AEROMAGNETIC, GRAVITY, AND ELECTRICAL RESISTIVITY EXPLORATION BETWEEN PAHALA AND PUNALUU, HAWAII

by

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GEOPHYSICAL EXPLORATION FOR HAWAIIAN GROUNDWATER, PHASE II

OWRR Project No. B-008-HI, Grant Agreement No. 14-01-0001-1494

Principal Investigators: Doak C. Cox & William M. Adams

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If one tried to set aside instruments and seek for that which existed before the instruments, one might span all the evolutions of past and present, exhaust Heaven, earth, man, and things, and one would not be able to find anything bearing even a name, much less reality.

Ch'uan-shan i-shu
Chou-i-wai-chuan, 5:25a-b
circa 1650 A.D.

ABSTRACT

Aeromagnetic, electrical resistivity, and gravity surveys were conducted in the area between Pahala and Punaluu, Hawaii to delineate barriers to ground-water movement. The geophysical data are interpreted and compared to determine the sectors of relatively low gradient ground water between the barriers.

In the Pahala area, two barriers to lateral ground-water movement have been located: the Kolea barrier, which trends roughly east to west, and the second barrier, associated with a "crack" used as the Pahala dump, designated by this study as the Pahala dump barrier. The Pahala dump barrier definitely appears to terminate at the Kolea barrier. These barriers are defined by magnetic, gravity, and electrical sounding and profiling observations.

In the Punaluu area, electrical sounding and profiling observations agree with the conclusions of an earlier infra-red study that a large fresh-water outflow, associated with a relatively high head of the water table, occurs. Magnetic and gravity observations agree on the presence of a skewed prismatic body with the top of the body being close to the ground surface.

Two test holes have been drilled in the area. The findings verify the geophysical predictions.

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INTRODUCTION

The economic importance of the availability of a ground-water supply in Pahala has been described by Hussong (1967), and some of the meteorological background, together with a description of some electrical resistivity soundings, have been presented by Hussong and Cox (1967). The results of these works indicated that additional geophysical exploration would be appropriate before drilling was initiated to substantiate estimated ground-water depths.

The dominant interest has since changed from spot estimation of the depths to the ground-water table to the outlining of essentially isopiestic ground-water bodies. The purpose of this report is to describe the geophysical exploration effort conducted in the field to delineate hydrogeologic elements such as dikes, dike zones, and faults that might act as barriers to the horizontal movement of ground water. From such delineation, drilling sites might be selected for verifying the estimated water-table depths. In general, higher heads would be found by drilling on the mauka or inland side of any barrier to the seaward flow of ground water. This work was conducted in November and December 1967 and January, February, and April of 1968 and 1969.

AEROMAGNETICS

Introduction

Aerial magnetic surveys delineate sub-surface rock structures which might control the flow of ground water under the basaltic terrain of the Hawaiian islands. Malahoff and Woollard (1965) have shown that the aeromagnetic data obtained at altitudes of about 12,000 to 14,000 feet revealed anomalies representing major rift zones on the islands. It was therefore expected that lower altitude and closer spacing of flight paths in making the aeromagnetic survey would provide a fast means for detailed mapping of geological structures such as rift-zones dike systems, etc.

The area surveyed, on the southern coast of Hawaii, is shown in Figure 1. This work was done in April 1969.

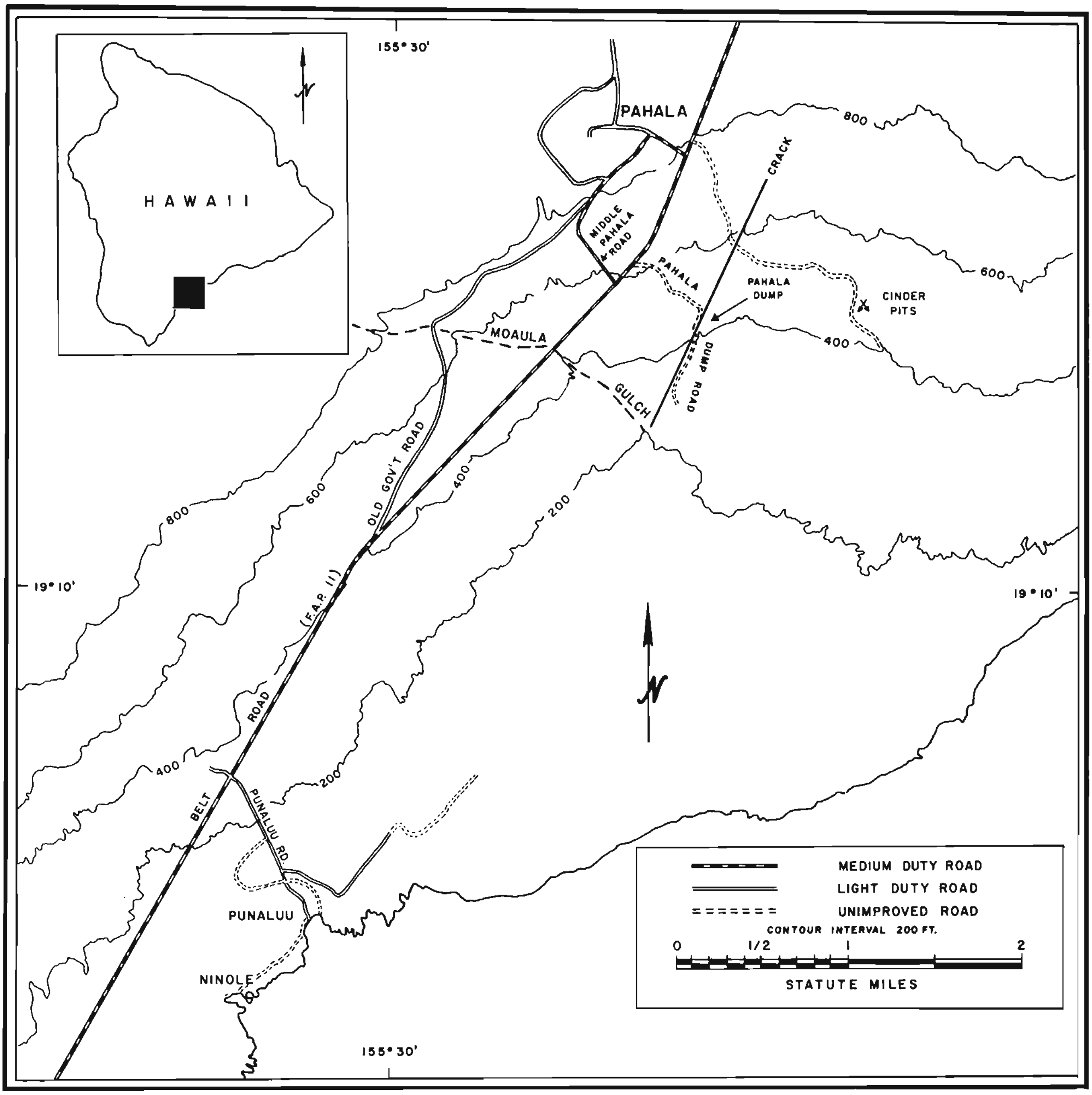

FIGURE 1. LOCATION MAP SHOWING THE PAHALA-PUNALUU AREA ON THE ISLAND OF HAWAII.

Instruments and Procedures

The total magnetic field observations were made by using an ELSEC Proton Magnetometer, type 592/G, manufactured by the Littlemore Scientific Engineering Co., Oxford, England. The magnetometer units, shown in Figure 2a, are transistorized and packaged for easy handling and maintenance.

The instruments were installed in racks mounted in the space made available behind the pilot's and co-pilot's seats of a Piper Apache twin-engine 5-seater aircraft by removing two of the passenger seats. The battery, location camera, and the other magnetometer units were interconnected as shown in the block diagram of Figure 2b. The magnetometer sensing head, the "bird," was towed by the aircraft from the baggage door by means of a braided polyprophylene rope through which passed the cable connecting the head to the counter unit. The end of the tow rope was anchored to a ring welded to the instrument rack. The door was closed after the 100-foot cable was fully extended.

The procedure followed for operating the magnetometer is given in the brochure provided by the manufacturer. In brief, the operational procedures are:

1. Check the battery voltage and the circuit continuity.
2. Check the zeros and nines of the counter for proper operation.
3. Set the tuning knobs for the ambient magnetic field strength.
4. Run the instrument on automatic fixed-period polarization cycle.
5. Check the proper operation of the camera and the synchronization of the time marks on the chart.
6. Mark at the right time the hundred digit value of the counter reading on the records.

Positioning of flight paths was accomplished by a 16mm Bell and Howell, Model 200EE, movie camera mounted in a rack (as shown in Fig. 2a) to enable vertical focus through a port in the floor of the aircraft. Color pictures of the ground were taken during flight. The camera was triggered electrically at a speed of 1 frame/second and provided a synchronous time mark on the chart in the recorder unit. Because of the time-synchronization mechanism, *i.e.*, the synchronous triggering of the camera and the tick mark in the chart (see Fig. 3), it was difficult to locate a reading. An error of ±5 second equivalent to ±700

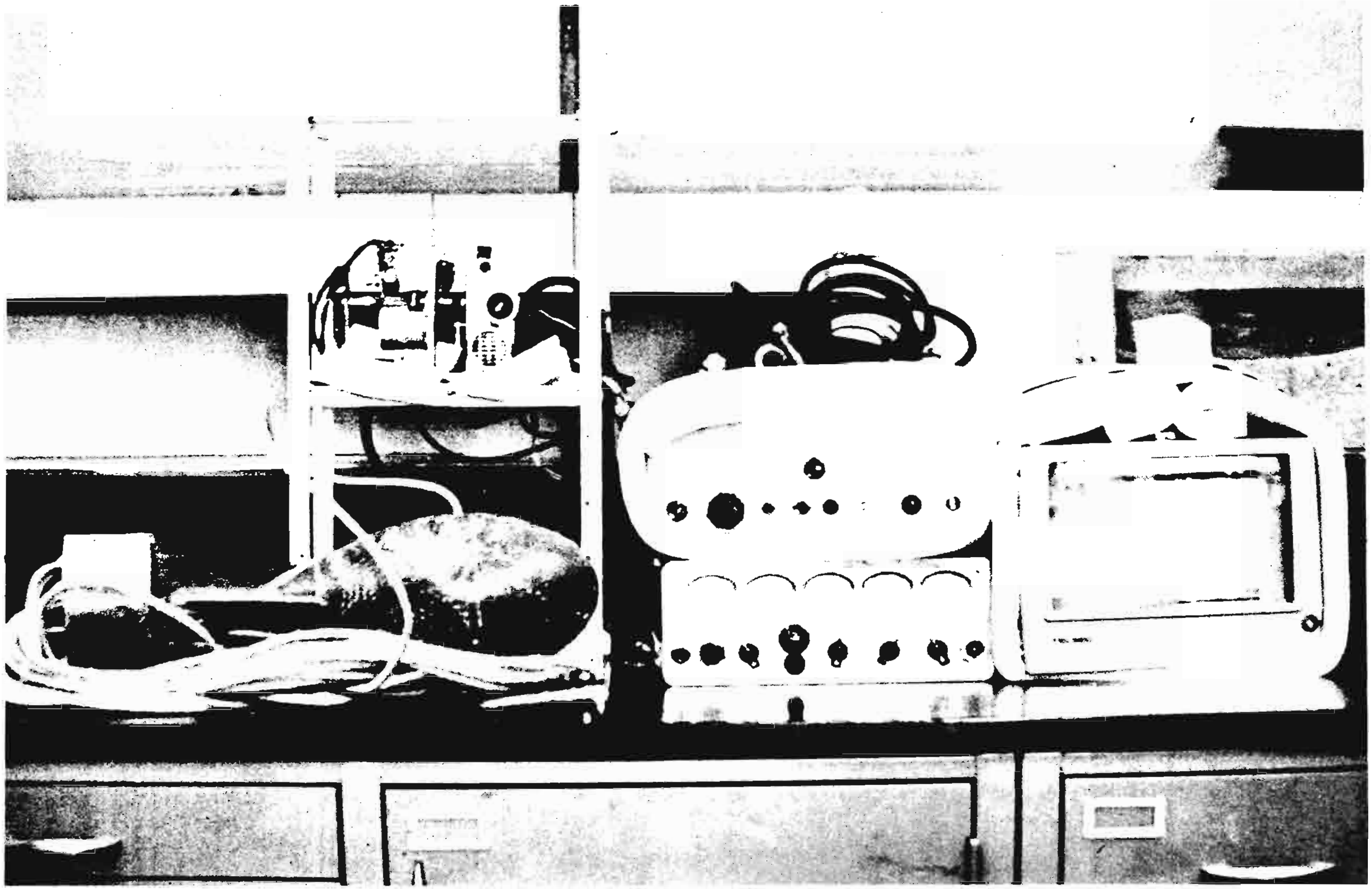

FIGURE 2a. PICTURE OF THE ELSEC MAGNETOMETER UNITS.

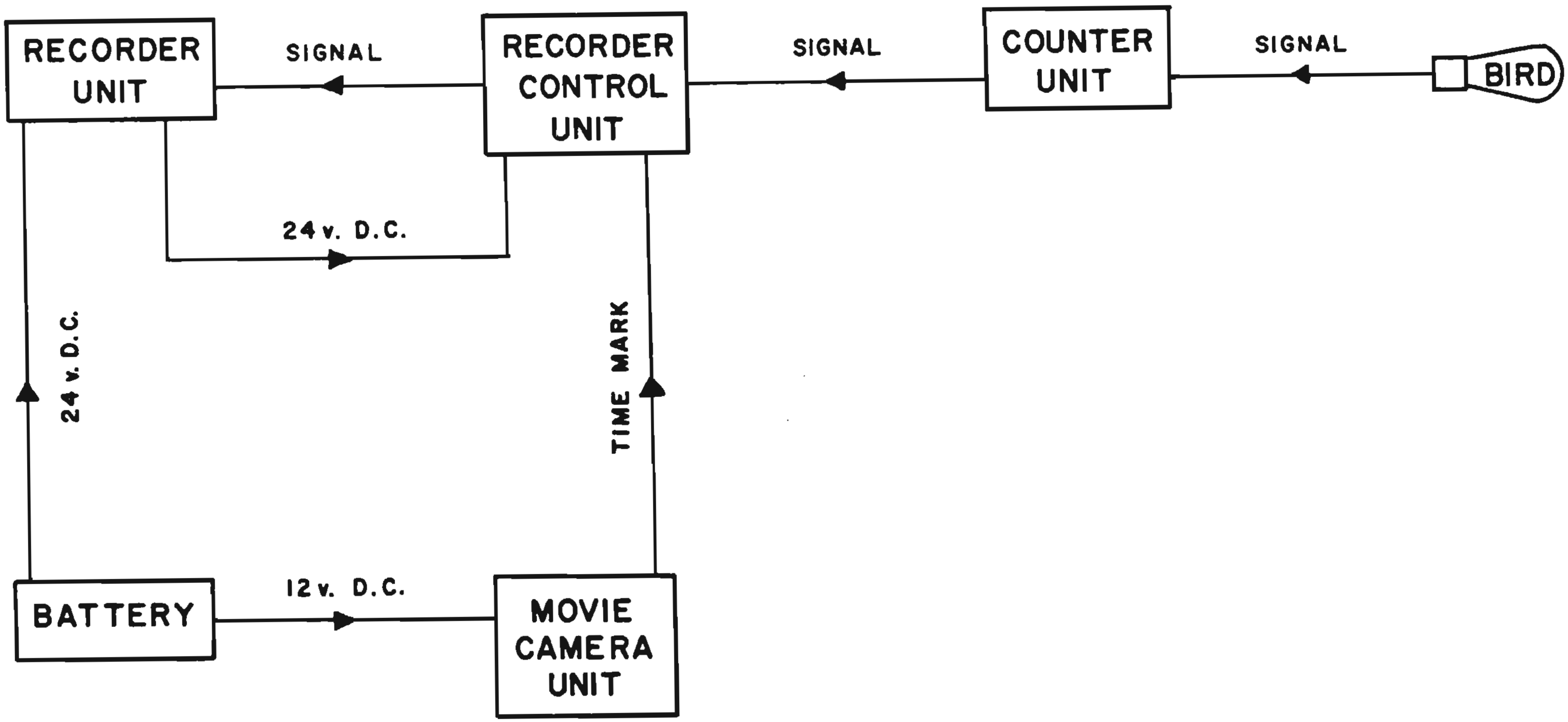

FIGURE 2b. BLOCK DIAGRAM OF THE AEROMAGNETIC APPARATUS.

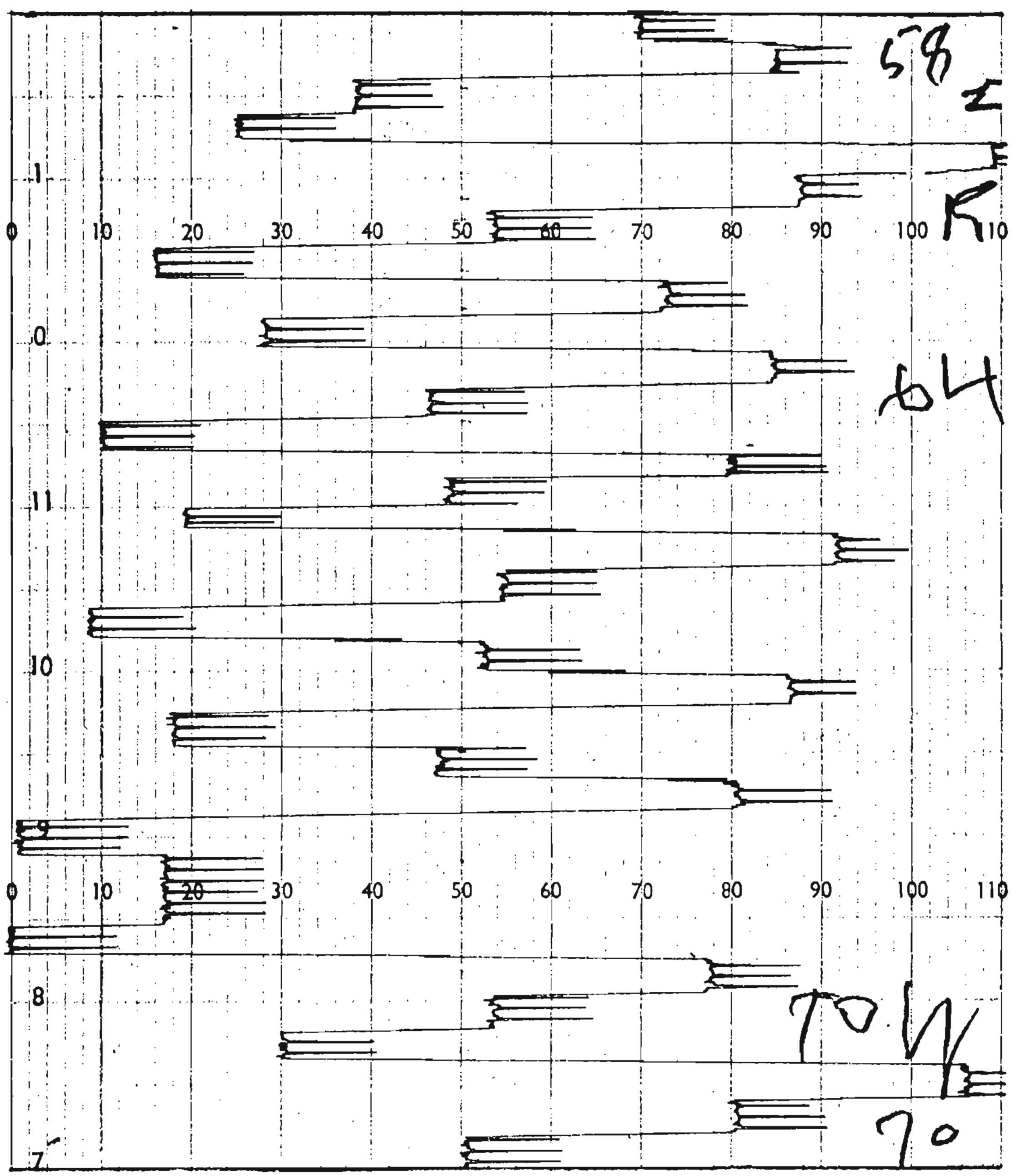

FIGURE 3. SAMPLE OF A CHART SHOWING THE RAPID VARIATIONS OF OBSERVATIONS IN THE FIELD.

feet may occur in locating the absolute position of a magnetic reading. Additional correlation between the camera and the recording chart was provided by holding a light-colored filter in front of the camera lens for a few seconds and simultaneously marking the chart by hand.

The power for both the magnetometer and the camera units was supplied by a 24-volt battery accumulator which could last for 12 hours of continuous operation.

The aircraft was flown about 100 mph. Polarization cycling periods of 6.4 or 2.6 seconds were chosen for the recording of magnetic field, depending on the magnetic gradients encountered. At a speed of 100 mph, the 6.4 second period permitted a surface sampling interval of about 800 feet.

Magnetic storms on the sun affect the operation of a magnetometer adversely and render the data taken during such a period unuseable. The nearest magnetic observatory should be contacted prior to and after a flight to determine the presence of such storms.

Results and Discussion

The magnetic field measured at about the 1500-foot altitude in the Pahala-Punaluu area is shown in Figure 4.

For comparison, the regional magnetic field map of the Island of Hawaii by Malahoff and Woollard (1965) is reproduced here as Figure 5. As is to be expected from the lower elevation of the flight paths, Figure 4 shows a higher value of the field strength and greater details of the anomalous features than Figure 5 although the general pattern of the field remains the same.

The features of interest on Figure 4 are the closed, or partially closed, contours labeled with the letters H through O. The anomalies to the east of Pahala labeled, H, I, J, and K, defy meaningful geophysical interpretation but appears to indicate a complicated structure.

The very steep gradient just north of M indicates a relatively shallow feature intersecting the coastline. The feature runs in a northwest-southeast direction.

The other partially closed features at L, M, N, and O may be interpreted semi-quantitatively using the curve-matching technique described by Vacquier (1951). By pairing the high at M with the low at L and

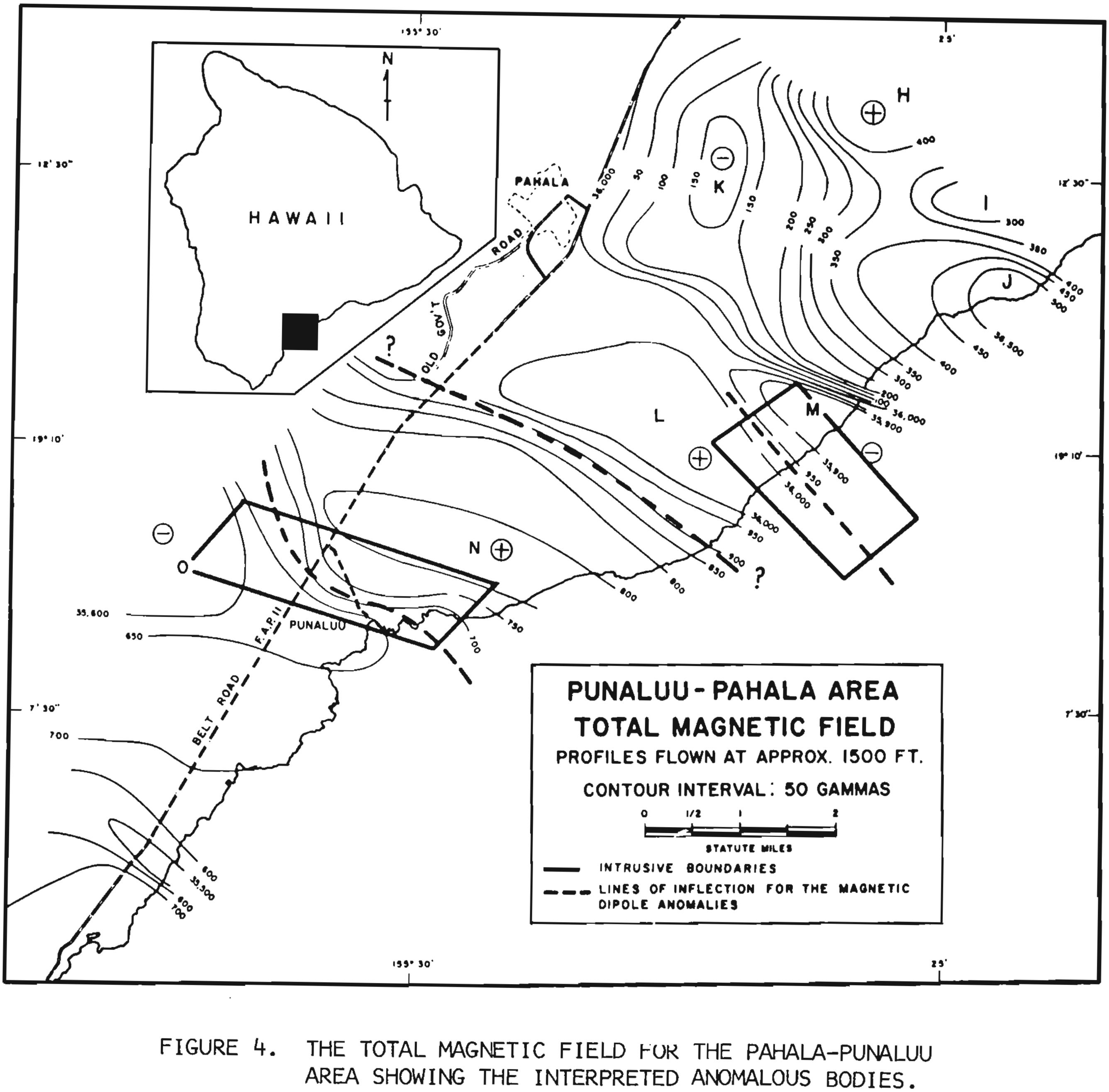

FIGURE 4. THE TOTAL MAGNETIC FIELD FOR THE PAHALA-PUNALUU AREA SHOWING THE INTERPRETED ANOMALOUS BODIES.

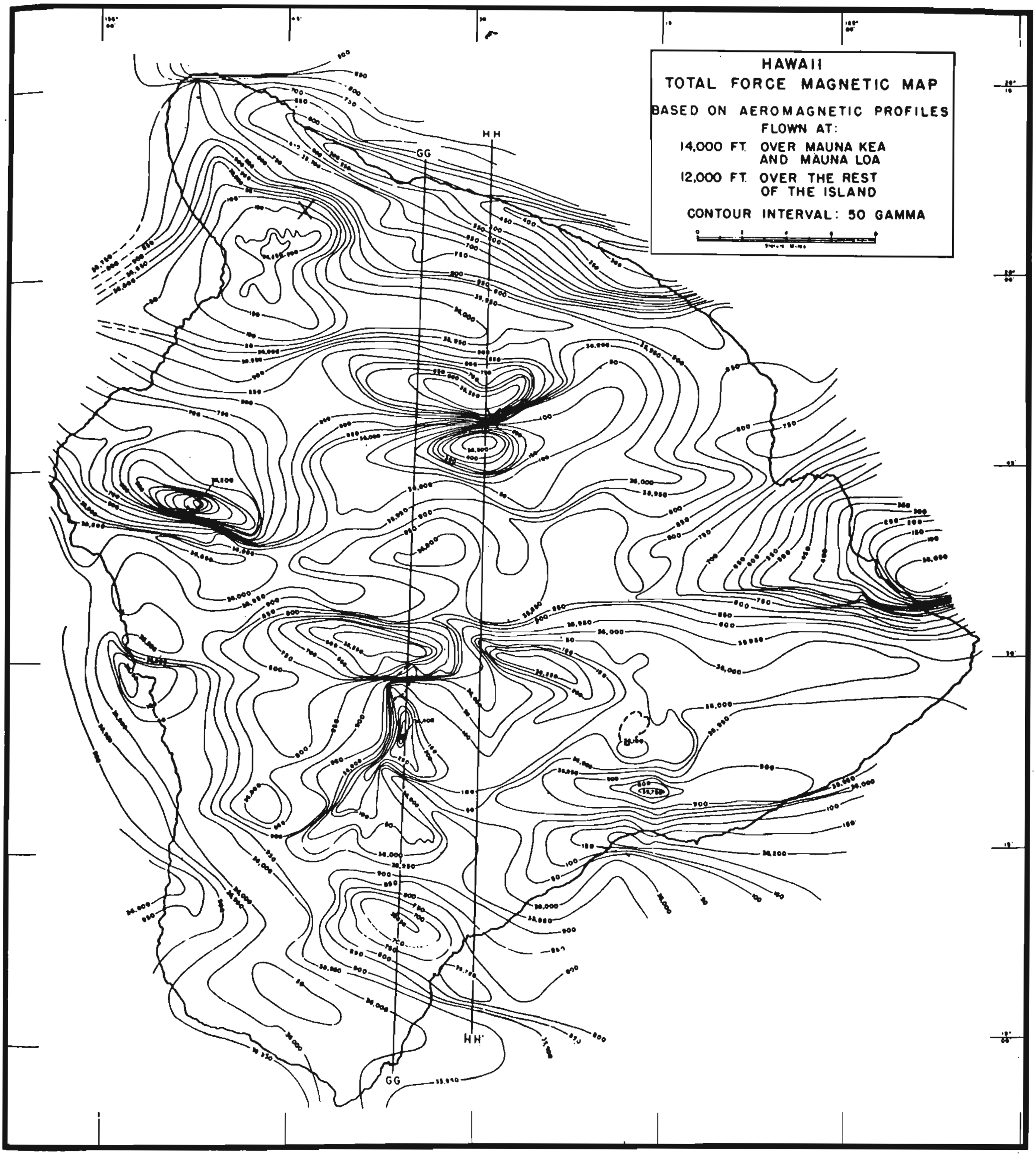

FIGURE 5. TOTAL MAGNETIC FIELD MAP OF THE ISLAND OF HAWAII (FROM MALAHOFF AND WOOLLARD, 1965).

the high at N with the low at O, two bipole anomalies are determined. The interpretation of the bipole anomalies are the prismatic bodies outlined in Figure 4. At these altitudes the depth to the top of the anomaly is approximately equal to the distance over which the maximum gradient of the bipole anomaly occurs. The approximate depth to the top of the body at L-M is 1/2 mile and the depth to the top of the body at N-O is 1/3 of a mile. Since the depth is measured from the plane of observation (*i.e.*, the altitude at which the sensor was flown) the tops of the anomalies occur near the ground surface.

ELECTRICAL RESISTIVITY

Introduction

With the transfer of emphasis from spot estimations of the depth to the ground-water table to the outlining of essentially isopiestic ground-water bodies, the resistivity method has transferred its focus from spot soundings to reconnaissance profiling. In this light, the work by Hussong and Cox (1967) was reviewed. In addition, new electrical field work was done in the Pahala-Punaluu area. The current work consisted of electrical resistivity sounding on the Old Government Road along the same path followed by the gravity microsurvey described in this report (p. 39) an electrical profile across the Pahala dump, an electrical profile along Punaluu Road, three soundings in the Punaluu area, east of Hussong's sounding S-8, and one on the coast near the Punaluu Pavillion (see Fig. 6).

Field Procedure

The field procedures for the electrical resistivity profiling and the electrical resistivity sounding have been described by Adams (1968) and Hussong (1967), respectively.

Instrumentation

The equipment (Fig. 7) was constructed by the electronics shop of the Hawaii Institute of Geophysics. The circuitry of the self-contained battery-powered system is shown as Figure 8. Considerable

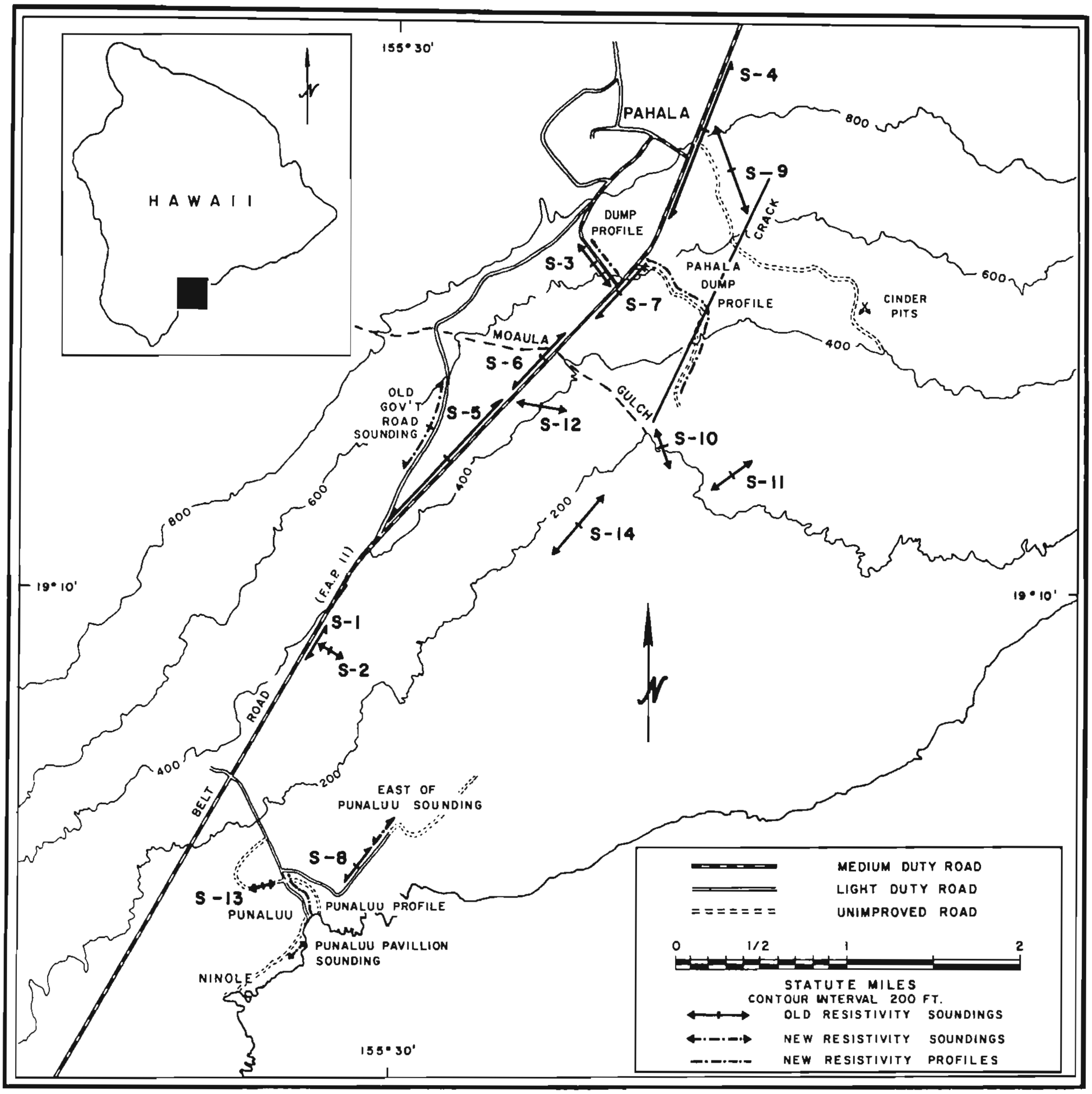

FIGURE 6. LOCATION OF DC RESISTIVITY SOUNDINGS AND PROFILES IN THE PAHALA AREA FROM HUSSONG AND COX (1967) AND THE NEW WORK HEREIN REPORTED. REFER TO FIGURE 1 FOR NAMES OF ROADS.

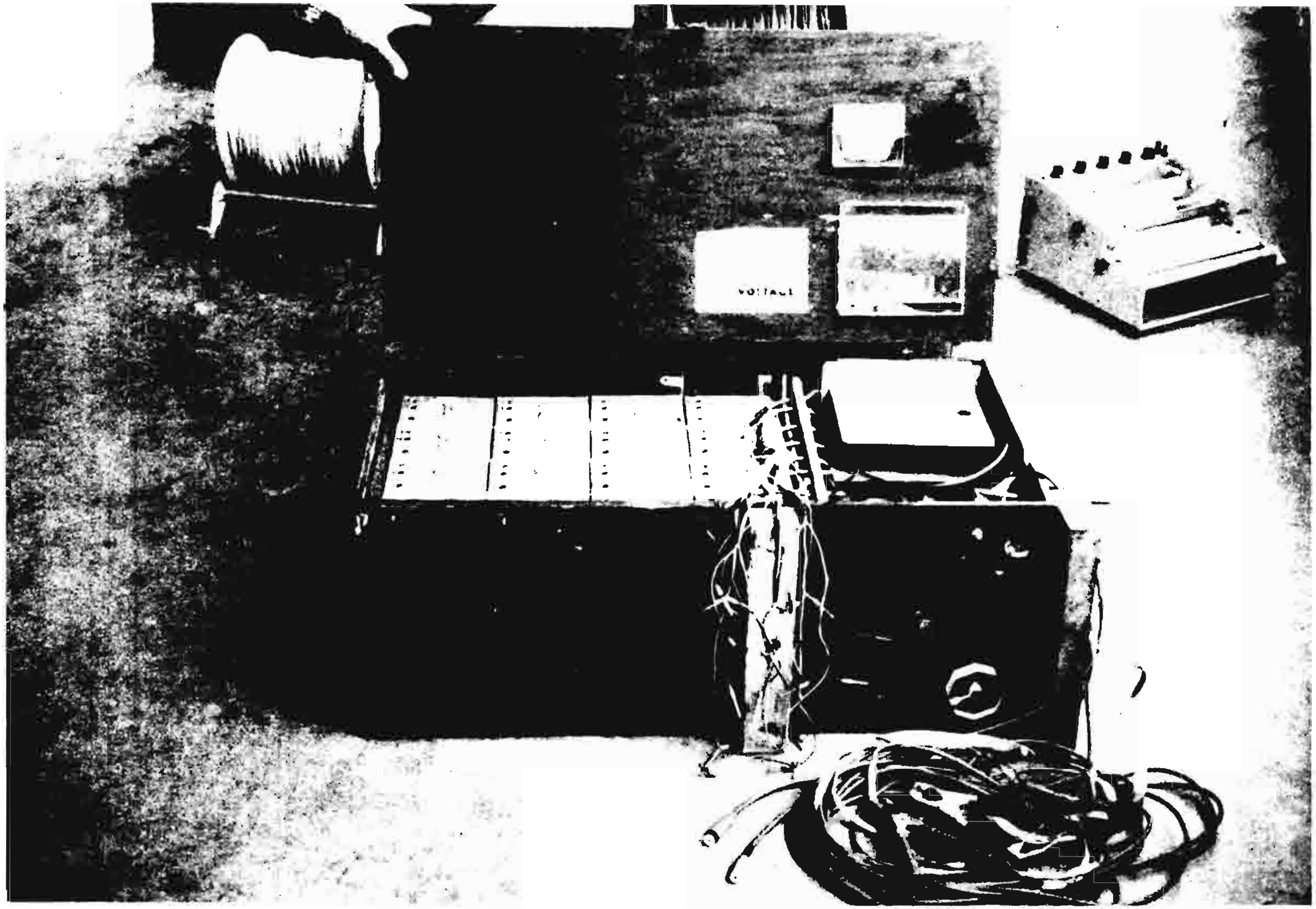

FIGURE 7. ELECTRICAL RESISTIVITY FIELD EQUIPMENT CONSTRUCTED AT THE UNIVERSITY OF HAWAII.

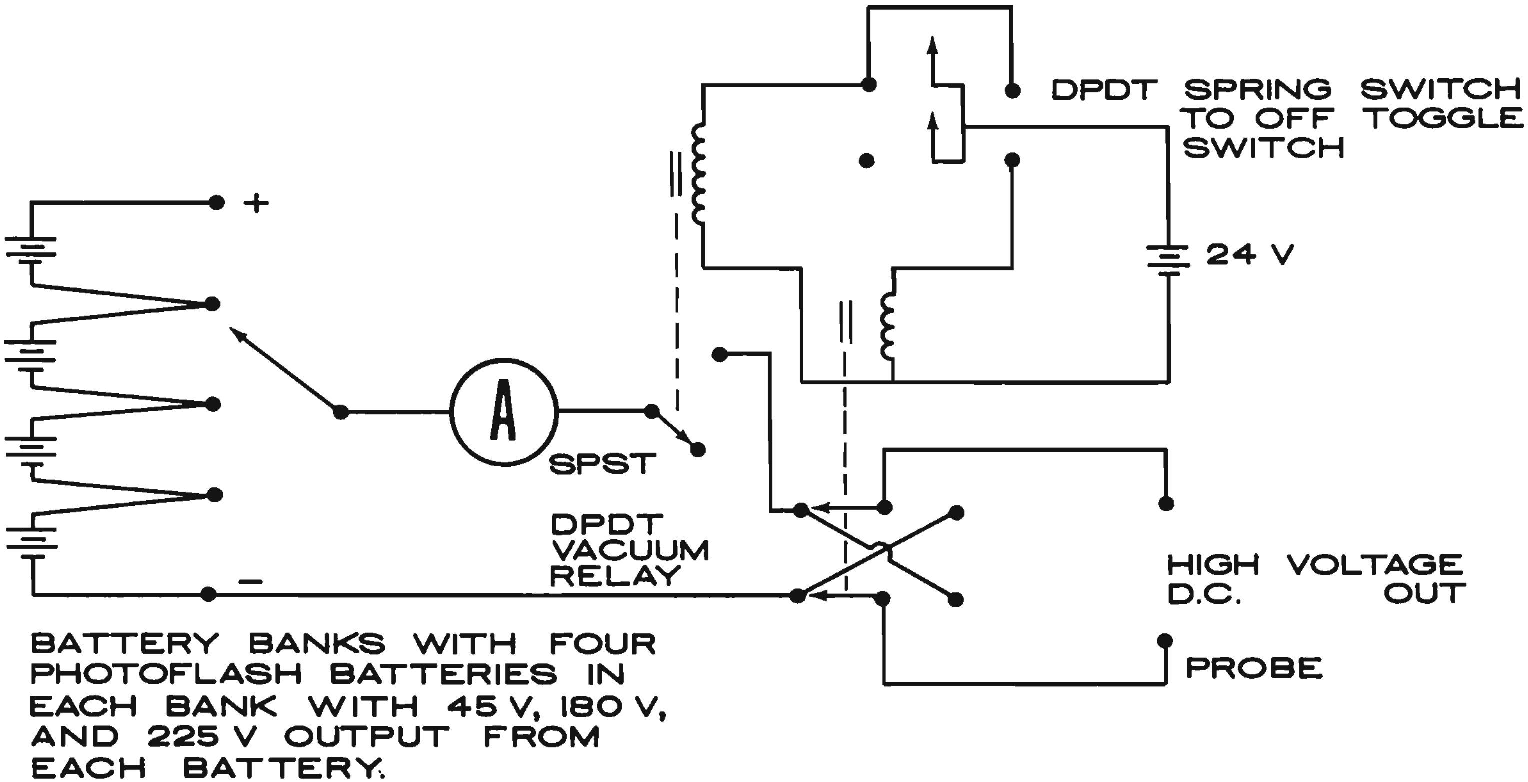

FIGURE 8. CIRCUITRY OF CONSTRUCTED ELECTRICAL RESISTIVITY EQUIPMENT.

difficulty was encountered with the switching system until appropriate high-amperage kilovolt vacuum switches were procured and installed.

DATA RECORDING. Typical field recordings indicating the data obtained and the procedure used are shown as Figures 9a and 9b. The record, shown as Figure 9a, for station 13 on the Pahala dump road (see Fig. 6 for site location) indicates that the major offsets of the trace are the result of reversals of polarity in the electrode spread. The small oscillations are background "noises" which theoretically could have been compensated by the nulling system available on the Heath Recorder. However, the nulling system did not permit full compensation without additional external wiring which was deemed unnecessary for a field effort.

Field notes were made directly on the record, as can be seen. These included the current flowing through the source electrodes in milliamperes as read on a Weston Model 911 DC meter. The voltage between the potential electrodes was later scaled from the recording, converted to millivolts, and noted on the record.

The record for profile station 15 on the Pahala dump road (Fig. 9b) is an example of a rather good situation. The background noise was negligible and the base line is unusually stable. The spike before the second right-hand shift is due to manual jitter of the switch for the low-voltage relay control circuit. An initial overshoot may sometimes be noted, but the decay is extremely rapid. At some field stations, up to ten seconds were required before the recording was stabilized.

INTERPRETATION. Interpretation of the sounding data was done by using the curve-matching technique and theoretical curves published by *Compagnie Generale de Geophysique* 1963.

Results

PAHALA SECTOR--NEW METHOD

Electrical Sounding. The area of the high-head ground water body which is developed by the Pahala shaft will be referred to as the Pahala sector. Hussong (1967) expressed the opinion that this sector is bounded by the southwest rift zone of Kilauea volcano and a zone in Mauna Loa rocks defined by three confused electrical resistivity soundings near the junction of the Middle Pahala Road and the Belt Road (see S-5, S-6,

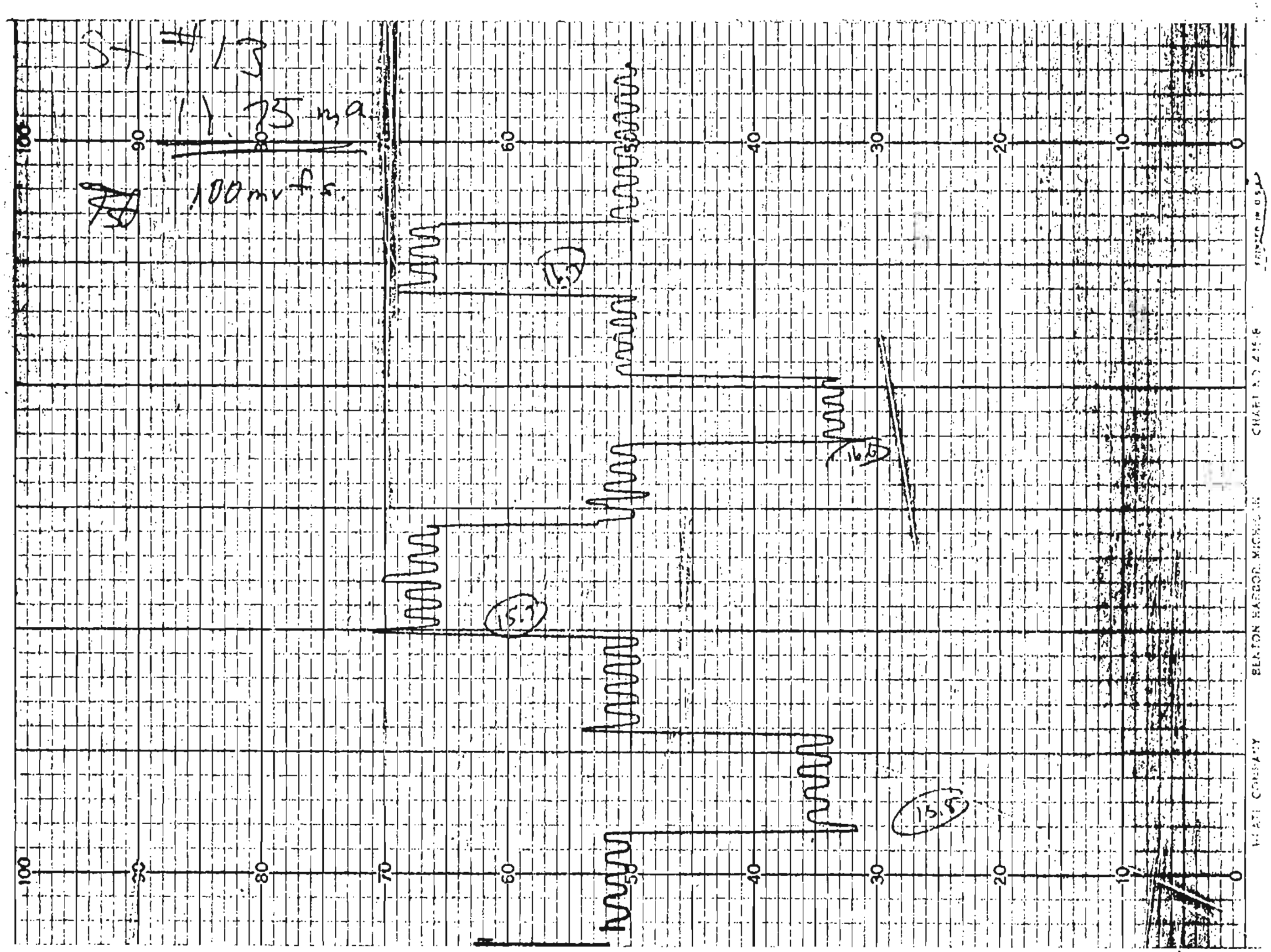

FIGURE 9a. COPY OF RECORDING MADE AT STATION 13. THE ORDINATE IS TIME AND THE ABCISSA IS 100 MILLIVOLTS FULL SCALE.

FIGURE 9b. COPY OF RECORDING MADE AT STATION 15. THE ORDINATE IS TIME AND THE ABCISSA IS 250 MILLIVOLTS FULL SCALE.

and S-12 in Fig. 6).

Using another plotting method, a different interpretation of the soundings reported by Cox and Hussong (1967) located a barrier just north-east of soundings S-6, S-12, S-10 and S-11 (Fig. 6). The alternative method is described by Voyoff, Hasegawa, and Ellis (1963), and may be described as a profiling technique that uses sounding data.

In applying the technique, apparent resistivity values are located at different x, z coordinates. The x coordinate corresponds to the position of the center of the sounding spread along the surface. The z coordinates are represented by the various AB/2 spacings used during sounding. The AB/2 spacings are plotted on a log scale. The apparent resistivities are located on the cross-section and are contoured. The resulting map will reflect the electrical conductivity distribution along this profile. Distortion will be present as the depth has not been corrected for the lateral variation in resistivity. In the case of the Pahala sector, four cross-sectional profiles are chosen. The first cross-section consists of the soundings S-1, S-5, S-6, S-7 and S-4. (See Fig. 6 for the location of these soundings.) This cross-section follows the Belt Road between Punaluu and Pahala. The contoured cross-section (Fig. 10), shows a large discrepancy in apparent resistivity values, compared to the other soundings, at S-7. The apparent resistivity values on both sides of S-7 are compatible and easily contoured. The sounding at S-7 represents the condition of a high groundwater table which is known to exist in the Pahala area (Hussong, 1967). The high water content of the rocks are reflected by the lower apparent resistivities observed. This representation indicates that the situation which exists at S-7 begins somewhere between S-6 and S-7 and ends somewhere between S-7 and S-4 along the profile. The difference in apparent resistivities is smaller between S-7 and S-4 than between S-6 and S-7.

The second profile consists of the soundings S-3, S-7, S-10 and S-11. This cross-section begins at the Middle Pahala Road and trends approximately north to south down to about the 200-foot elevation contour (Fig. 6). The contoured cross-section is shown in Figure 11. Again, a large discrepancy is observed between soundings S-7 and S-10. This discrepancy indicates that soundings S-3 and S-7 are located within the sector of high fresh-water head and soundings S-10 and S-11 are not in

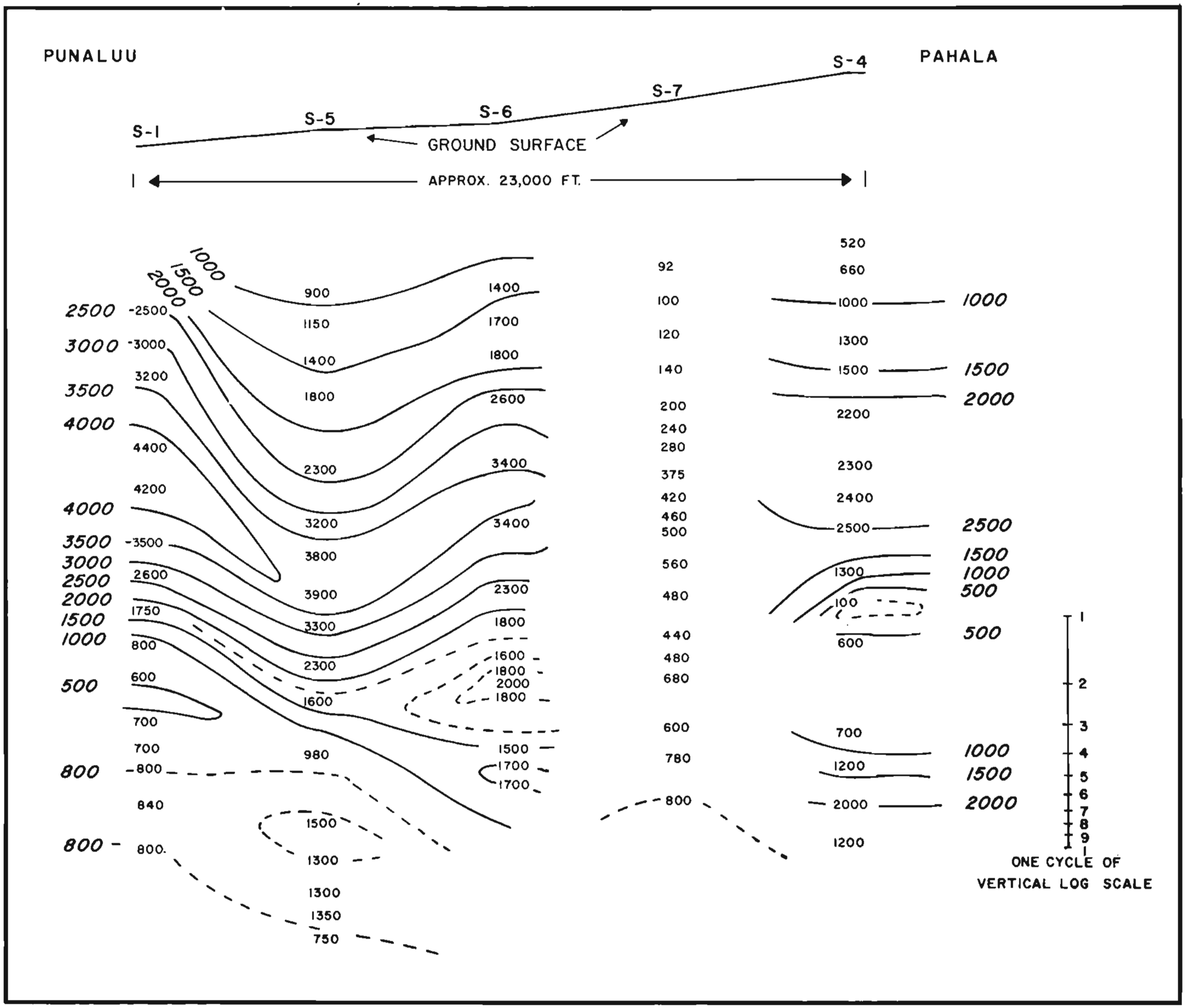

FIGURE 10. CONTOURED RESISTIVITY CROSS-SECTION OF SOUNDINGS S-1, S-5, S-7, AND S-4. DASHED CONTOURS BETWEEN THE NORMAL 500 Ω-M CONTOUR INTERVAL ARE ADDED FOR CLARITY AND CORRESPOND TO VARIOUS CONVENIENT INTERVALS.

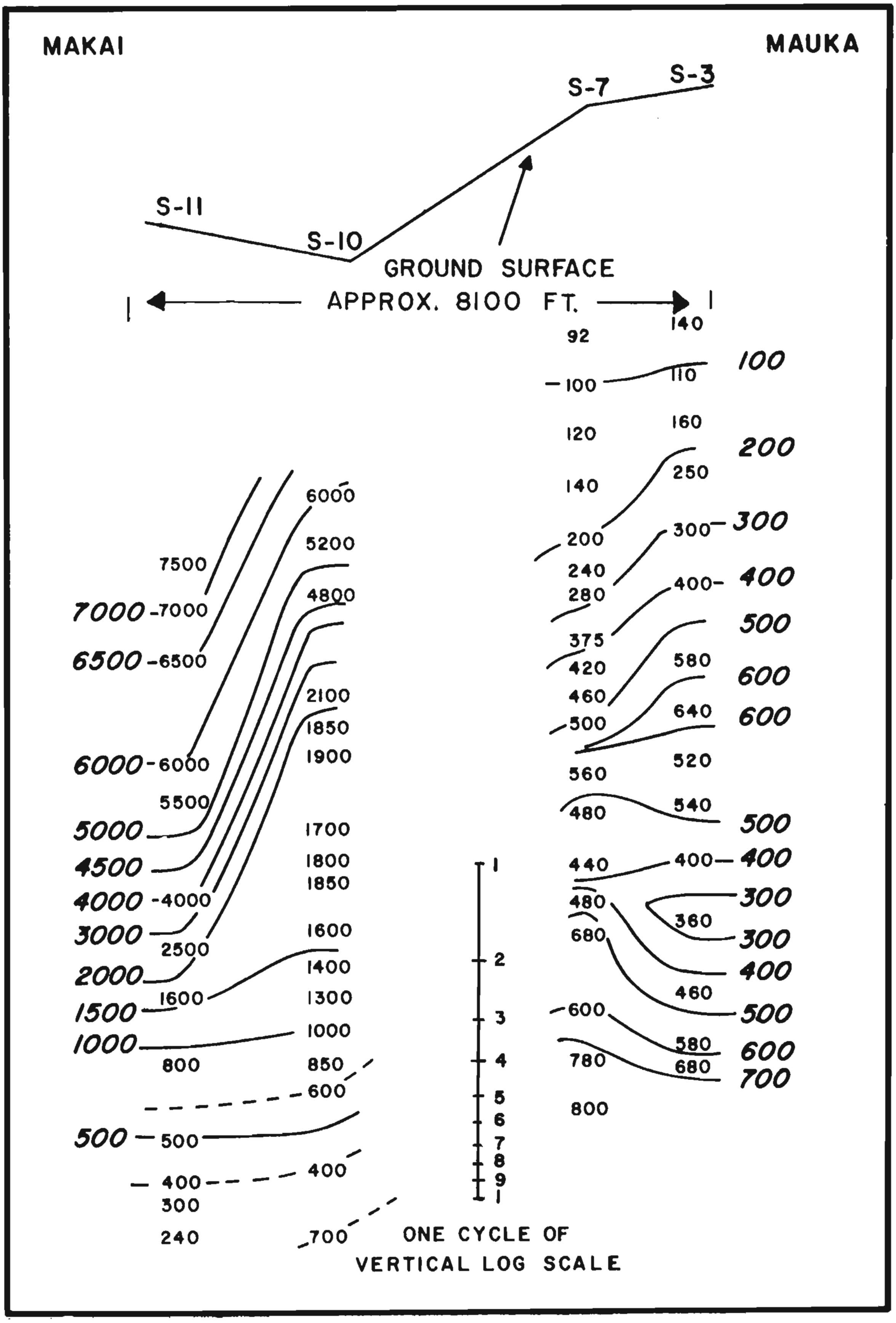

FIGURE 11. CONTOURED RESISTIVITY CROSS-SECTION OF SOUNDINGS S-3, S-7, S-10, AND S-11. DASHED CONTOURS BETWEEN THE NORMAL 500 Ω-M CONTOUR INTERVAL ARE ADDED FOR CLARITY AND CORRESPOND TO VARIOUS CONVENIENT INTERVALS.

this sector. Hence, the barrier observed between S-6 and S-7 extends in a southerly direction between S-7 and S-10.

The third profile consists of the soundings S-6, S-12, S-10, and S-11. The contoured values, presented in Figure 12, do not show any breaks. This suggests that the area covered by the profile is continuous and completely removed from the anomalous ground-water sector penetrated by the Pahala well. (Refer to CONCLUSIONS, Fig. 28, p. 52.)

The fourth profile consists of soundings S-6, S-12, and S-14 (Fig. 6). The contoured values are presented in Figure 13. This profile is also consistent with the profile presented in Figure 12.

In summary, these profiles indicate the existence of a barrier, called the Kolea barrier. The existence of still another barrier between sounding S-7 and S-4 is also indicated but the orientation and location of this barrier cannot be determined with respect to the Pahala shaft from the existing data.

Electrical profiling. Electrical resistivity profiling was conducted down the Middle Pahala Road at the site of Hussong's sounding S-3 (Fig. 6), and continued on the makai (seaward)side of the Belt Road along the Pahala dump road seaward. The locations of these stations are shown in Figure 14.

A Wenner spread having an electrode interval or "a" spacing of 200 feet was used. The points on the map in Figure 14 indicate electrode positions. Because four electrode positions are associated with each Wenner spread, no data will be indicated for the two outermost electrode positions. Data are plotted at the center of the spread.

The reduced data for Pahala are given in Table 1. For each station, the current recorded by the ammeter is placed in the second column. If there is notable variation in the potential between the electrodes, several values are recorded (third column). The fourth column gives the full-scale of the recorder in millivolts. The potential given in the fifth column is the value after the conversion from scale units to millivolts. The desired apparent resistivity given in the last column is obtained in ohm-feet by dividing the potential by the current (mv) and multiplying by 2π times the "a" spacing of the Wenner spread (ft).

The apparent resistivity values are plotted in Figure 15. A high appears between station 21 and station 33. Note in Figure 14 that the line of the profile is actually a dogleg, running downhill to station 23

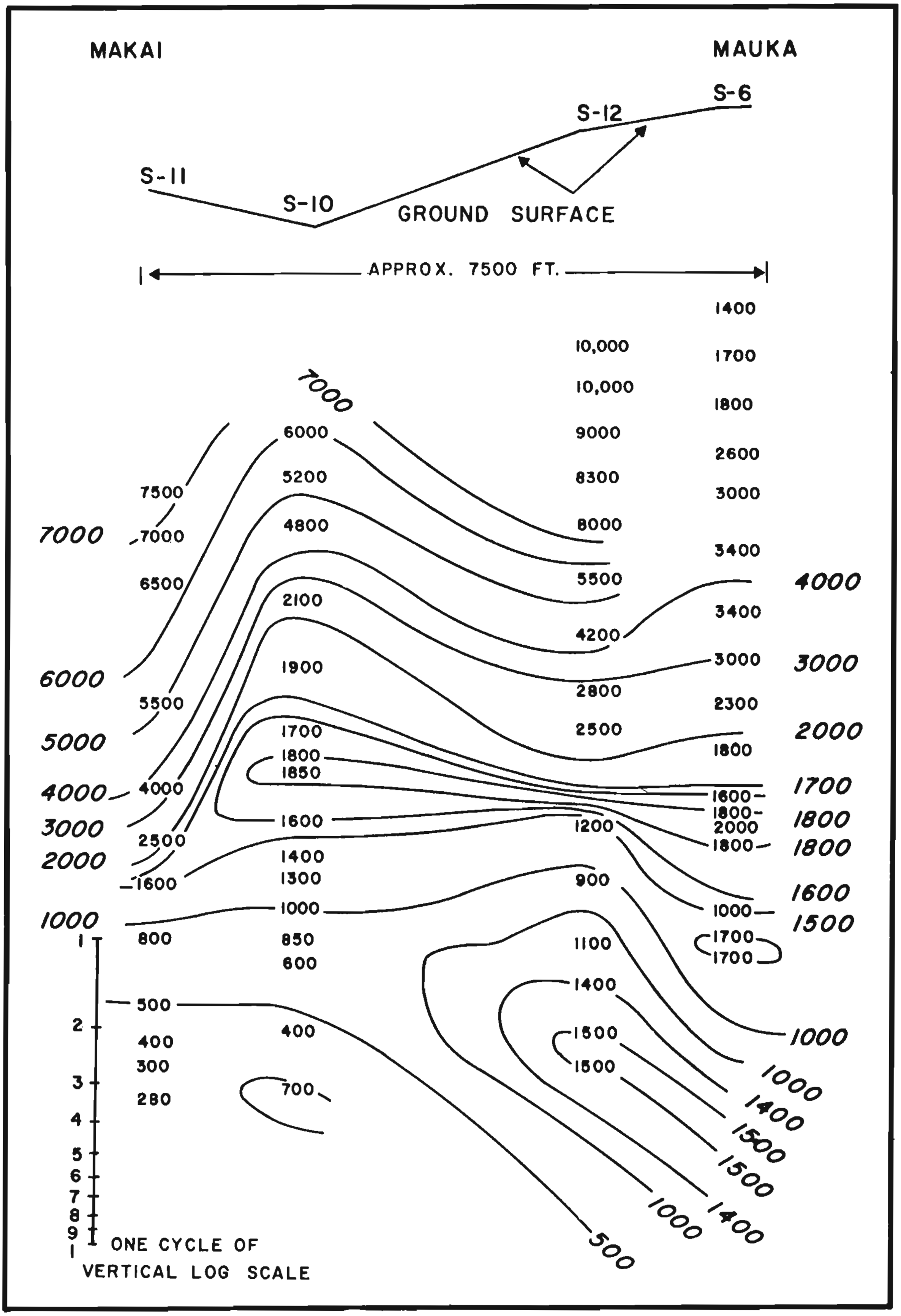

FIGURE 12. CONTOURED RESISTIVITY CROSS-SECTION OF SOUNDINGS S-6, S-12, S-10, AND S-11. DASHED CONTOURS BETWEEN THE NORMAL 500 Ω-M CONTOUR INTERVAL ARE ADDED FOR CLARITY AND CORRESPOND TO VARIOUS CONVENIENT INTERVALS.

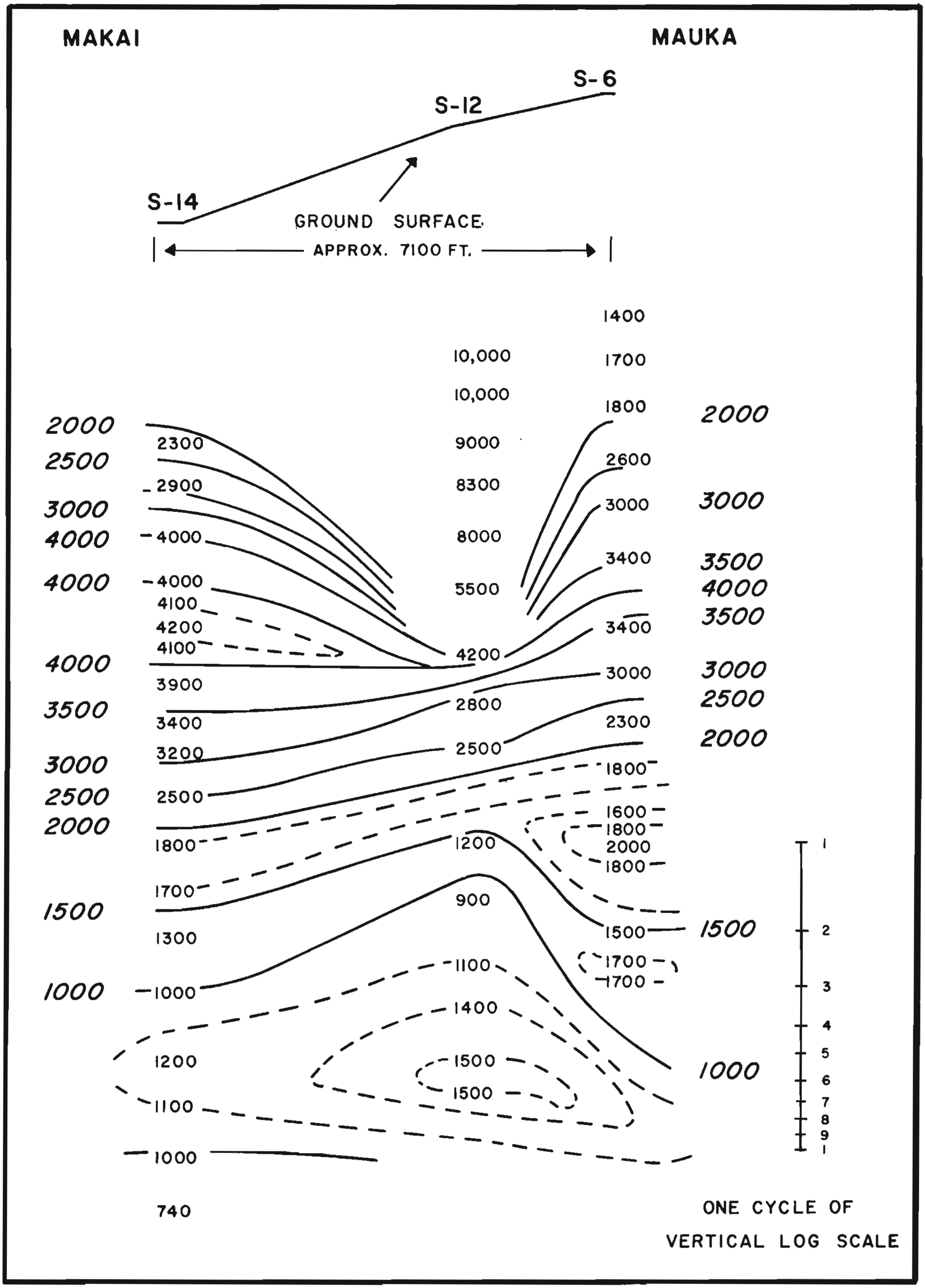

FIGURE 13. CONTOURED RESISTIVITY CROSS-SECTION OF SOUNDINGS S-6, S-12, AND S-14. DASHED CONTOURS BETWEEN THE NORMAL 500 Ω-M CONTOUR INTERVAL ARE ADDED FOR CLARITY AND CORRESPOND TO VARIOUS CONVENIENT INTERVALS.

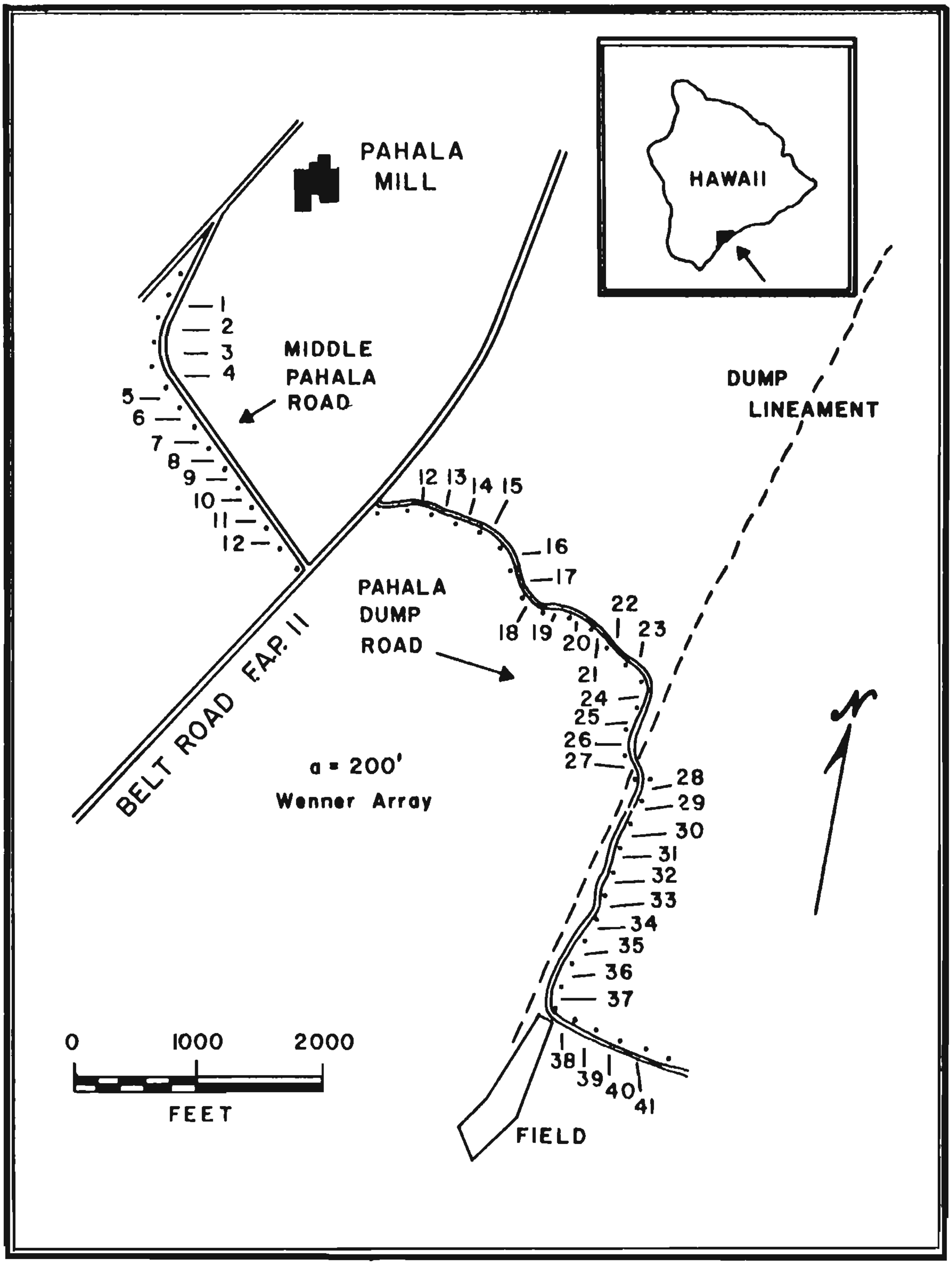

FIGURE 14. PAHALA DUMP RESISTIVITY PROFILE LOCATIONS: WENNER SPREAD WITH ELECTRODE INTERVAL OF 200 FEET.

TABLE 1. PAHALA DUMP ROAD APPARENT RESISTIVITY DATA.

STATION NUMBER	CURRENT, I (MILLIAMPERES)	POTENTIAL (SCALE UNITS)	FULL-SCALE (MILLIVOLTS)	POTENTIAL, E (MILLIVOLTS)	APPARENT RESISTIVITY $R_a = 2\pi\ 200\ E/I$ (OHM-FEET)
		MIDDLE PAHALA ROAD			
1	58	45.9	100mv f.s.	~ 46.5	1000
		46.5	(10 IN)		
		46.7			
		47.0			
		47.8			
		46.0			
2	21.5	8.7	250	21.7	1230
	23.5	9.6		24.0	1280
3	67.5	20.0	250	50.0	930
	69.5	21.4	250	53.5	968
4	48.5	14.3	250	35.7	930
5	52.5	11.2	250	28.0	672
6	50.5	31.5	100	--	785
	48.5	29.7	100	--	766
7	54.5	36.6	100	--	850
8	89.5	45.-	100	--	628
	86.5	43.-	100	--	628
9	45.-	13.3	250	33.3	930
	50.7	16.2		40.5	1000
10	80.5	26.8	250 ?	67.-	1040
	76.-	25.5		63.8	1050
11	41.-	41.2	50	20.6	628
	49.5	50.3	50	25.1	635
12	63.0	16.1	250	40.3	803
	59.5	14.7		36.7	780
		PAHALA DUMP ROAD			
12 (duplicate)	100.5	45.5	250	114	1360
13	11.75	16.1	100	--	1720
14	41.-	24.2	250	60.5	1850
15	44.4	30.1	250	75.-	2120
16	27.2	43.0	100	--	1980
	23.8	36.2		D	1920
17	61.1	31.-	250	70.5 (?)	1590
	61.1	30.4		76.2	1570
18	44.0	26.6	250	66.3	1910
19	22.7	14.5	250	36.3	2010
	25.2	15.1		37.7	1880
	26.8	16.4		41.0	1930
20	29.6	25.2	250	63	2680
	34.7	29.8		74	2690
21	42.0	43.4	250	104	3140
22	10.5	23.5	250	58.8	7050
23	16.5	20.9	250	52.0	3960
24	10.1	20.4	250	51.0	6300
25	20.5	26.1	250	15.2	3990
26	39	47	250	117	3770
27	31	42	250	105	4270
28	50	40	250	100	2520
29	40	40	250	100	3140
30	48.5	47.5	250	109	2830
31	31	41	250	102	4150
32	30.5	41	250	102	4210
33	26.5	34.5	250	86	4080
34	31.8	29.5	250	74	2920
35	59	41.5	250	104	2200
36	58	32.5	250	81	1760
37	89.8	46.0	250	109	1530
38	24	18	250	45	2360
39	82	28	250	70	1075
40	140	35	250	88	726
41	140	33	250	82	735

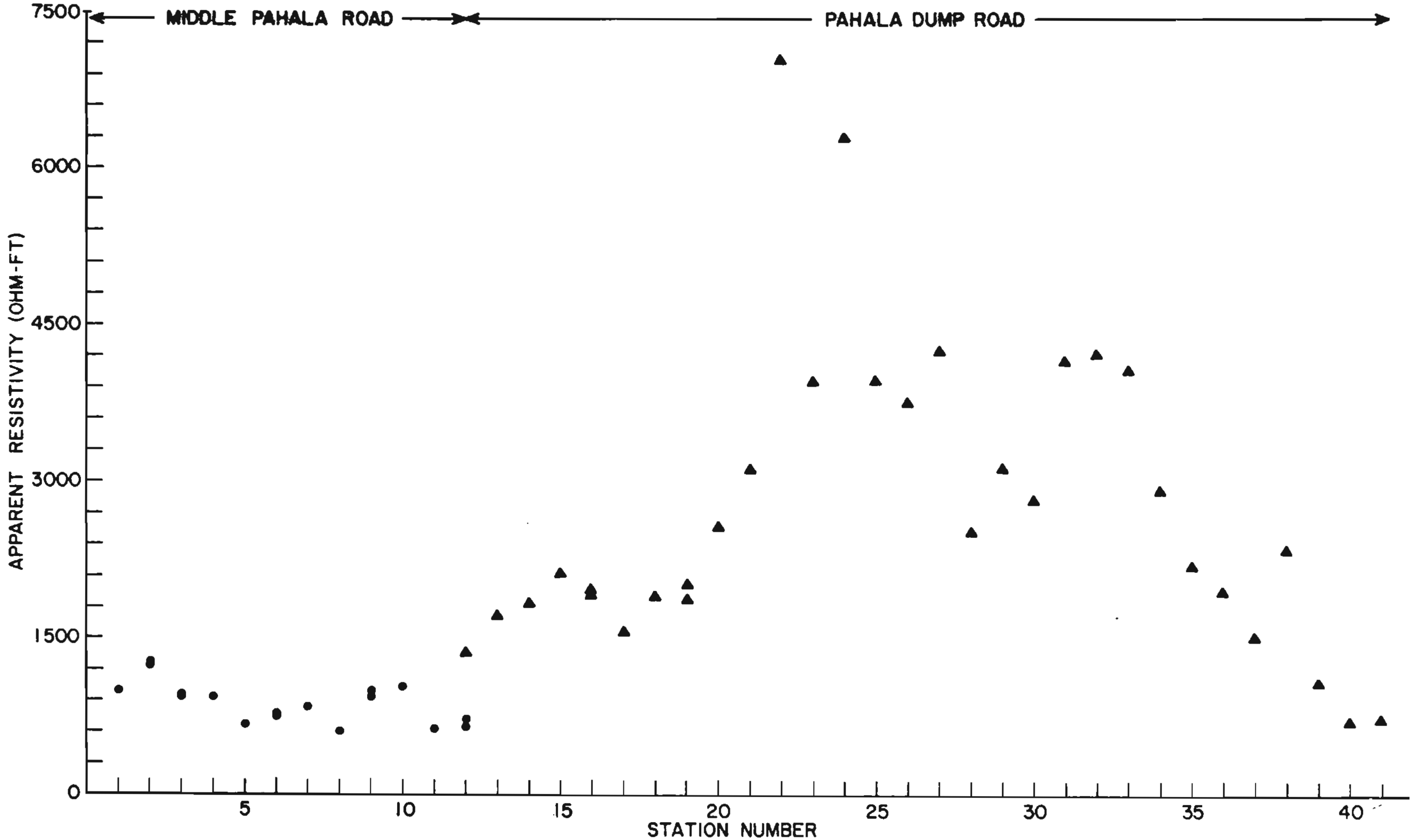

FIGURE 15. APPARENT RESISTIVITY PROFILE ON MIDDLE PAHALA AND PAHALA DUMP ROADS.

then turning about 90° to the right (along the Pahala dump) and again making a 90° turn to the left at station 37, approximately regaining the original direction. Consequently, the high is actually associated with the segment of the line askew of the downhill trend.

Because the anomaly extends beyond the refuse dump, it is not related to the refuse material at the Pahala Dump. Therefore, the crack of the Pahala Dump itself constitutes the resistivity anomaly.

The apparent resistivity profile line increases significantly *before* it becomes parallel to the crack. An ideal crack, forming a semi-infinite half-plate, would only double the apparent resistivity. In practice, the line was about 100 feet from the crack. An increase by a factor of four was observed. The decrease in apparent resistivity toward the end of the line, still parallel and not more than 200 feet from the crack, is probably attributable to the bagasse disposal in the area as can be seen on the lower right portion of the aerial photograph shown as Figure 16.

This lineament feature is shown on topographic and geologic maps for this area. The aerial photograph shows the lineament feature trending in both directions from the Pahala dump. On the basis of the resistivity high and the reinterpreted soundings, the Pahala dump lineament is identified as a probable ground-water barrier.

OLD GOVERNMENT ROAD. An electrical resistivity sounding was made on the Old Government Road for correlation with the gravity microsurvey conducted on this road. The sounding data obtained by using the Schlumberger spread are given in Table 2 and in Figure 17 together with sounding S-5 (Fig. 6). Despite intensive efforts at two different times, January and April of 1968, by experienced personnel, satisfactory data could not be obtained for an AB/2 spacing greater than 200 feet. However, a comparison of this sounding to sounding S-5 taken on the nearby Belt Road and reported by Hussong and Cox (1967, Fig. 10) is informative. If both soundings were surveying the same ground-water sector, the Old Government Road sounding should be displaced to greater depths compared to S-5 because it is at a higher elevation. Instead, the reverse is noticed: the crest value is at 50 to 70 feet compared to 100 feet at S-5, and the trough is at 300 feet compared to at least 400 (shown as 500) feet. Hence, the site of the sounding could be another ground-water sector or the water content of the ground has fluctuated greatly with time. Considering the distance between the two soundings, it is not likely that they are in different

FIGURE 16. AERIAL PHOTOGRAPH OF PAHALA DUMP LINEAMENT. THE DUMP AREA IS INDICATED BY THE CIRCLE AND THE BAGASSE DISPOSAL AREA IS INDICATED BY THE SMALL ARROW AT THE LOWER RIGHT HAND CORNER.

TABLE 2. DATA AND REDUCTION FOR SOUNDING ON OLD GOVERNMENT RAOD.

SIZE	V CHART 1)	CHART 2) FULL-SCALE (MV)	V (MV) 3)	A (MA) 4)	R 5) Ω-M
15/1	38	250	95	8	1350
15/2	39	250	98	4.2	1265
20/2	23	250	57	4.2	1370
20/4	46	250	115	4.3	1350
25/4	44	250	110	6.0	1400
30/4	46	250	115	8.9	1460
40/4	29	250	72	9.8	1460
50/4	42	250	105	21.8	1440
50/10	42	250	105	8.4	1560
70/10	45	250	112	18.7	1470
100/10	42	250	105	56	935
100/20	48	250	120	31.8	945
140/20	33	250	82.5	71.6	552
200/20	8	250	20	72	290
200/40	45	100	45	55	410
250/40	21	100	21	51.5	320
300/40	17	50	34	47.5	800*
500/40	9	250	22	108	624*
500/100	10	250	25	106	288
700/100	10	250	25	130	465
700/100	25	100	25	210	294
1000/10	12	100	12	167	960
1000/200	35	100	35	165	531
1400/200	22	100	22	212	495
2000/200	21	50	42	224	1880*
2000/400	26	100	26	168	775
2500/400	33	100	33	280	935
2000/400	36	100	36	232	750
2000/200	14	25	56	235	2400*
1400/200	36	50	68	110	1550*
1000/100	22	50	44	150	1450*
700/100	15	100	15	143	258
500/100	38	100	38	148	322
500/40	15	100	15	182	256
300/40	26	100	26	154	193
200/40	21	250	52.5	107	245
200/20	22	100	22	106	210
140/20	19	250	47.5	75	302

* NOT PLOTTED IN FIGURE.

1) VOLTAGE READ IN CHART UNITS.
2) FULL SCALE OF VOLTAGE CHART.
3) VOLTAGE IN MILLIVOLTS AS CONVERTED FROM CHART UNITS.
4) SOURCE CURRENT IN MILLIAMPERES.
5) APPARENT RESISTIVITY IN OHM-METER.

ground water sectors.

In Table 3 the rainfall in the Pahala area for several months prior

TABLE 3. PRECIPITATION DATA FOR RAIN GAUGE STATION, PAHALA 21, FOR THE PERIODS PRIOR TO THE TAKING OF SOUNDING S-5 AND THE OLD GOVERNMENT ROAD SOUNDING.

YEAR	MONTH	OBSERVED PRECIPITATION (INCHES)	DEPARTURE FROM MEAN (INCHES)	
1966	JUNE	.16	-1.17	
	JULY	1.44	- .08	
	AUGUST	2.10	- .96	
	SEPT.	6.44	3.91	S-5 SOUNDING DONE
1967	NOV.	13.37	7.93	
	DEC.	11.64	7.21	OLD GOVERNMENT ROAD SOUNDING DONE
1968	JAN.	17.24	9.21	OLD GOVERNMENT ROAD SOUNDING DONE
	FEB.	10.65	4.06	
	MARCH	4.89	- .69	
	APRIL	9.37	6.21	SECOND SOUNDING EAST OF PUNALUU DONE

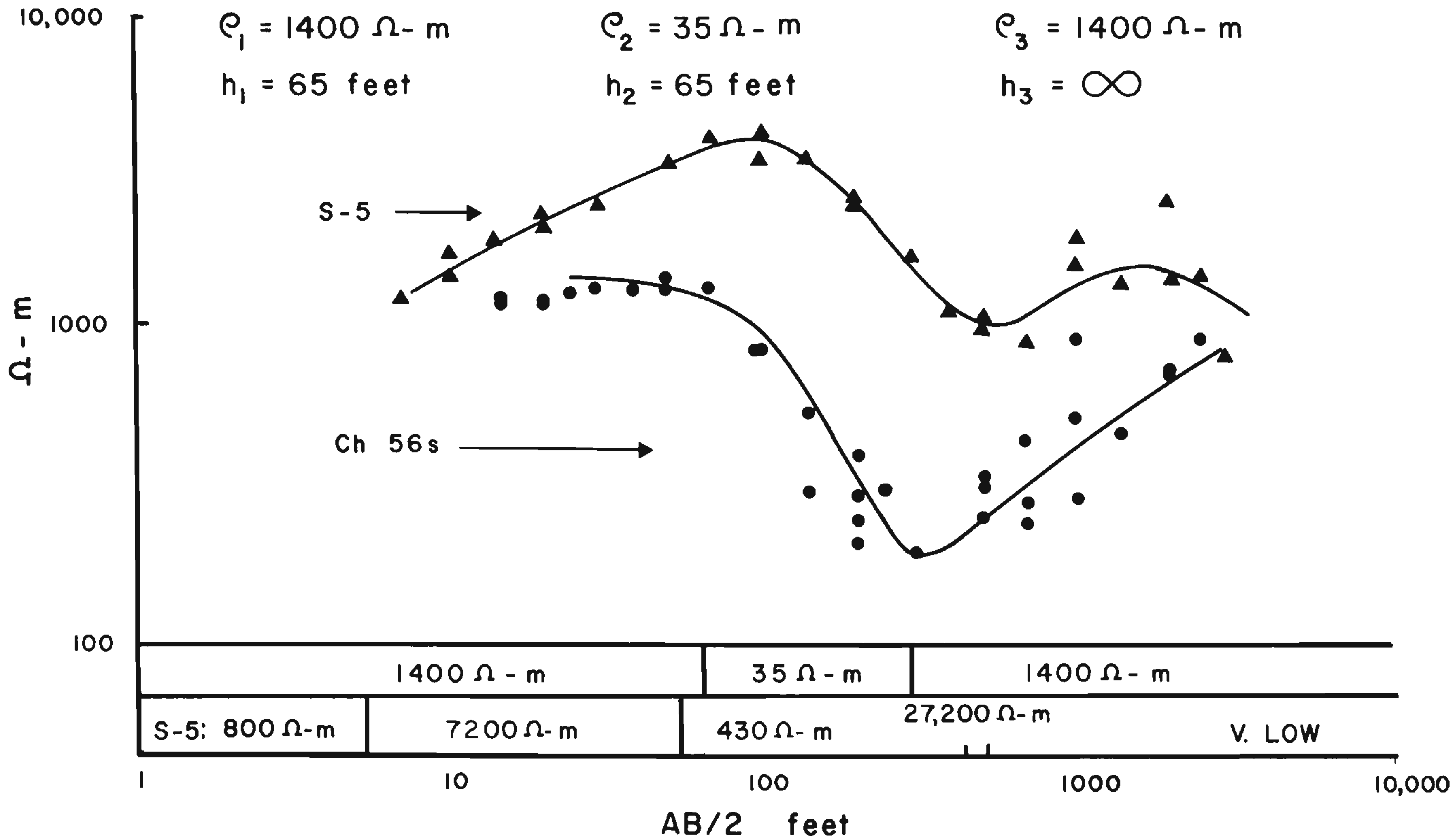

FIGURE 17. SOUNDING ON THE OLD GOVERNMENT ROAD. SCHLUMBERGER SPREAD USED. TRIANGLES REPRESENT SOUNDING S-5 FROM HUSSONG AND COX (1967).

to the taking of the soundings, are recorded. This precipitation data indicates that the area experienced moderate rainfall prior to taking sounding S-5 compared to the period before the Old Government Road sounding. As a result, the ground was dryer during sounding S-5, thus accounting for the higher resistivities observed at that time. The lateral shift of the sounding (along the AB/2 axis) is attributed to different concentrations of water in the zone of aeration.

PUNALUU SECTOR. Further geophysical explorations were made in the Punaluu area near Punaluu Bay and Ninole Springs because of the very large thermal anomalies noted by Adams and Lepley (1968).

The station locations for the electrical resistivity profiling, conducted on the lower portion of the Punaluu Road, are shown in Figure 18. For this line, the Wenner spread, selected on the basis of elevation, had a spacing of 100 feet. The apparent resistivities are given in Table 4 and plotted in Figure 19 which also shows station elevations corrected with respect to station number 18 which is approximately 5 feet above msl. The shoreline is approximately 300 feet south of station 18.

There is obviously a strong correlation of apparent resistivity with elevation. An abrupt change in slope, which occurs in both the values of elevation and the apparent resistivity, appears at stations 16, 17, and 18 where the resistivity should have decreased with the elevation but did not. The anomaly indicates little or no invasion by salt water and probably high outflows of fresh water, as suggested by the infrared thermal anomalies reported by Adams and Lepley (1968).

A stronger seaward decrease in resistivity should have been anticipated in the vicinity of these stations solely from the effect of decreasing elevation and consequently decreasing depth to the water table. An even stronger decrease might have been expected from the decreasing depth to the salt-fresh interface. At Hussong's (1967) sounding S-13 (Fig. 18), a water-table elevation of 2 feet was estimated. In accordance with the Ghyben-Herzberg theory (Cox, 1954), the salt-fresh interface, which should be only about 80 feet below sea level at S-13, should be shallower at stations 16 to 18, because of their proximity to the shore.

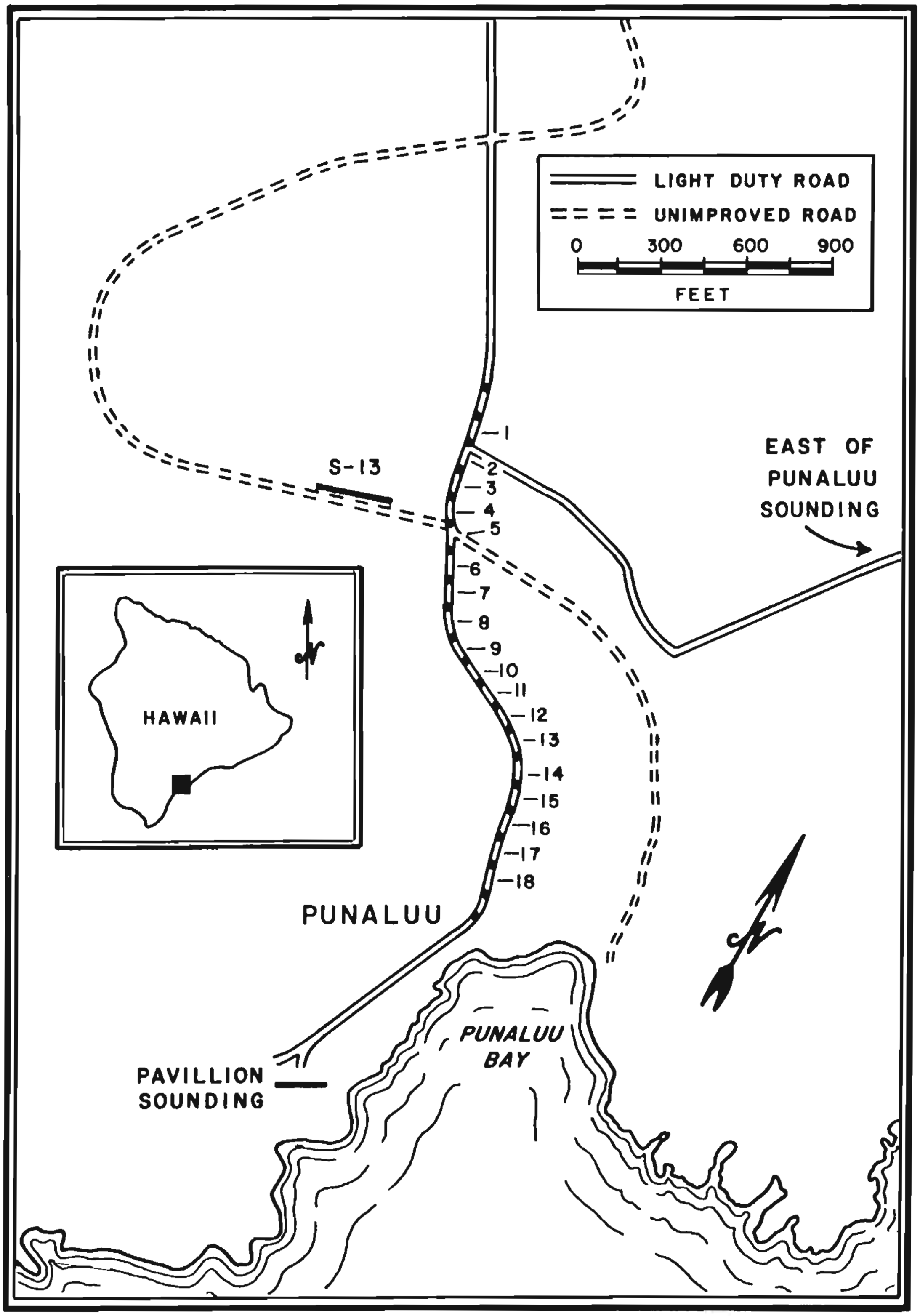

FIGURE 18. LOCATION MAP FOR PUNALUU STATIONS.

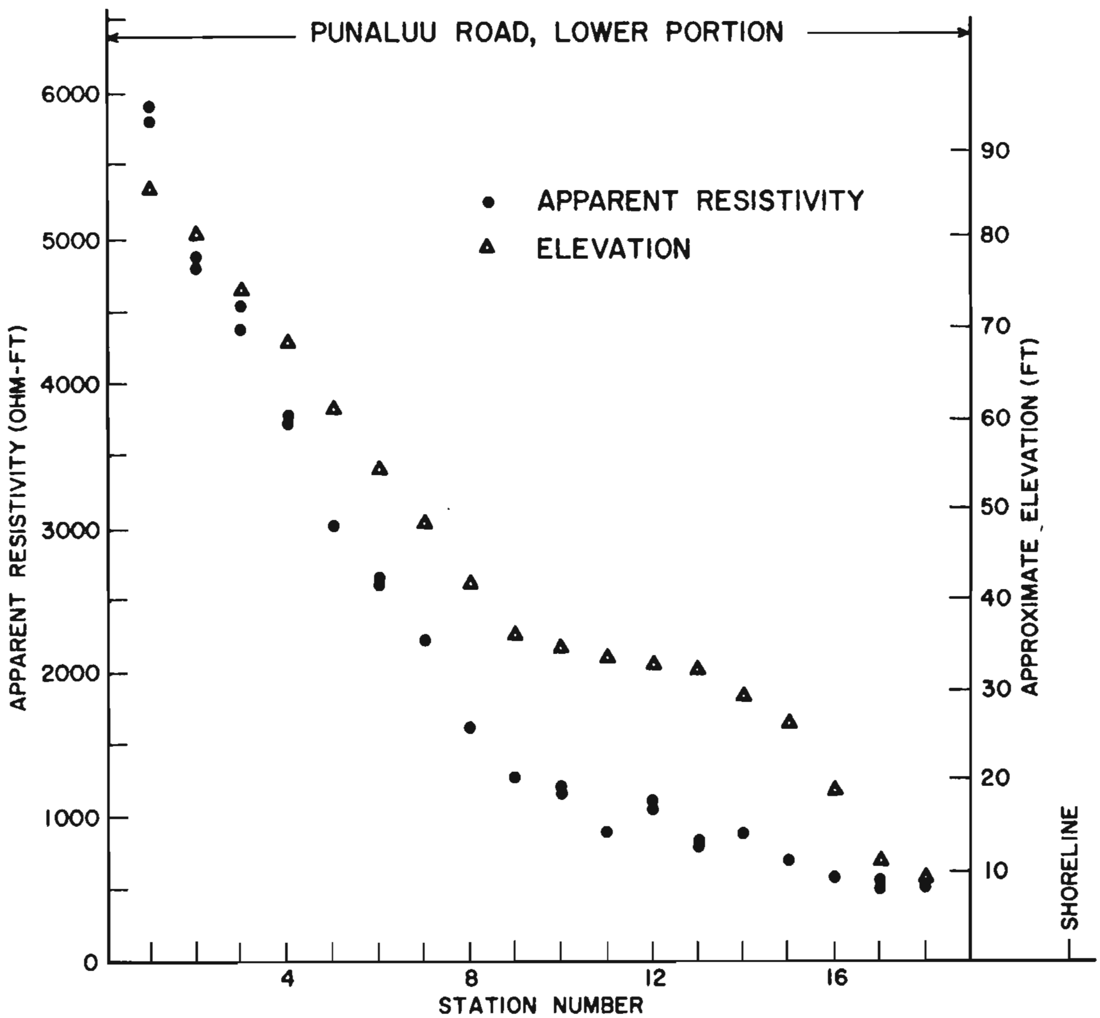

FIGURE 19. APPARENT RESISTIVITY AT PUNALUU.

Therefore, at these stations the interface is less than 100 feet below the surface and should be within the zone of influence of the resistivity profile spread with its "a" distance of 100 feet. But stations 16 to 18 do not indicate an interface within the zone of influence of the resistivity profile spread. Therefore, there is probably a high outflow of fresh water in this area consistent with the infrared thermal anomaly in Punaluu Bay. A sounding was run in this same area near the Pavilion on the beach (see Pavilion Soundings, p. 37 for a discussion).

TABLE 4. VALUES OF APPARENT RESISTIVITY FOR PUNALUU.

STATION NUMBER[1]	CURRENT, I (MILLIAMPERES)	POTENTIAL (SCALE UNITS)	FULL-SCALE (MILLIVOLTS)	POTENTIAL, E (MILLIVOLTS)	APPARENT RESISTIVITY $R_a = 2\pi\ 200\ E/I$ (OHM-FEET)
1	6.8	25.2	250	63.0	5820
	6.4	24.1	250	60.1	5940
2	8.0	24.5	250	61.2	4810
	8.2	25.4	250	13.8	4870
3	9.5	26.5	250	66.1	4380
	9.8	28.5	250	71.1	4580
4	9.2	21.8	250	54.8	3760
	9.8	23.6	250	59.0	3790
5	11.2	22.2	250	55.1	3040
6	14.8	24.9	250	62.0	2630
	13.5	22.9	250	57.0	2650
7	25.0	35.5	250	89.0	2230
	20.0	28.4	250	71.0	2230
8	46.0	46.5	250	116.-	1580
	42.0	43.3		108.-	1620
9	24.5	19.8	250	49.5	1270
	24.9	20.3	250	50.3	1280
10	25.1	18.9	250	47.2	1180
	24.0	18.5	250	46.2	1210
11	35.0	20.1	250	50.-	900
12	25.3	17.2	250	43.-	
	23.3	16.2	250	40.5	
13	37.5	49.-	100	--	825
	33.5	42.7	100	--	800
14	27.9	16.1	250	40.2	895
	28.2	16.2	250	40.5	900
15	62.5	28.5	250	71.2	717
	61.5	28.2	250	70.5	725
16	74.2	28.2	250	70.5	596
17	56.5	20.2	250	50.5	561
	47.3	16.2	250	40.5	536
18	65.0	21.2	250	53.0	511
	60.0	19.2	250	48.6	508
	77.0	25.6	250	64.0	517
	78.0	26.1	250	65.1	521

[1]WENNER SPACING = 100 FT.

The anomaly detected in the profile along the Punaluu Road indicates that the water table thickness near the shore at the head of Punaluu Bay is such that the profile spread did not sense the salt-water interface. This would indicate that the water table at this point may extend as much as 100 feet below mean sea level. It was also reported earlier from sounding S-13 that the water table extended to 80 feet below sea level. This would imply that the water table between the site of sounding S-13 and the shore near the head of the bay had a nearly constant head of 2 feet.

East of Punaluu Sounding. An unexpectedly high head of fresh water was found by Hussong and Cox (1967, p. 30, Fig. 12) at their location S-8. To determine if this condition existed eastward, a sounding was conducted. Two different soundings were done at this site but at different times due to operational difficulties on the pahoehoe flow at the site. The sounding data obtained in January 1968 are given in Table 5 and Figure 20. A curve from chart 80s (EAEG, 1966) is traced. This shows a peculiar jump at an AB/2 value of 130 feet. Such a sharp change in slope is usually attributable to lateral resistivity variations. The only possible interpretation of the data indicates a lower conductive layer (ρ =0 ohm-meters) which is inconsistent with the interpretation of sounding S-8 by Hussong (1967). The second sounding was made at the same site in April 1968 with the intention of learning more about this lower layer.

TABLE 5. DATA AND REDUCTION FOR FIRST SOUNDING ON PAHOEHOE EAST OF PUNALUU.

SIZE	V CHART[1)]	CHART FULL-SCALE (MV)	V (MV)	A (MA)	R Ω-M
5/1	43	250	108	0.16	8500
7/1	15.5	250	39	0.11	8550
10/1	40	100	40	0.26	7700
10/2	35	250	88	0.22	10,000
14/2	36	250	90	0.50	8600
20/2	29	250	72.5	0.87	8300
20/4	30	250	75	0.41	9150
25/4	43	250	108	1.05	8150
40/4	52	250	130	4.50	5800
50/4	24	250	60	3.70	5050
50/10	64	250	160	3.48	5700
70/10	44	250	110	6.95	3890
100/10	54	100	54	12.6	2140
140/20	34	250	85	9.0	2300
200/20	37	50	74	23.2	3200
200/40	47	50	94	14.3	3300
250/40	46	50	92	26.4	2720

1) REFER TO TABLE 2 FOR AN EXPLANATION OF THE TABLE HEADINGS.

The data obtained are given in Table 6 and Figure 21. It becomes apparent that the underlying layer is not perfectly conductive but has a resistivity of about 400 Ω-m, suggested by smoothing the scattered

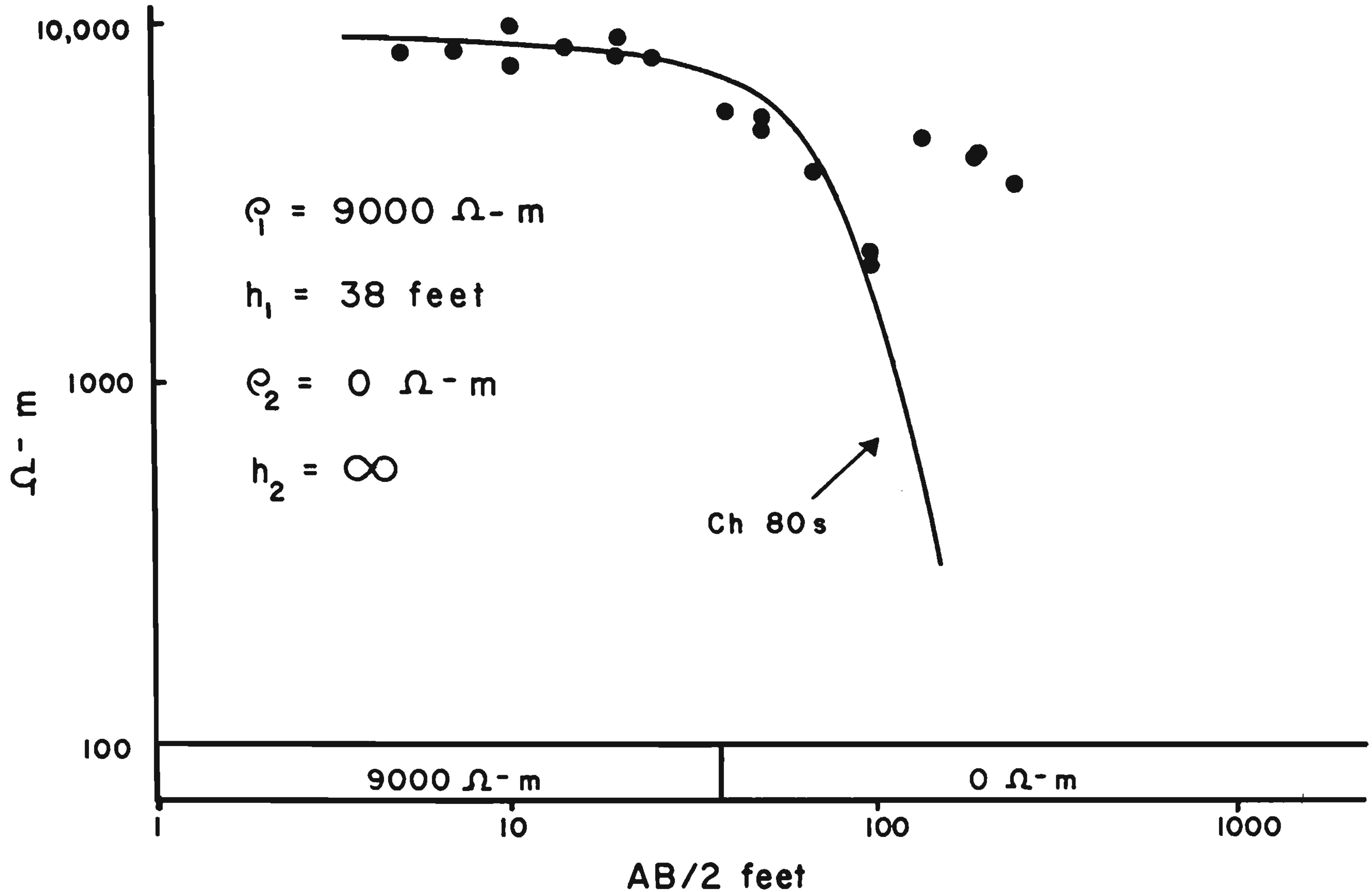

FIGURE 20. FIRST SOUNDING ON PAHOEHOE EAST OF PUNALUU.

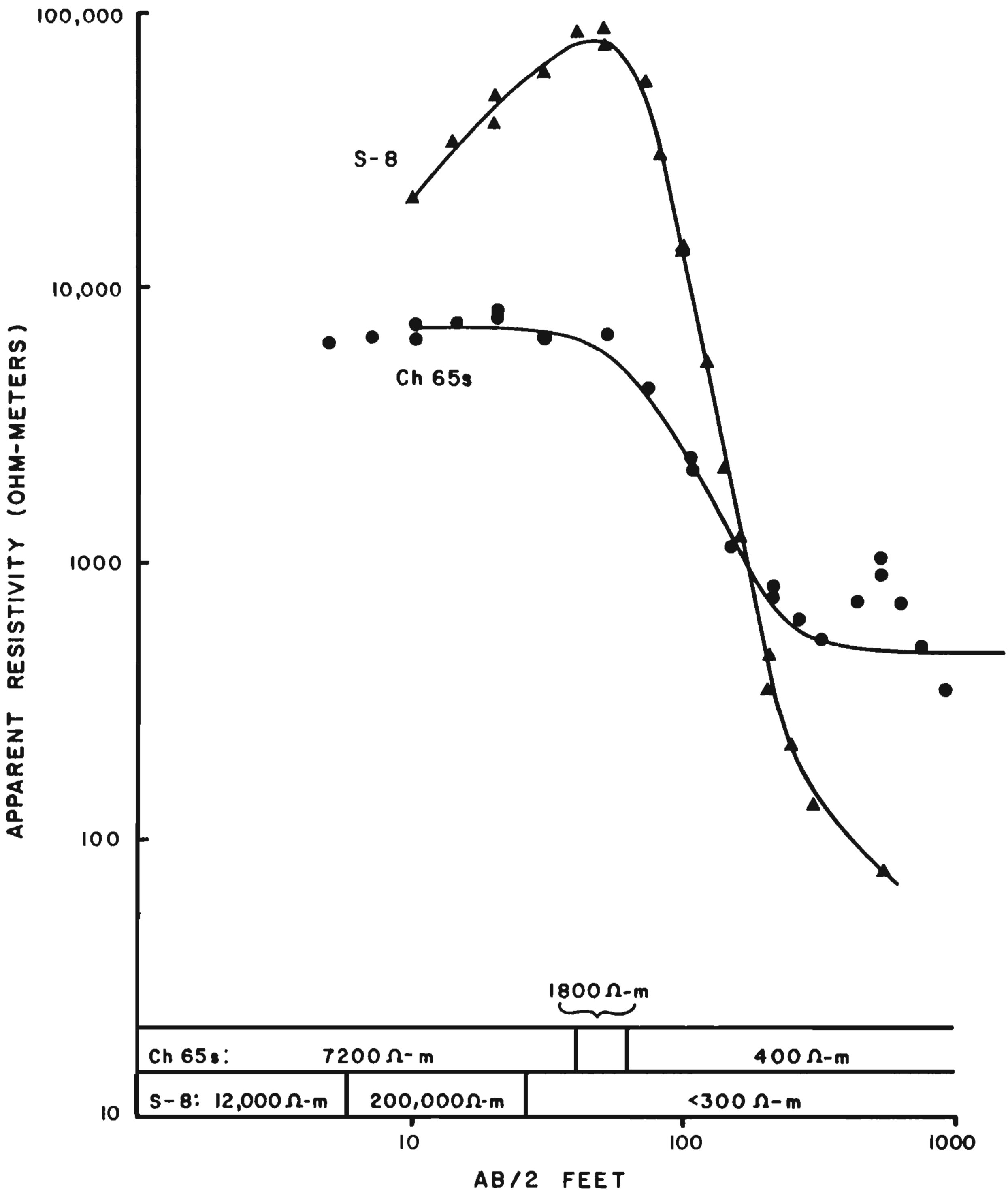

FIGURE 21. SECOND SOUNDING OF PAHOEHOE EAST OF PUNALUU. ALSO SHOWN IS SOUNDING S-8 FROM HUSSONG AND COX (1967).

data. The second interpretation is consistent with Hussong's interpretation of sounding S-8. Hence, the fresh-water head found at S-8 does extend eastward. The differences in resistivities of the second layers between this new sounding and sounding S-8 may be attributed to the differences in rainfall prior to the taking of the soundings, as mentioned in the previous section.

TABLE 6. DATA AND REDUCTION FOR SECOND SOUNDING ON PAHOEHOE EAST OF PUNALUU.

SIZE	V CHART[1)]	CHART FULL-SCALE (MV)	V (MV)	A (MA)	R Ω-M
5/1	20	250	50	0.10	6250
7/1	13	250	32.5	0.118	6770
10/1	15	250	37.5	0.275	6700
10/2	29.5	250	74	0.245	7500
14/2	48	250	120	0.76	7600
20/2	45	250	113	1.4	8100
20/4	20	250	50	0.30	8300
30/4	26	250	65	1.1	6800
50/10	51	100	51	1.10	5750
70/10	33	250	82.5	4.7	4280
100/10	32	250	80	17.5	2270
100/20	15	250	37.5	3.85	2440
140/20	30	250	75.0	30.0	1200
200/20	26	250	15	82	790
200/40	38	250	95	56.5	855
300/40	32	100	32	68	530
500/40	19	50	38	127	930
700/100	16	50	12	124	360
850/100	6	50	76	185	740
400/50	24	100	48	110	770
250/50	34	250	85	80	660

1) REFER TO TABLE 2 FOR AN EXPLANATION OF THE TABLE HEADINGS.

Note that the hump in the data curve is similar to that in Figure 20 but at a different depth. As the two soundings are at the same location, and any lateral resistivity variation is considered highly unlikely to change within four months, the humps are considered to be scatter in the data due to procedural limitations.

Pavilion Soundings. The well-known outflow of brackish water at Ninole Springs and other locations have been indicated by an infrared survey (Adams and Lepley, 1968). An electrical sounding was conducted adjacent to the Punaluu Pavilion (see Fig. 18 for location) because the infrared images of the Punaluu beach area indicated that the fresh water outflow, apparent when swimming, might be very sizable. The effect of this flux on the ground-water table should be notable. The elevation of the center of the sounding is 14.4 feet.

The data obtained during the April 1968 sounding effort are given in Table 7 and plotted on Figure 22. The curve for a second layer, three

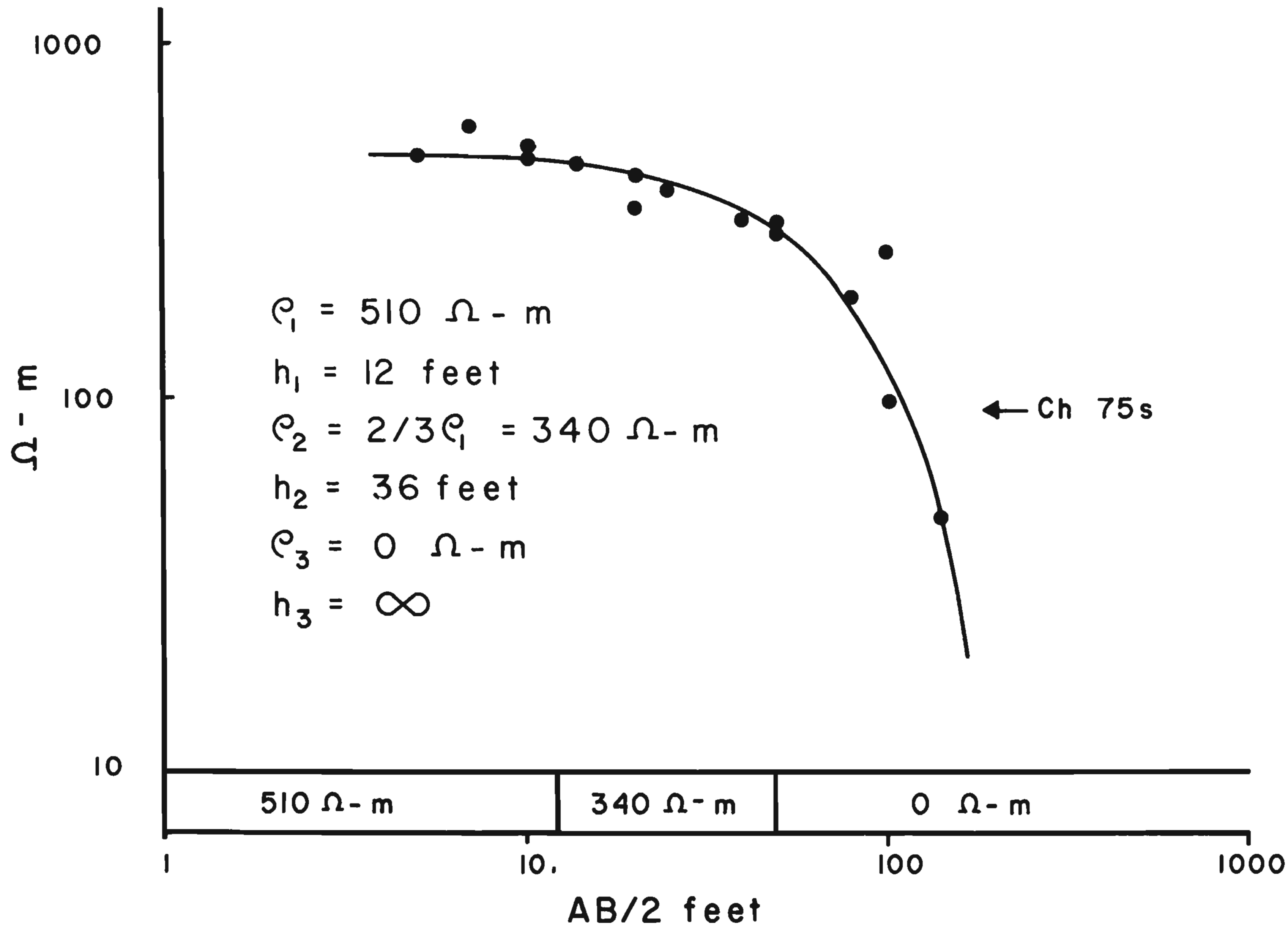

FIGURE 22. SOUNDING ADJACENT TO PUNALUU PAVILION. SCHLUMBERGER SPREAD USED.

times the thickness of the first layer, has been traced from chart 75s in the master curves (Compagnie Generale de Geophysique, 1963). Thus, at a distance of less than 100 feet from the ocean, and seaward of the beach on the right flank of Punaluu Bay, the fresh-water lens appears to be 36 feet thick, which would indicate a head of about 1 foot. Further consideration of this data and an attempt to resolve the 1-foot head difference observed at Punaluu will be made in the conclusion of this report.

TABLE 7. DATA AND REDUCTION FOR SOUNDING ADJACENT TO PUNALUU PAVILION.

SIZE	V CHART[1]	CHART FULL SCALE (MV)	V (MV)	A (MA)	R Ω-M
5/1	46	250	115	2.8	512
/1	45	250	113	4.6	612
10/1	28	250	70	7.0	500
10/2	42	250	105	5.2	522
14/2	46	250	115	12.0	490
20/2	35	250	87.5	19.7	440
20/4	42	250	105	14.3	365
25/4	40	250	100	19.4	405
30/4	39	100	97.5	11.6	956
40/4	43	250	108	63.5	340
50/4	29	250	72.5	89.5	330
70/10	32	250	80	97	205
100/10	21	100	52	90.5	280
100/20	15	250	38	91.5	102
140/20	2.9	250	7.25	76	50
ELEVATION:					

[1] REFER TO TABLE 2 FOR AN EXPLANATION OF THE TABLE HEADINGS.

GRAVITY

Introduction

The use of gravitational techniques in water resources research is restricted to locating possible barriers to lateral water movement. It is essential for the success of this method that a density contrast exist between the barrier and the matrix material. An anomalously high groundwater level observed in a sector would indicate the presence of an impermeable and possibly dense barrier between the observed sector and the coastline. Location of this barrier was the objective of the gravimetric survey.

Instrumentation

The availability of high-precision La Coste-Romberg gravimeters G19 and G93 at the Hawaii Institute of Geophysics, University of Hawaii permitted investigation of the usefulness of microsurveys[1] for detection of possible ground-water barriers in the Pahala region.

Field Surveys

PAHALA. The first site chosen was along the Old Government Road, running westward out of Pahala (see Fig. 23 for location of all 4 profiles). Although this road does not trend along the maximum topographic gradient of the terrain, it is relatively straight and only used infrequently. Therefore, it was suitable and safe for the initial field efforts.

One hundred and twenty-five stations were occupied at approximate station intervals of 50 feet. The numbering started at the intersection of the Old Government and the Belt Road (FAP 11).

PUNALUU. The second site was parallel to the Punaluu Road which runs northwest from the coastal village of Punaluu up to the Belt Road. This profile generally ran parallel to the maximum gradient of the terrain. One hundred and one stations at approximately 50-foot intervals were occupied. The numbering started approximately 300 feet from the shore, where the asphalt road begins.

PAHALA DUMP. The third site was located south of Pahala across the Pahala dump which is noted by a "crack" on topographic maps. Twenty-three stations at intervals of 100 feet were occupied beginning about 1000 feet north of the crack on Pahala dump road. The profile followed this road to the crack, then departed from it to cross the crack, and continued southward for another 1300 feet.

SE PAHALA. The last site is located southeast of Pahala along the dirt road that leads to the "Cinder Hills." Fifty-nine stations at 100-foot intervals were occupied beginning about 800 feet southeast of the feature labeled the crack.

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[1] Because the survey area of investigation is smaller than normal, the prefix "micro" has been used.

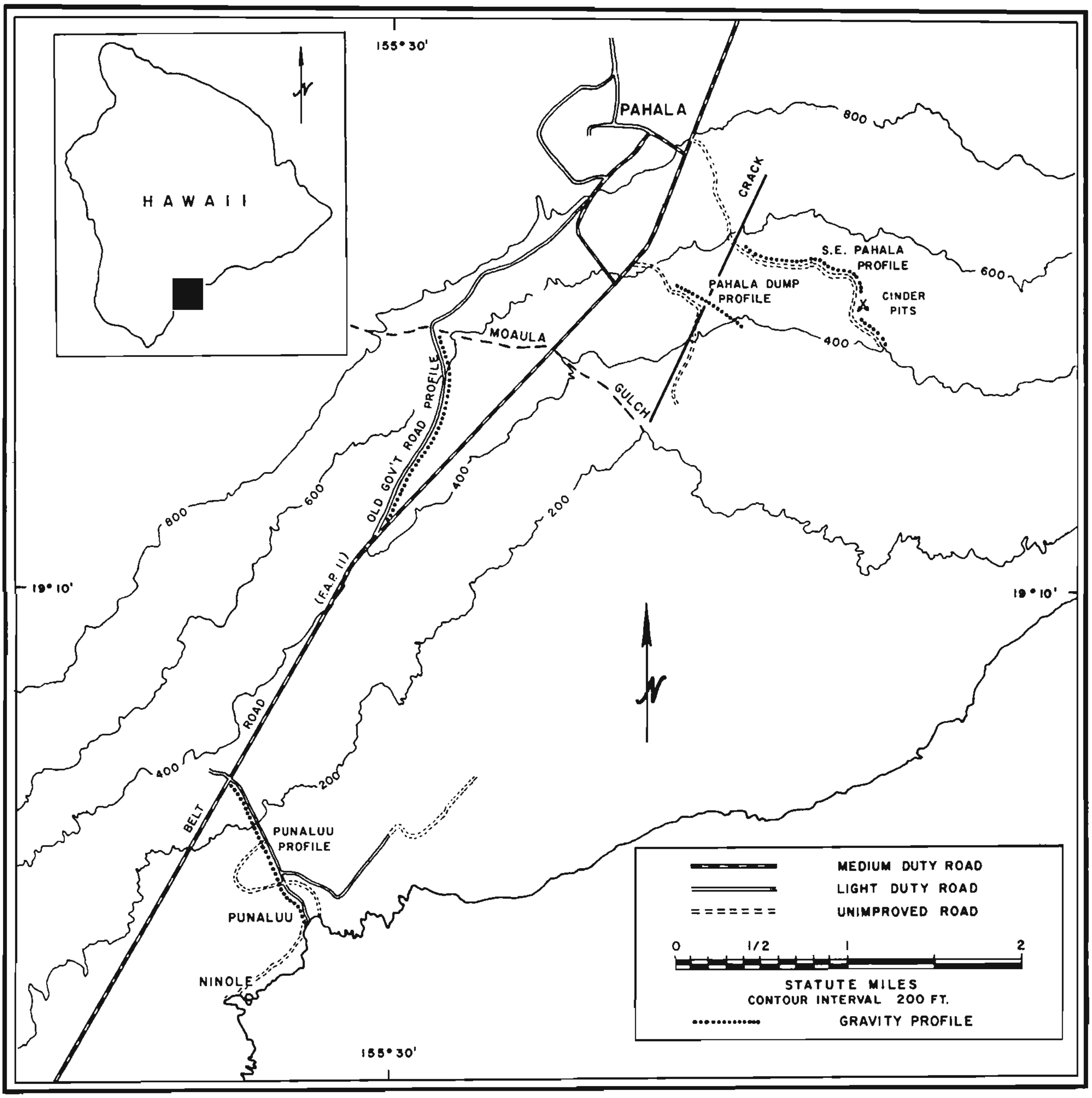

FIGURE 23. LOCATION MAP FOR GRAVITY MICRO-PROFILES IN THE PAHALA-PUNALUU AREA.

Data Reduction

Reduction of the observations for the scale unit of the gravity meter dial, and the astronomical, free air, Bouguer, topographic, and regional corrections were made. The astronomical, the free air, and the Bouguer corrections were programmed and calculated on the IBM 360 computer. The CED program (Appendix A) performed the drift and earth-tide corrections and the Density 2 program (Appendix B) did the topography and the Bouguer corrections. The topographic corrections were made by assuming a two-dimensional relationship and using a graticule developed by Hubbert (1948).

Each profile was surveyed independently, with elevations relative to one station on the profile line. Later, each profile was tied to sea-level by relating a station on each line to the nearest known bench marker.

The regional trend in this area was taken as 4.3 mgal/mile, increasing from south to north as determined from Kinoshita (1963). The Old Government Road line is oriented so that the line is parallel to a regional gravity contour and experiences no change. The regional trends are removed from the Punaluu, Pahala Dump, and the southeast Pahala lines. The trend on each of these lines was removed relative to some station on each line. The profiles for the Punaluu, Pahala, Pahala Dump, and Southeast Pahala sites are plotted in Figures 24, 25, and 26. The data are given in Tables 8, 9, 10, and 11.

Results

PUNALUU. A slight anomaly of about one milligal is observed along the Punaluu profile. The anomaly maximum extends between station 28 and 76. Assuming that this anomaly is caused by some intrusive feature, the small magnitude of the anomaly would indicate either a small density contrast between the intrusive rock and country rock or a very deep structure, or both. Using the 1/2 slope method outlined by Nettleton (1940), the estimated depth to center of mass below sea level is 2100 feet.

PAHALA. Again, this profile reveals a broad gentle sloping anomaly of

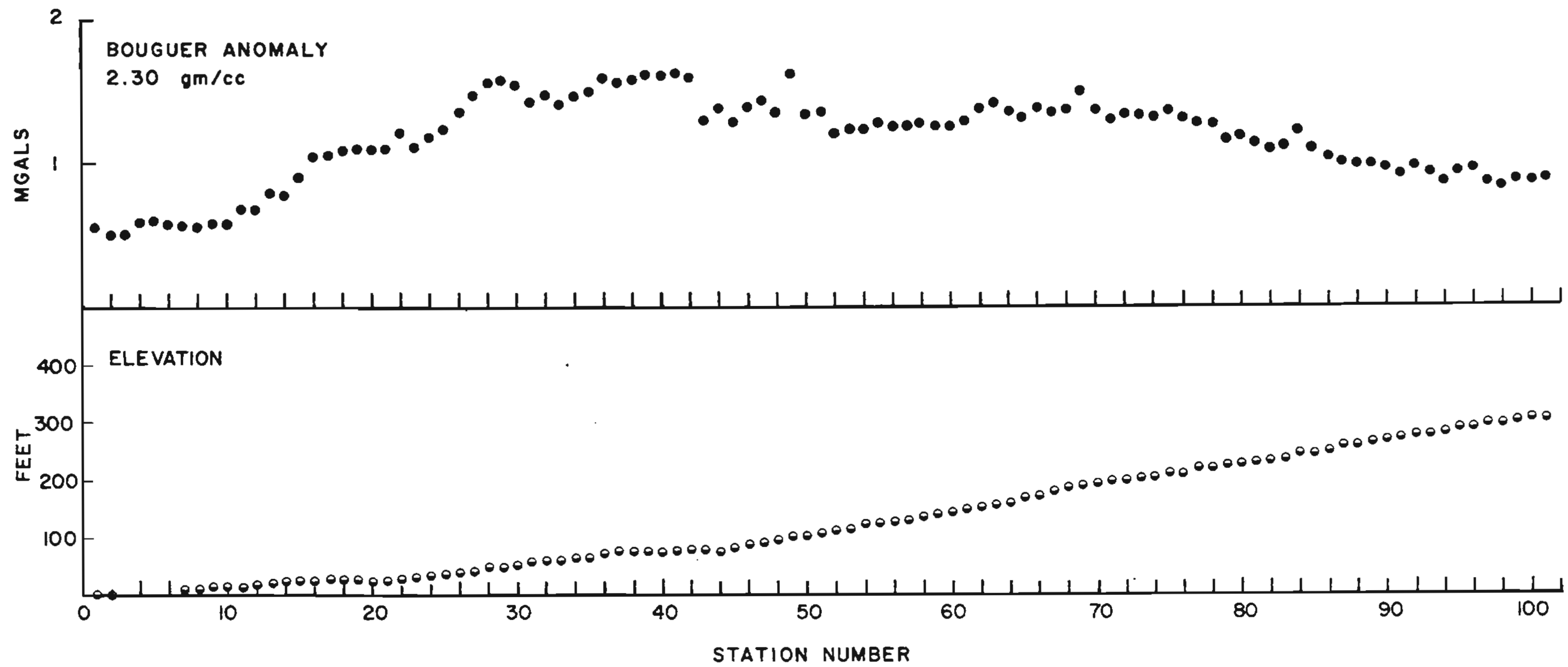

FIGURE 24. BOUGUER ANOMALY AND ELEVATION ALONG THE PUNALUU ROAD. ELEVATION IS SHOWN RELATIVE TO STATION 1.

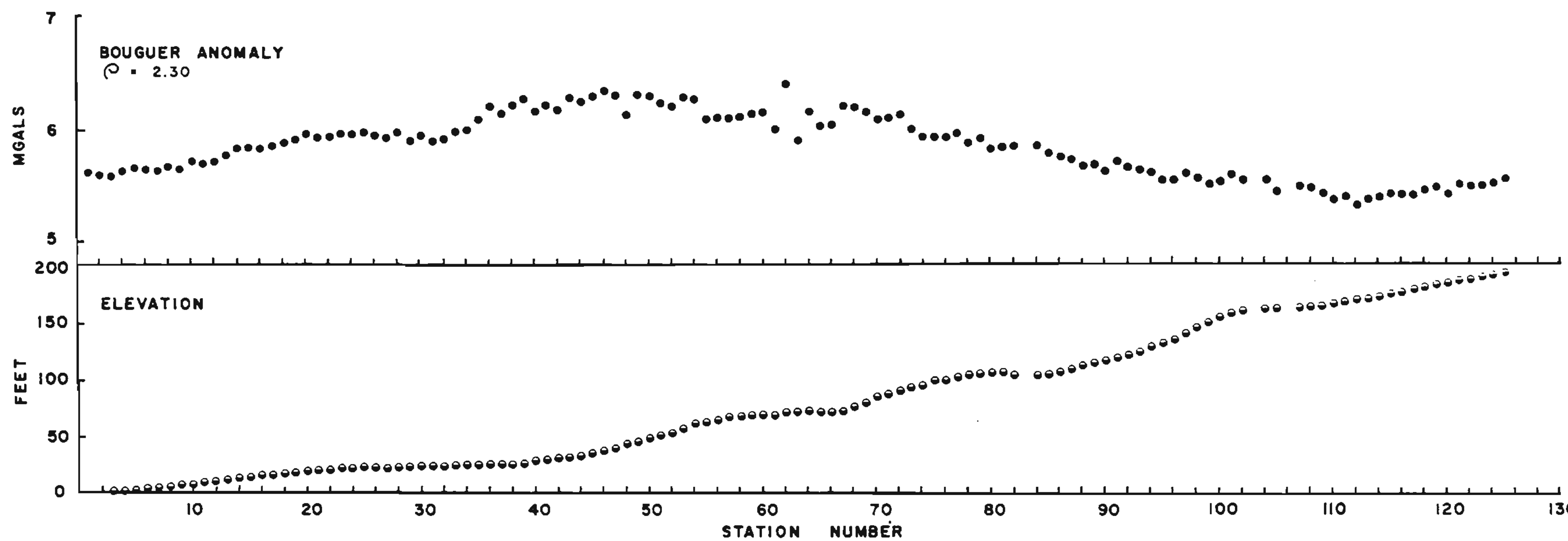

FIGURE 25. BOUGUER ANOMALY AND ELEVATION ALONG THE OLD GOVERNMENT ROAD. ELEVATION IS SHOWN RELATIVE TO STATION 1.

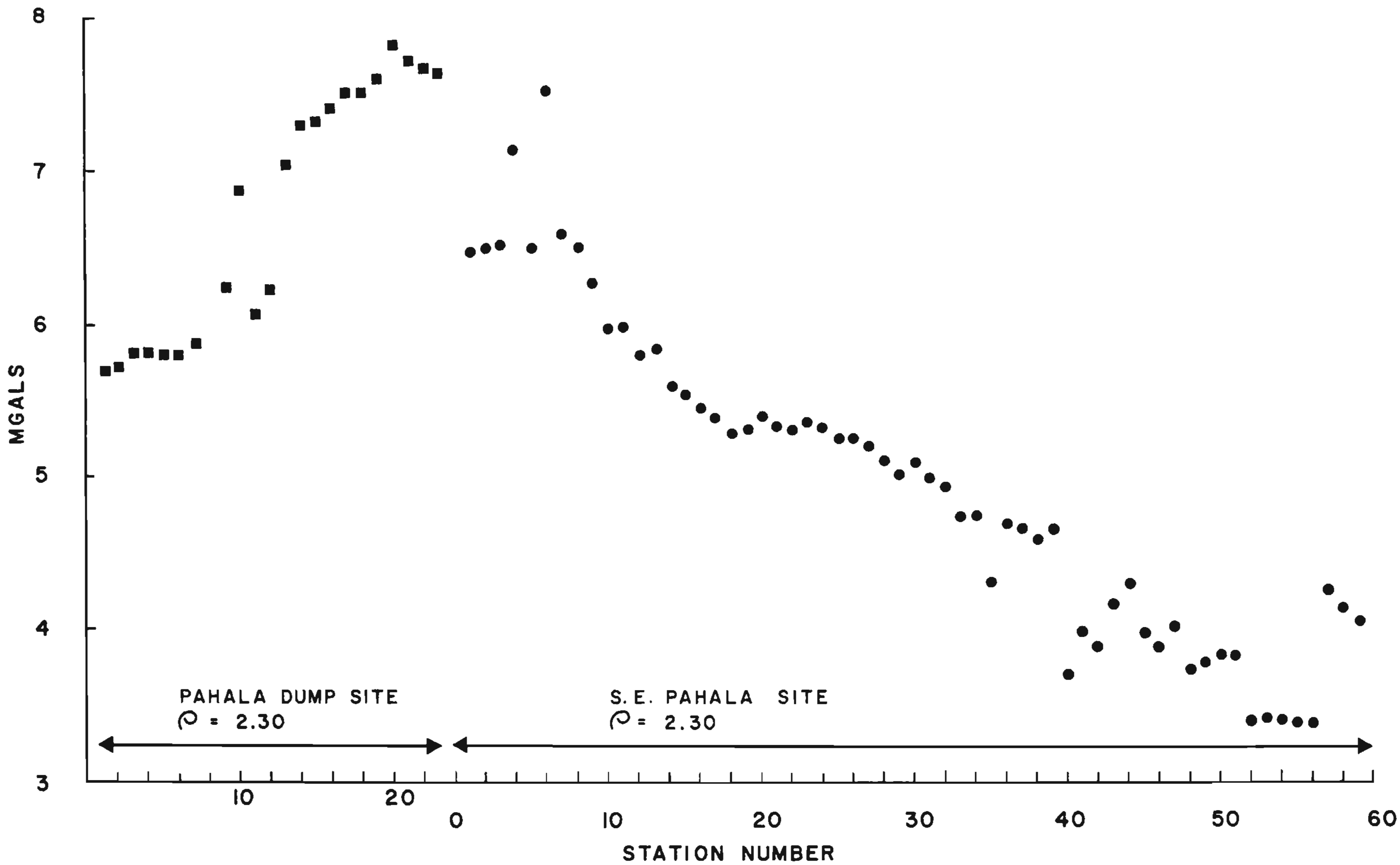

FIGURE 26. BOUGUER ANOMALY FOR THE PAHALA DUMP AND SE PAHALA PROFILES.

TABLE 8. GRAVITY SURVEY DATA FOR THE OLD GOVERNMENT ROAD.

STATION NUMBER	GRAVITY mgal	BOUGUER ANOMALY mgal	STATION NUMBER	GRAVITY mgal	BOUGUER ANOMALY mgal	STATION NUMBER	GRAVITY mgal	BOUGUER ANOMALY mgal
1	0.0	5.63	43	-1.29	6.30	85	-6.35	5.81
2	-0.07	5.61	44	-1.44	6.26	86	-6.47	5.78
3	-0.11	5.60	45	-1.51	6.31	87	-6.64	5.76
4	-0.14	5.64	46	-1.58	6.35	88	-6.87	5.70
5	-0.17	5.67	47	-1.76	6.32	89	-7.02	5.71
6	-0.24	5.66	48	-2.10	6.15	90	-7.21	5.65
7	-0.30	5.65	49	-2.09	6.33	91	-7.24	5.74
8	-0.32	5.69	50	-2.31	6.31	92	-7.51	5.69
9	-0.43	5.67	51	-2.56	6.26	93	-7.69	5.67
10	-0.45	5.73	52	-2.74	6.22	94	-7.89	5.64
11	-0.57	5.70	53	-2.87	6.30	95	-8.19	5.58
12	-0.61	5.73	54	-3.17	6.29	96	-8.44	5.59
13	-0.63	5.78	55	-3.38	6.11	97	-8.74	5.64
14	-0.66	5.84	56	-3.47	6.13	98	-9.06	5.60
15	-0.73	5.85	57	-3.61	6.12	99	-9.40	5.54
16	-0.80	5.84	58	-3.64	6.14	100	-9.69	5.57
17	-0.82	5.87	59	-3.67	6.16	101	-9.85	5.63
18	-0.84	5.90	60	-3.67	6.18	102	-10.07	5.58
19	-0.86	5.92	61	-3.85	6.02	103	---	---
20	-0.84	5.97	62	-3.91	6.12	104	-10.12	5.58
21	-0.93	5.94	63	-4.08	5.93	105	-10.25	5.48
22	-1.00	5.95	64	-3.91	6.18	106	---	---
23	-1.02	5.98	65	-3.95	6.05	107	-10.26	5.53
24	-1.05	5.97	66	-3.93	6.06	108	-10.33	5.49
25	-1.04	5.99	67	-3.84	6.23	109	-10.42	5.46
26	-1.06	5.96	68	-4.13	6.20	110	-10.56	5.40
27	-1.07	5.94	69	-4.45	6.17	111	-10.58	5.44
28	-1.03	5.99	70	-4.77	6.11	112	-10.72	5.36
29	-1.10	5.91	71	-4.94	6.13	113	-10.57	5.61
30	-1.08	5.97	72	-5.12	6.15	114	-10.68	5.62
31	-1.18	5.91	73	-5.43	6.02	115	-10.79	5.66
32	-1.17	5.94	74	-5.62	5.96	116	-10.92	5.65
33	-1.15	6.00	75	-5.78	5.96	117	-11.03	5.64
34	-1.16	6.01	76	-5.87	5.96	118	-11.08	5.69
35	-1.08	6.11	77	-5.98	5.99	119	-11.20	5.70
36	-0.96	6.22	78	-6.23	5.90	120	-11.38	5.64
37	-1.01	6.16	79	-6.28	5.90	121	-11.37	5.76
38	-0.96	6.23	80	-6.35	5.85	122	-11.49	5.71
39	-0.97	6.29	81	-6.32	5.87	123	-11.64	5.72
40	-1.17	6.18	82	-6.22	5.88	124	-11.72	5.74
41	-1.23	6.23	83	---	---	125	-11.80	5.78
42	-1.35	6.19	84	-6.21	5.89			

TABLE 9. GRAVITY SURVEY DATA ON PUNALUU ROAD.

STATION NUMBER	GRAVITY mgal	BOUGUER ANOMALY/mgal WITH REGIONAL	WITHOUT REGIONAL	STATION NUMBER	GRAVITY mgal	BOUGUER ANOMALY/mgal WITH REGIONAL	WITHOUT REGIONAL
1	0.0	0.56	0.56	52	-5.48	2.60	1.20
2	-0.10	0.51	0.49	53	-5.69	2.66	1.23
3	-0.05	0.56	0.51	54	-5.93	2.70	1.23
4	0.06	0.68	0.59	55	-6.13	2.77	1.27
5	0.05	0.72	0.59	56	-6.39	2.78	1.25
6	-0.02	0.74	0.58	57	-6.60	2.82	1.25
7	-0.20	0.76	0.57	58	-6.78	2.78	1.28
8	-0.44	0.79	0.56	59	-7.02	2.89	1.26
9	0.67	0.85	0.58	60	-7.25	2.91	1.25
10	-0.83	0.89	0.58	61	-7.46	2.98	1.29
11	-0.77	1.00	0.68	62	-7.64	3.11	1.38
12	-0.88	1.02	0.68	63	-7.89	3.18	1.41
13	-0.89	1.14	0.78	64	-8.26	3.15	1.35
14	-0.98	1.16	0.77	65	-8.60	3.14	1.31
15	-0.85	1.28	0.89	66	-8.83	3.24	1.38
16	-0.70	1.43	1.04	67	-9.19	3.24	1.34
17	-0.70	1.46	1.05	68	-9.51	3.30	1.37
18	-0.72	1.49	1.08	69	-9.66	3.45	0.49
19	-0.74	1.51	1.09	70	-10.02	3.36	1.37
20	-0.72	1.52	1.09	71	-10.25	3.34	1.31
21	-0.79	1.52	1.09	72	-10.40	3.39	1.34
22	-0.71	1.64	1.20	73	-10.59	3.43	1.34
23	-1.03	1.57	1.11	74	-10.81	3.43	1.31
24	-1.09	1.66	1.18	75	-10.94	3.52	1.37
25	-1.24	1.74	1.23	76	-11.17	3.49	1.31
26	-1.34	1.89	1.35	77	-11.37	3.50	1.28
27	-1.40	2.04	1.47	78	-11.49	3.53	1.28
28	-1.48	2.14	1.55	79	-11.69	3.46	1.17
29	-1.65	2.18	1.56	80	-11.75	3.51	1.19
30	-1.84	2.18	1.53	81	-11.90	3.49	1.14
31	-2.18	2.10	1.42	82	-12.10	3.49	1,10
32	-2.30	2.19	1.47	83	-12.32	3.54	1.12
33	-2.50	2.15	1.41	84	-12.61	3.68	1.23
34	-2.59	2.24	1.46	85	-12.91	3.58	1.10
35	-2.73	2.30	1.49	86	-13.26	3.56	1.04
36	-2.81	2.44	1.59	87	-13.58	3.57	1.02
37	-3.00	2.43	1.55	88	-13.90	3.57	0.99
38	-3.03	2.51	1.58	89	-14.19	3.60	0.99
39	-3.04	2.57	1.61	90	-14.46	3.60	0.96
40	-3.04	2.61	1.61	91	-14.71	3.60	0.92
41	03.07	2.65	1.62	92	-14.87	3.69	0.97
42	-3.14	2.67	1.60	93	-15.13	3.68	0.93
43	-3.51	2.40	1.30	94	-15.44	3.66	0.87
44	-3.50	2.52	1.38	95	-15.67	3.77	0.94
45	-3.78	2.46	1.29	96	-15.80	3.81	0.96
46	-3.96	2.59	1.38	97	-16.10	3.74	0.86
47	-4.15	2.67	1.44	98	-16.33	3.73	0.83
48	-4.46	2.62	1.35	99	-16.54	3.81	0.89
49	-4.68	2.92	1.62	100	-16.78	3.82	0.88
50	-4.92	2.67	1.34	101	-16.92	3.86	0.89
51	-5.14	2.72	1.35				

TABLE 10. GRAVITY SURVEY DATA ON PAHALA DUMP.

STATION NUMBER	GRAVITY MGAL	BOUGUER ANOMALY/MGAL WITH REGIONAL	WITHOUT REGIONAL
1	-26.78	5.71	5.71
2	-26.39	5.70	5.73
3	-25.86	5.76	5.83
4	-25.43	5.75	5.84
5	-25.03	5.70	5.82
6	-25.38	5.65	5.82
7	-23.76	5.72	5.89
8	-23.45	5.05	5.21
9	-23.23	6.08	6.26
10	-24.00	6.71	6.89
11	-23.62	5.88	6.07
12	-22.34	6.03	6.25
13	-22.76	6.75	7.05
14	-21.93	6.94	7.31
15	-21.83	6.88	7.33
16	-21.20	6.91	7.42
17	-20.67	6.94	7.52
18	-20.19	6.87	7.52
19	-19.71	6.90	7.61
20	-19.20	7.05	7.83
21	-19.12	6.87	7.71
22	-18.77	6.83	7.67
23	-18.39	6.77	7.63

TABLE 11. GRAVITY SURVEY DATA ON SOUTHEAST PAHALA.

STATION NUMBER	GRAVITY MGAL	BOUGUER ANOMALY|MGAL WITH REGIONAL	WITHOUT REGIONAL
1	-30.04	6.46	6.46
2	-29.41	6.43	6.48
3	-28.74	6.42	6.50
4	-27.09	7.02	7.12
5	-26.90	6.40	6.48
6	-25.45	7.44	7.52
7	-26.08	6.49	6.57
8	-25.86	6.40	6.48
9	-26.21	6.19	6.24
10	-26.68	5.94	5.96
11	-26.81	5.95	5.96
12	-27.21	5.80	5.79
13	-27.36	5.86	5.83
14	-27.43	5.63	5.57
15	-27.44	5.62	5.52
16	-27.50	5.54	5.43
17	-27.66	5.48	5.37
18	-27.62	5.41	5.27
19	-27.62	5.44	5.28
20	-27.64	5.50	5.38
21	-27.31	5.40	5.31
22	-27.25	5.30	5.28
23	-27.06	5.29	5.33
24	-26.73	5.19	5.30
25	-26.98	5.04	5.22
26	-27.04	5.01	5.22
27	-27.44	4.90	5.15
28	-27.69	4.83	5.07
29	-27.97	4.78	4.98
30	-27.99	4.88	5.05
31	-28.08	4.79	4.97
32	-27.98	4.71	4.90
33	-28.34	4.47	4.69
34	-28.17	4.41	4.71
35	-27.98	3.39	4.31
36	-26.99	4.20	4.65
37	-25.76	4.07	4.61
38	-25.16	3.93	4.54
39	-24.97	3.91	4.60
40	-25.94	2.94	3.71
41	-25.81	3.13	3.98
42	-25.56	2.97	3.90
43	-24.78	3.15	4.17
44	-24.20	3.22	4.31
45	-23.70	2.72	3.97
46	-23.31	2.59	3.89
47	-22.78	2.69	4.03
48	-23.07	2.38	3.73
49	-22.97	2.41	3.79
50	-22.95	2.39	3.84
51	-23.09	2.35	3.82
52	-23.31	1.92	3.41
53	-23.20	1.91	3.42
54	-23.37	1.87	3.41
55	-23.52	1.79	3.39
56	-23.21	1.75	3.39
57	-23.19	2.56	4.26
58	-23.25	2.41	4.14
59	-23.40	2.32	4.05

approximately one milligal amplitude. The high in this case is centered near station 56. As in the Punaluu anomaly, the intrusive body either has a small density contrast or is deep-seated, or both. Using the same method mentioned before, the estimated depth to the center of mass of the anomaly is 1400 feet below sea-level.

PAHALA DUMP SITE. The profile at the dump site is shaped differently from the others. It appears that only 1/2 of the anomaly was traversed when this profile stopped. The unusual change in density of points at station 10 is attributed to the inability of the terrain correction to adequately correct for the gully at the Dump.

SE PAHALA SITE. This profile appears to be the other half of the Dump anomaly. From the location map it can be seen that these profiles are displaced about 2000 feet northwest-southeast along the "Dump Crack." When these two profiles are combined, an anomaly of several milligal-amplitude just southwest of the dump feature is revealed. The depth to center of mass below sea-level is about the same magnitude as observed on the Pahala and Punaluu profiles (1800 feet).

SURFACE EXPLORATION

The indications of possible ground-water barriers from the aeromagnetics, electrical resistivity soundings, the gravity microsurveys, and the electrical resistivity profiling prompted a surface exploration for some expression of these possible barriers. The best exposure of the rocks occurs in the gullies through the area. A section of Moaula Gulch (shown in Fig. 23 as the broken line) was walked out in an attempt to visually locate any intrusive material having a dominantly vertical orientation, such as that anticipated for a dike. Exposure above the Belt Road was extremely good--with about 80 percent of the rock estimated to be *in situ*. Below the Belt Road, it is estimated that less than 20 percent of the rock was *in situ*. There was, however, no evidence of dikes.

CONCLUSIONS

The area under consideration will be separated into two parts and each discussed separately. The area is divided into the Pahala sector, north of the 19° 10' paralle, and the Punaluu sector, south of the 19° 10' parallel (see Fig. 27).

The locations of all geophysical work discussed in this section of the report are shown in Figure 27.

Pahala Section

The Kolea barrier was described in the Electrical Resistivity section (p. 10) and shown in Figure 28. This barrier, transcribed to the aeromagnetic map (Fig. 28) extends seaward, corresponding with the high magnetic gradient located above M. However, this feature has no magnetic expression near Pahala, for unknown reasons.

The high ground-water head observed at the Pahala well is partly explained by the Kolea barrier. If the ground water flowed seaward parallel to the Kolea barrier, outflow into the ocean would occur along the coast north of the barrier. But no infrared anomalies are observed in this area. Therefore, another barrier preventing flow along the Kolea barrier must exist. The complicated geologic structure reflected by the magnetics in the area may be responsible for blocking the flow. But closer to Pahala is a surface feature known as the "crack," which Stearns and Macdonald (1946) labeled an extensive vent. Located southeast of Pahala, the crack is used as a dump, hence, the feature has been referred to as the Pahala dump barrier. This feature does have some geophysical expression. A slight resistivity anomaly, reported here, occurs at the dump and the gravity survey, corresponding with the resistivity profile, revealed the center of the anomaly to be about 700 feet southeast of the Pahala dump. The Pahala dump barrier appears to be the nearest structure to Pahala that intersects the Kolea barrier and may act as a hydrologic barrier. The geophysical evidence presented indicates that the Pahala dump barrier actually is terminated by the Kolea barrier.

The prismatic body located below the Kolea barrier in Figure 28 has no geophysical expression other than magnetics. Its relationship to the ground-water condition in that area is not known.

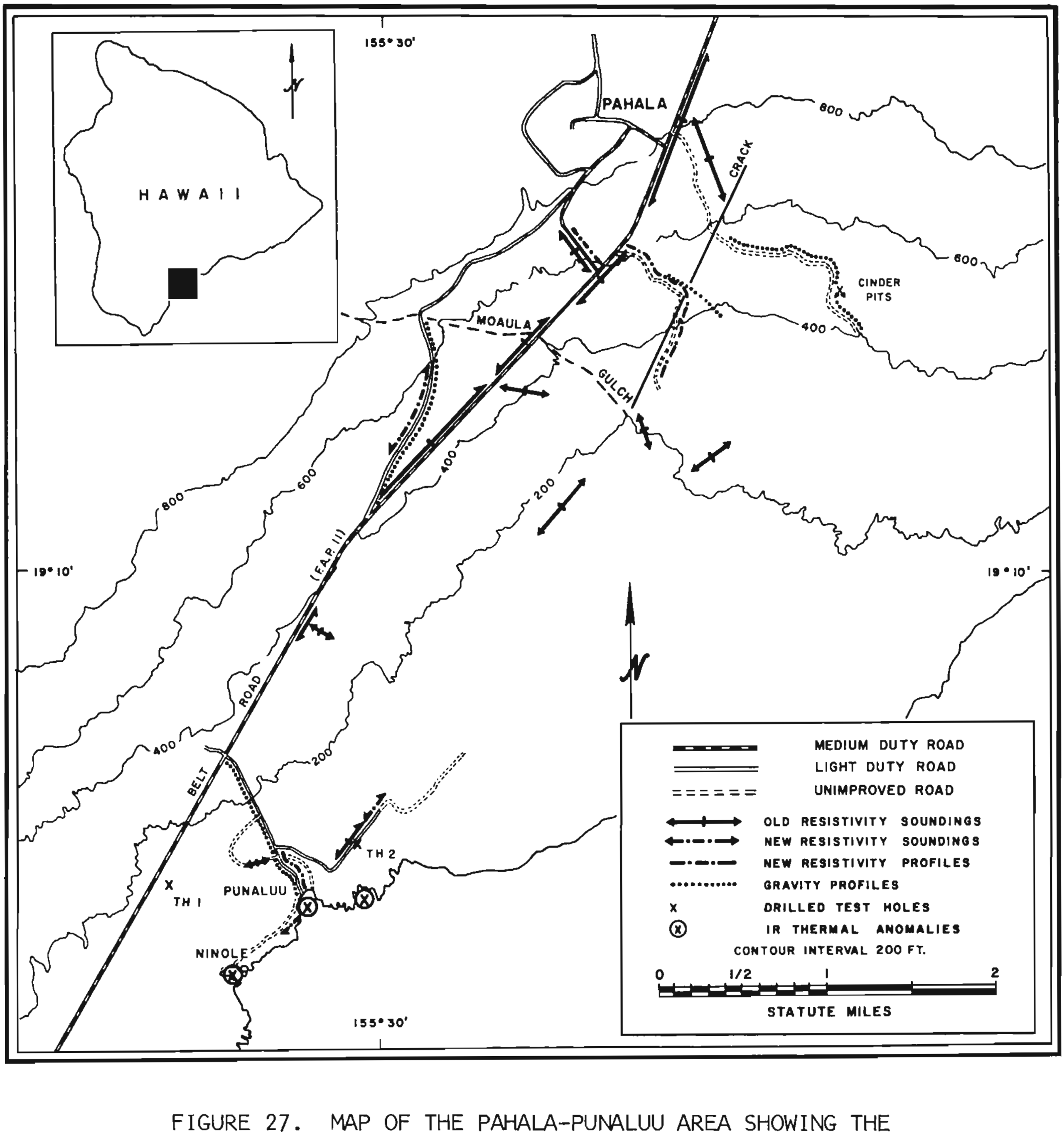

FIGURE 27. MAP OF THE PAHALA-PUNALUU AREA SHOWING THE LOCATION OF ALL THE SURVEYS REPORTED HERE.

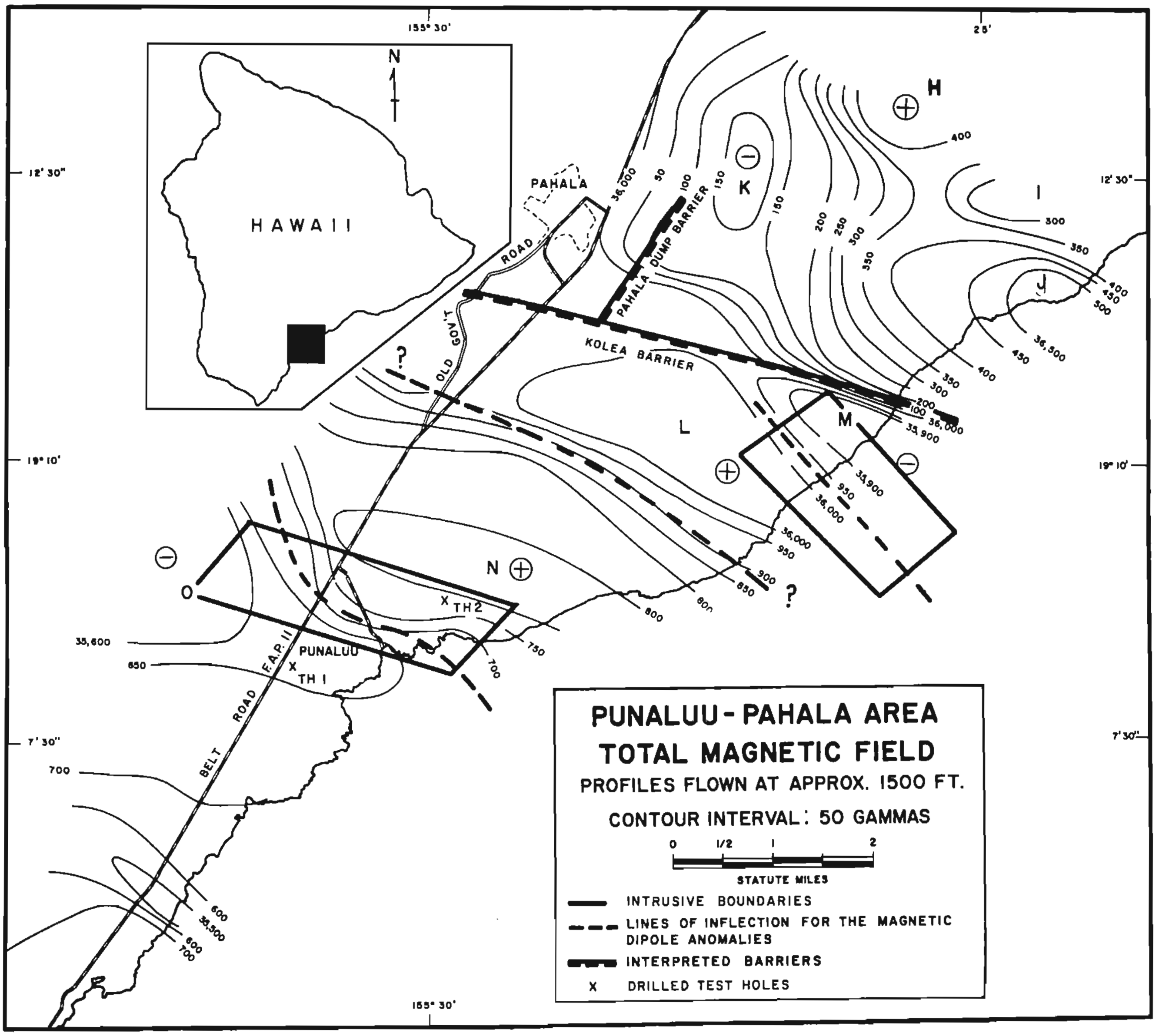

FIGURE 28. MAP OF THE PAHALA-PUNALUU AREA SHOWING THE GEOPHYSICAL FEATURES INTERPRETED FOOM THE SURVEYS REPORTED HERE.

Punaluu Section

The interpretation of the magnetic anomaly at Punaluu reveals the presence of the anomalous body sketched in Figure 28. Depth estimated from the magnetic anomaly place the top of the body near the ground surface. The gravity survey conducted along the Punaluu road reveals a one milligal anomaly whose center corresponds with the intersection of the line of inflection (dashed line in Fig. 28) of the magnetic dipole and the Punaluu road. The small amplitude of this anomaly may be understood if it is noticed that the entire gravity survey is confined to the top of the intrusive body. As a result only very small density contrasts exist and are observed. Such a density contrast may be due to the cooling and solidifying of an intrusive body causing the anomaly beginning at its extremities and advancing toward the center. The result is a slightly denser interior. Since the magnetics indicate that the top of the body is near the surface, the small gravity anomaly may be attributed entirely to a small density contrast.

Two holes were drilled in this area. One of these holes lies within the boundaries of the skewed body and the other lies outside the boundaries. The location of these holes are plotted in Figure 27. Hole 1 (TH1) lies outside the boundaries and the other (TH2) lies within the boundaries. Peterson (1969) has evaluated the ground water potential of these test holes. His analysis of the cores shows that TH1 is located in very porous rock and TH2 is located in a very massive, dense rock, probably a ponded basalt, not a dike. These facts are not contradictory to the gravity and magnetic interpretations.

The interpretation of the resistivity anomalies discussed earlier in the "Punaluu Sector" is more plausible when the above anomalous body is considered. The dense nature of the Punaluu anomalous body makes it impermeable. It reduces the salt-water intrusion in the area and increases the thickness of the basal water lens. Because of its location near the surface, ground water flowing toward the coast would flow around or up and over it. The effect of the diverted flow would be a flat water table behind the impermeable body and increased ground-water flow around it. The head, as indicated by sounding S-13, the Punaluu resistivity profiling, and the Punaluu Pavilion sounding show a decrease of one foot.

This decrease would be expected because more shoreline is exposed to the ocean near the Pavilion than at the head of the Bay.

The thermal infrared anomaly and the successful test hole in the vicinity of Ninole Springs also support the theory of the lateral flow of water around the Punaluu impermeable body.

The moderate magnetic gradient above Punaluu is probably part of the regional magnetic field in this area. The gravity anomaly along the Old Government Road correlates with the line of inflection of the moderate magnetic gradient. The existence of such a zone would also explain the difficulty encountered in correlating the electrical sounding on the Old Government Road with site S-5 of Hussong.

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Programming was done by R. Araki; Dr. G. Mcdonald discussed some geological aspects of the lineament; Drs. F. Peterson and D. Cox read the manuscript; however, the authors are solely responsible for the opinions expressed.

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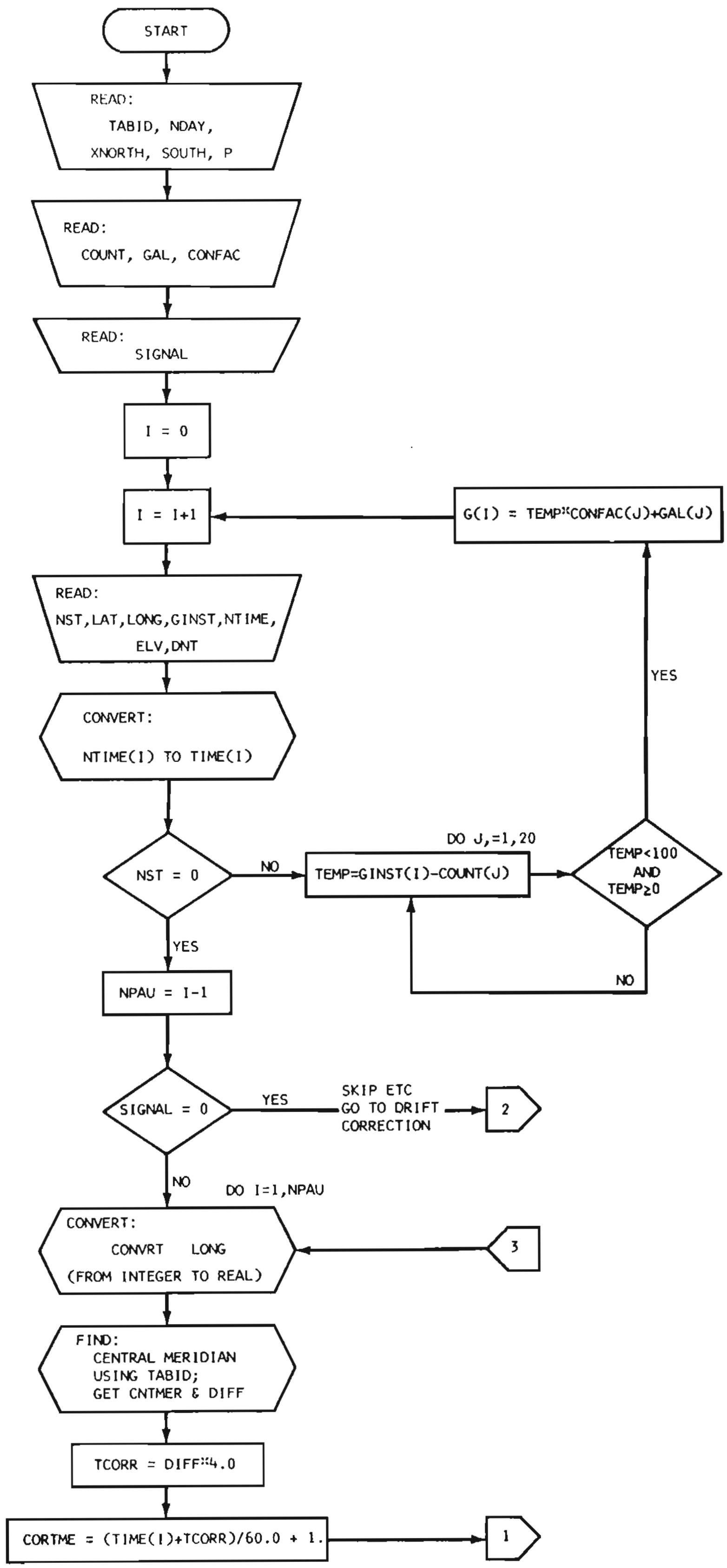
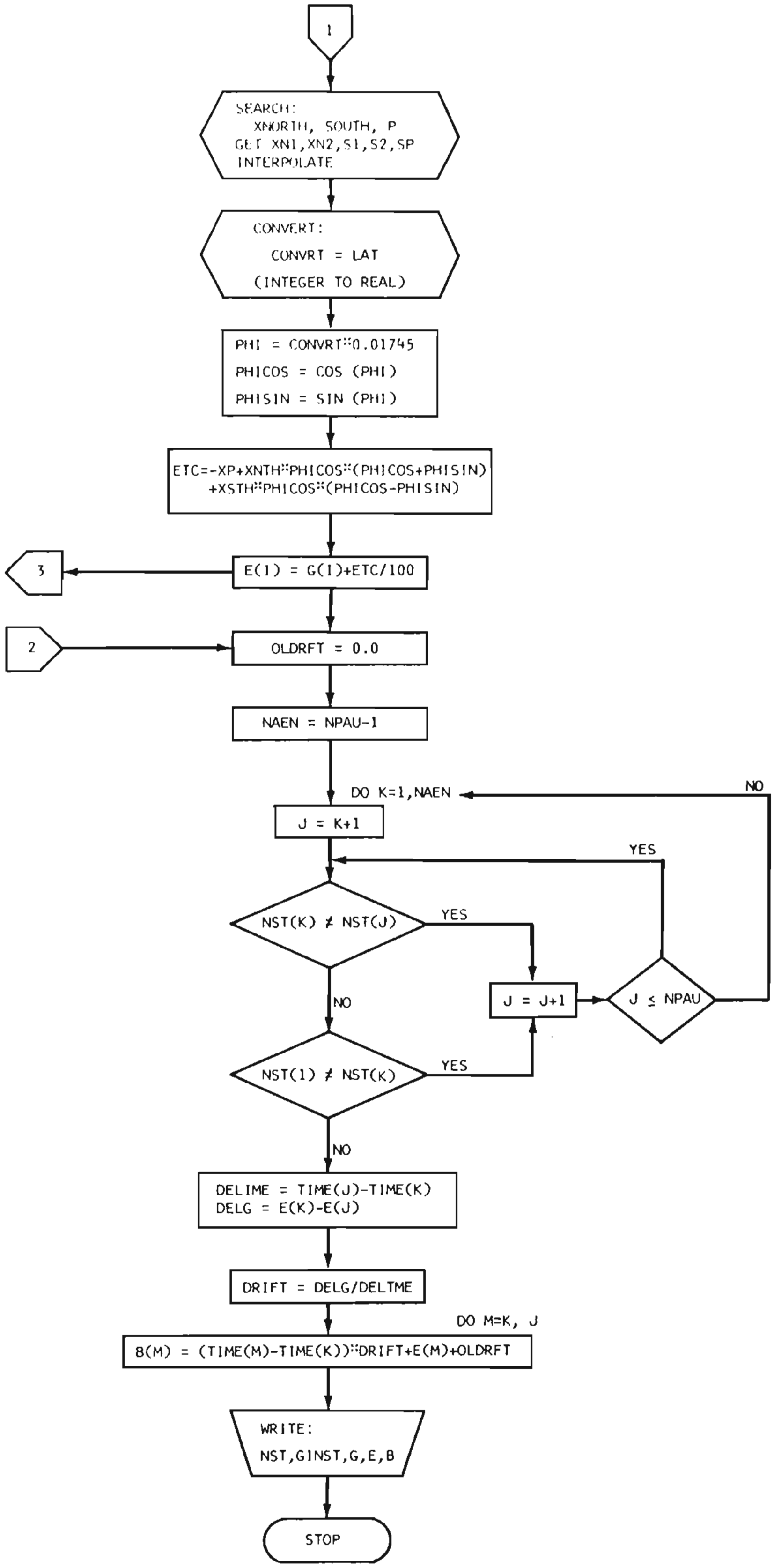
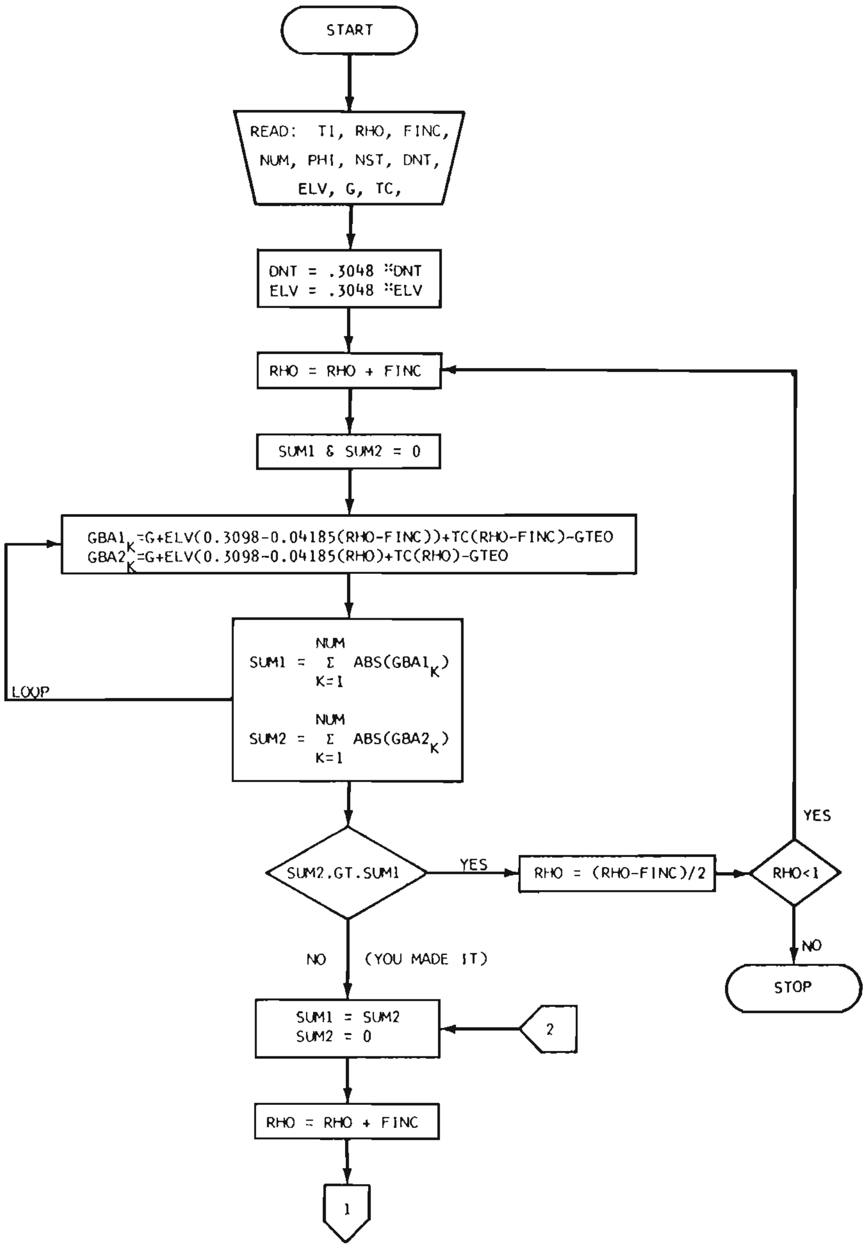
APPENDICES: FLOW CHARTS

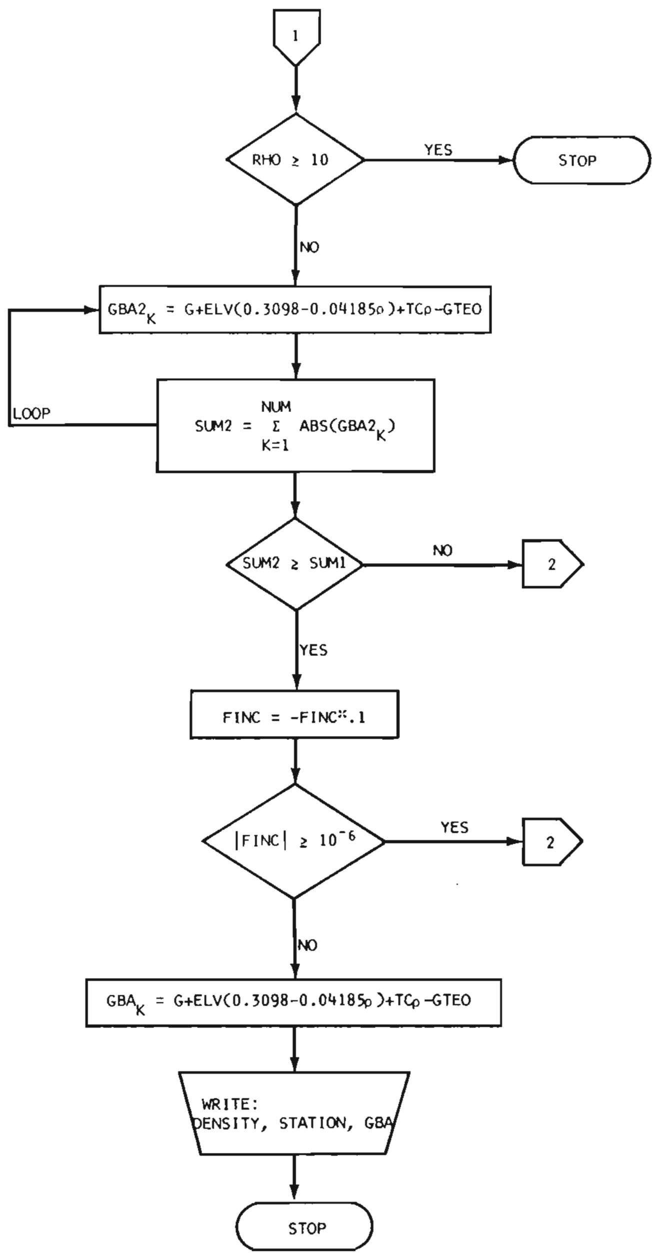
APPENDIX A. CORRECTION FOR EARTHTIDE AND DRIFT (CED)




1
SEARCH:
XNORTH, SOUTH, P
GET XN1,XN2,S1,S2,SP
INTERPOLATE
CONVERT:
CONVRT = LAT
(INTEGER TO REAL)
PHI = CONVRT*0.01745
PHICOS = COS (PHI)
PHISIN = SIN (PHI)
ETC=-XP+XNTH*PHICOS*(PHICOS+PHISIN)
+XSTH*PHICOS*(PHICOS-PHISIN)
3
E(I) = G(I)+ETC/100
2
OLDRFT = 0.0
NAEN = NPAU-1
DO K=1,NAEN
NO
J = K+1
YES
NST(K) ≠ NST(J)
YES
NO
J = J+1
J ≤ NPAU
NST(1) ≠ NST(K)
YES
NO
DELIME = TIME(J)-TIME(K)
DELG = E(K)-E(J)
DRIFT = DELG/DELTME
DO M=K, J
B(M) = (TIME(M)-TIME(K))*DRIFT+E(M)+OLDRFT
WRITE:
NST,GINST,G,E,B
STOP

APPENDIX B. DENSITY 2





1
RHO ≥ 10
YES
STOP
NO
GBA2K = G+ELV(0.3098-0.04185ρ)+TCρ-GTEO
LOOP
SUM2 = Σ ABS(GBA2K) NUM K=1
SUM2 ≥ SUM1
NO
2
YES
FINC = -FINC*.1
|FINC| ≥ 10-6
YES
2
NO
GBAK = G+ELV(0.3098-0.04185ρ)+TCρ-GTEO
WRITE: DENSITY, STATION, GBA
STOP