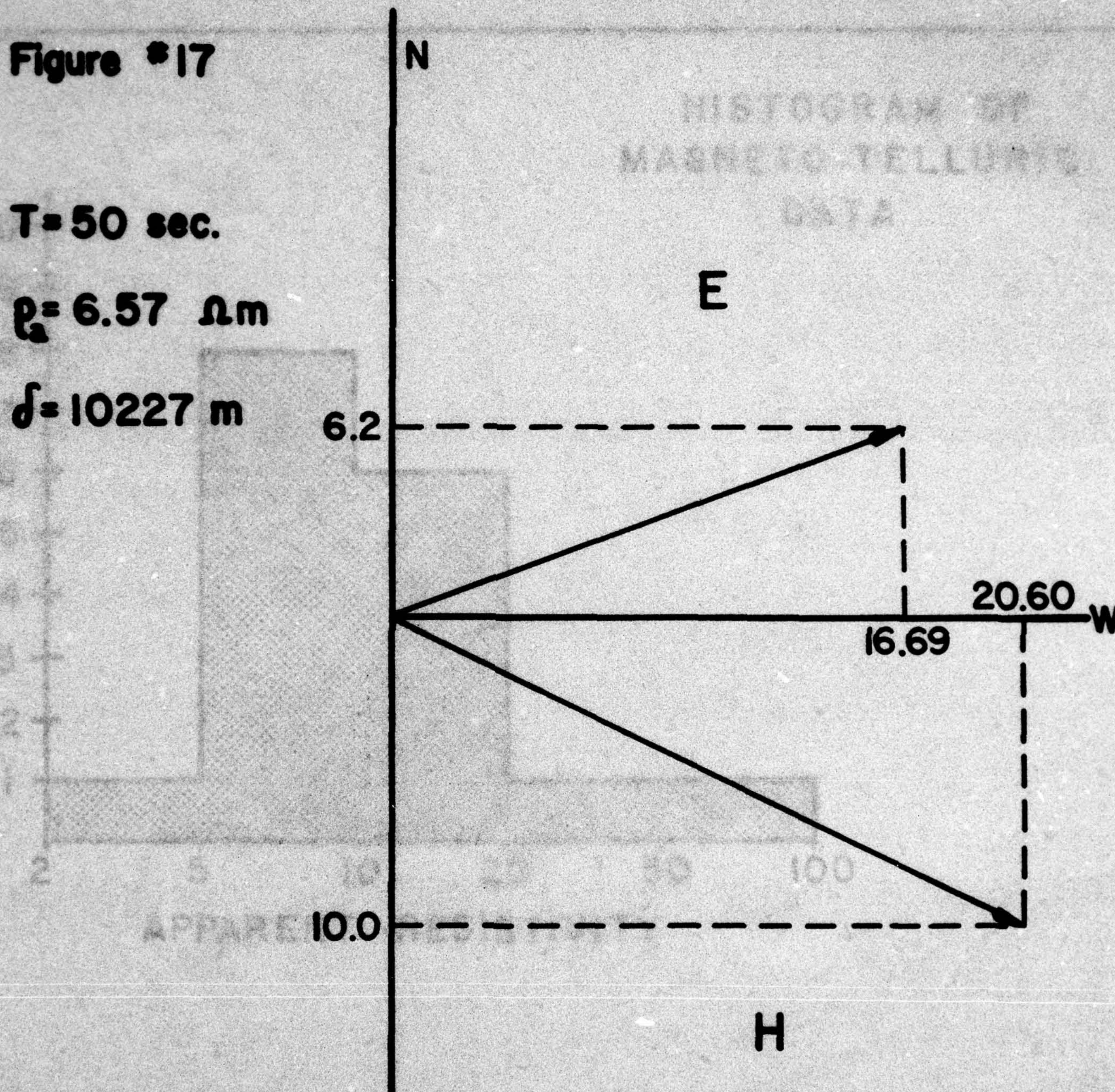


FIGURE 17

VECTOR DIAGRAM ILLUSTRATING THE COMPUTATION OF APPARENT RESISTIVITY FROM MAGNETOTELLURIC DATA.

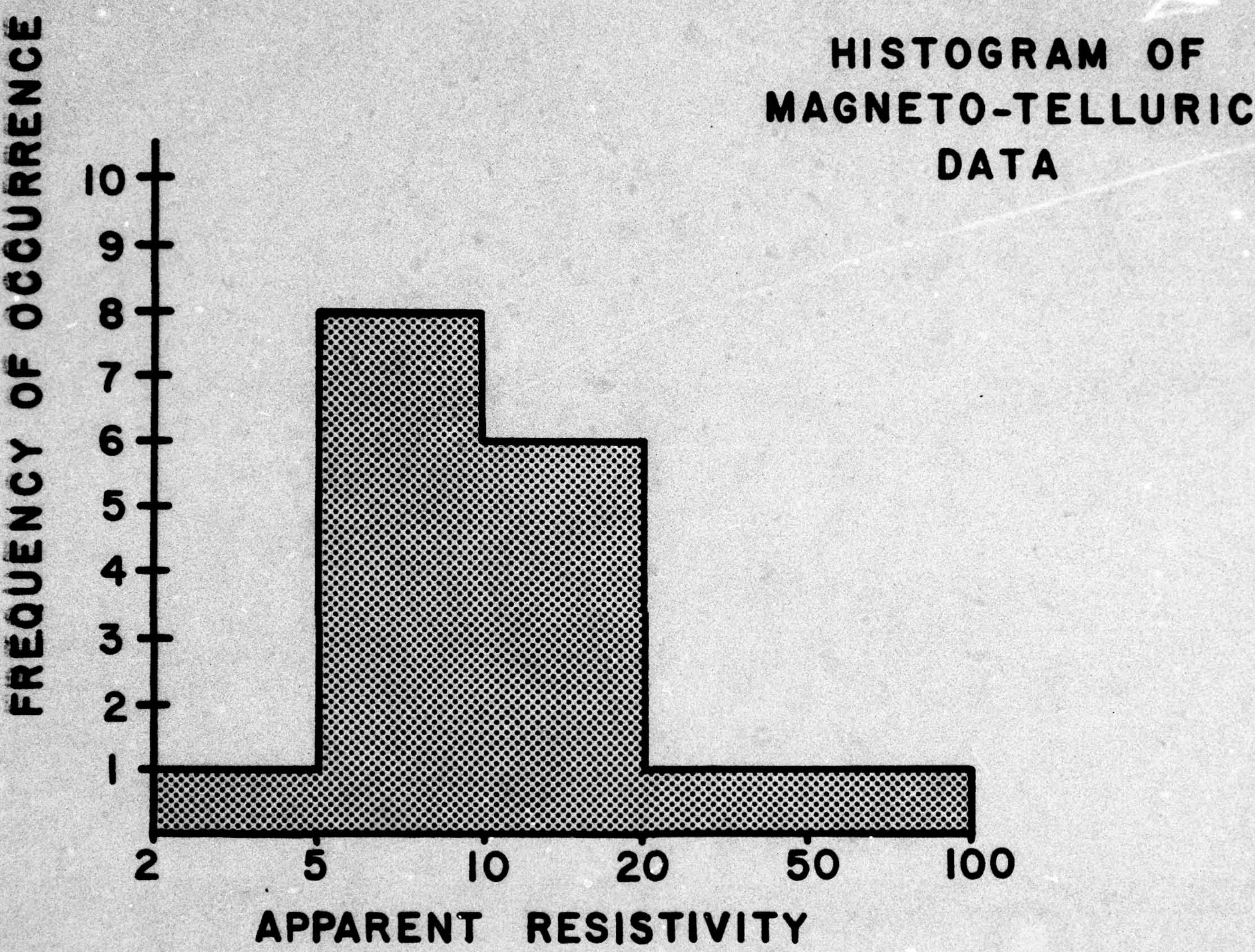


FIGURE 18

HISTOGRAM SHOWING THE DISTRIBUTION OF APPARENT RESISTIVITY VALUES COMPUTED FOR SUCCESSIVE SIGNALS ON A MAGNETOTELLURIC RECORD.

DAY	L1	CG S1	CG N1	A1	OR1	OR2	A2	H3	CG S2	CG N2	E1	CG S3	D1	M1	T1
16		☆	Δ	☆											√
17	O				O	O		O	√	Δ					
18	O					O + ☆	O +	O +	√	Δ ☆	O + ☆				+
19						√	√	☆ √	√	√	Δ √				☆ Δ
20	O					☆ √	O	O +	√	O +	O +	Δ O			Δ +
21						√	O	O		O	Δ	Δ O			O
22						☆ √	√	O	√		Δ	√			√
23						√	√	O +	Δ ☆		Δ	O +			O +
24						☆ √	√	√	√	√	Δ ☆				√
25						Δ ☆		√		☆ √	Δ	Δ·	Δ ☆		√
26						Δ ☆		O		Δ ☆		√	Δ ☆	√	√
27	☆					☆ √		O +		√	O +	O +	Δ	Δ	
28	Δ					☆		Δ		√	√	√		√	
29	√		☆ Δ			☆		O		√		Δ	Δ √	√	
30	Δ		Δ			√		Δ		Δ O +		Δ +	☆ √	√	
31	Δ					√		√	√		Δ √		√	√	
1	√					☆ √		O +		O +		O +	√	√	
2	√					☆ √		√		√		√	☆ √	√	
3	O					☆ √		√		Δ √		√	√	Δ	
4	√					☆ √		√		√		☆ √		Δ ☆	
5															

☆ NOISY
\+ EVENTS USED
O EVENTS NOT USED
√ NO EVENTS
Δ INCOMPLETE

TABLE 1
TABLE OF EVENTS

EVENT	VELO.	DIST.	TIME	S-P	FROM
23/6/15:39	8.5	320	37.65	37.27	SE
8/1/19:02	6.0	320	53.33	37.5	SW
27/7/21:20	6.1	26.6	4.36	3.0	WNW
18/7/9:32	5.22	249	47.70	32	ENE
20/7/4:46	7.0	89	12.71	11	NE

VELOCITY in kilometers/second

DISTANCE in kilometers

TIME in seconds

S-P in seconds

TABLE 2

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FINAL REPORT: EXPLORATION FOR GEOTHERMAL ENERGY ON OAHU, HAWAII.		5. TYPE OF REPORT & PERIOD COVERED Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George V. Keller, Jose Souto Augustine B. Furumoto		8. CONTRACT OR GRANT NUMBER(s) N00014-76-C-0824 New
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Geophysics Colorado School of Mines Golden, Colorado 80401		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS John Heacock, ONR, Dept. of the Navy Code 463, Arlington, VA 22217		12. REPORT DATE 10 NOV 1977
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) same as 11. (12) 41p.		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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