UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# An Evaluation of Ground Water Resources in Kailua-Kona, Hawai'i Using Electric Geophysical Measurements

by

Jim Kauahikaua
U.S. Geological Survey
Honolulu, Hawai'i

Kiyoshi Takasaki
U.S. Geological Survey
Honolulu, Hawai'i

and

Dallas B. Jackson
U.S. Geological Survey
Hawaiian Volcano Observatory
Hawaii National Park, Hawai'i

Open-File Report 85-33

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. The use of trade names is solely for descriptive purposes and does not imply endorsement by the Geological Survey.

1985

## ABSTRACT

The ground water resources of the Kailua-Kona area have been evaluated from available hydrogeologic and new electrical geophysical survey information. Available geologic mapping and results of drilled wells suggest that a large area south of Keauhou has lower-than-normal permeability. Electromagnetic loop-loop and Very Low Frequency (VLF) profiling along with Direct Current Schlumberger sounding confirm that a thicker-than-normal freshwater lens exists south of Keauhou and that this area deserves further exploration.

## INTRODUCTION

The goal of this report is to evaluate the ground water resources along the Kailua-Kona coast from Keahole Pt. south to the North Kona/South Kona district boundary and from the coast to an elevation of 305 m. The town of Kailua-Kona is located on the west slopes of Hualalai and Mauna Loa volcanoes and is the main population center and resort on the west side of the island of Hawai'i. The study described in this report was undertaken on behalf of the Hawaii County Department of Water Supply who wanted information that could be used to recommend sites for new ground water wells. The wells are needed to provide new water supplies for additional development in the Kailua-Kona area.

Some information was already available from wells drilled in the area and prior geologic studies (e.g., Davis and Yamanaga, 1968). Additional information was obtained by using electrical geophysical techniques. These techniques utilized the fact that electrical properties of a rock can vary considerably depending on the salinity of the pore fluid. Subsurface electrical properties determined by surface geophysical techniques can be interpreted in terms of subsurface ground water conditions.

## HYDROGEOLOGY

Along the west coast of the island of Hawai'i, fresh ground water can be found in a wedge-shaped body or reservoir floating upon saltwater; such a body is commonly called a freshwater basal lens. The freshwater body is thinnest at the coast and becomes progressively thicker inland. Immediately beneath the freshwater, there is the transition zone in which the salinity is transitional grading from freshwater to saltwater with increasing depth. Beneath the transition zone, rocks are completely saturated with saltwater, the salinity of which is approximately that of seawater.

Wells drilled within a distance of 3.2 km (2 miles) inland of the Kona coast tap basal aquifers consisting of highly permeable lava flows. The aquifers yield water readily to these coastal wells with little drawdown. Water levels are low, generally less than .6 m (2 ft) above sea level, and fluctuation of the water levels due to ocean tides is large (reflecting high permeability). The chloride content of the water in these wells generally exceeds 500 mg/l.

The Department-of-Water-Supply wells in the Keauhou area (wells 12-5 and 12-6 in Figure 1) are quite different than the typical Kona coastal wells described above. Water levels in the Keauhou wells stand at least two times higher, 1.2 m (4 ft) against .6 m (2 ft), and the water in them is more than 15-fold better in quality (30 mg/l against 500 mg/l). The aquifer yields water readily to wells but with a drawdown at least 5 times greater than other Kona wells. Fluctuation of the water levels due to ocean tides is very small.

To see if rainfall differences along the coast could explain the ground water anomaly in the Keauhou area, the rainfall between the 40-inch contour on the inland side and the 50-inch contour on the ocean side of the Kona rainfall high (Figure 1) was integrated in 1.6 km (1 mile) wide sections perpendicular to the coast (Dan Lum, Hawaii State Department of Land and Natural Resources, written communication, 1974). A generalization correlating rainfall input with ground water quality can be made for much of the Kona coast but rainfall per se does not satisfactorily explain the anomaly that exists near Keauhou.

The anomalous conditions at the Keauhou wells (higher water levels, higher pumping drawdowns, and small tidal fluctuations) strongly suggest locally lower-than-normal permeability of the aquifer. The low permeability might be the result of lava flows which were slowed or perhaps ponded between the volcanoes of Hualalai and Mauna Loa (Figure 2) thus becoming more massive and less porous by losing most of their dissolved gases before they cooled. Applying this hypothesis, Figure 2 shows the area where the southern flank of Hualalai and the northwest flank of Mauna Loa meet near Keauhou; the light contours represent the present shape of the ground surface and the dark dashed contours represent the hypothetical ground shapes of each of the volcanoes presuming the other did not exist. The hypothetical contours intersect along the line of contact of the two lavas mapped by Stearns and Macdonald (1946), suggesting that the interfingering of the lavas extends into the subsurface near this contact.

The restriction to flow caused ponding and thickening of the lavas which resulted in reduction of clinkers and voids thus

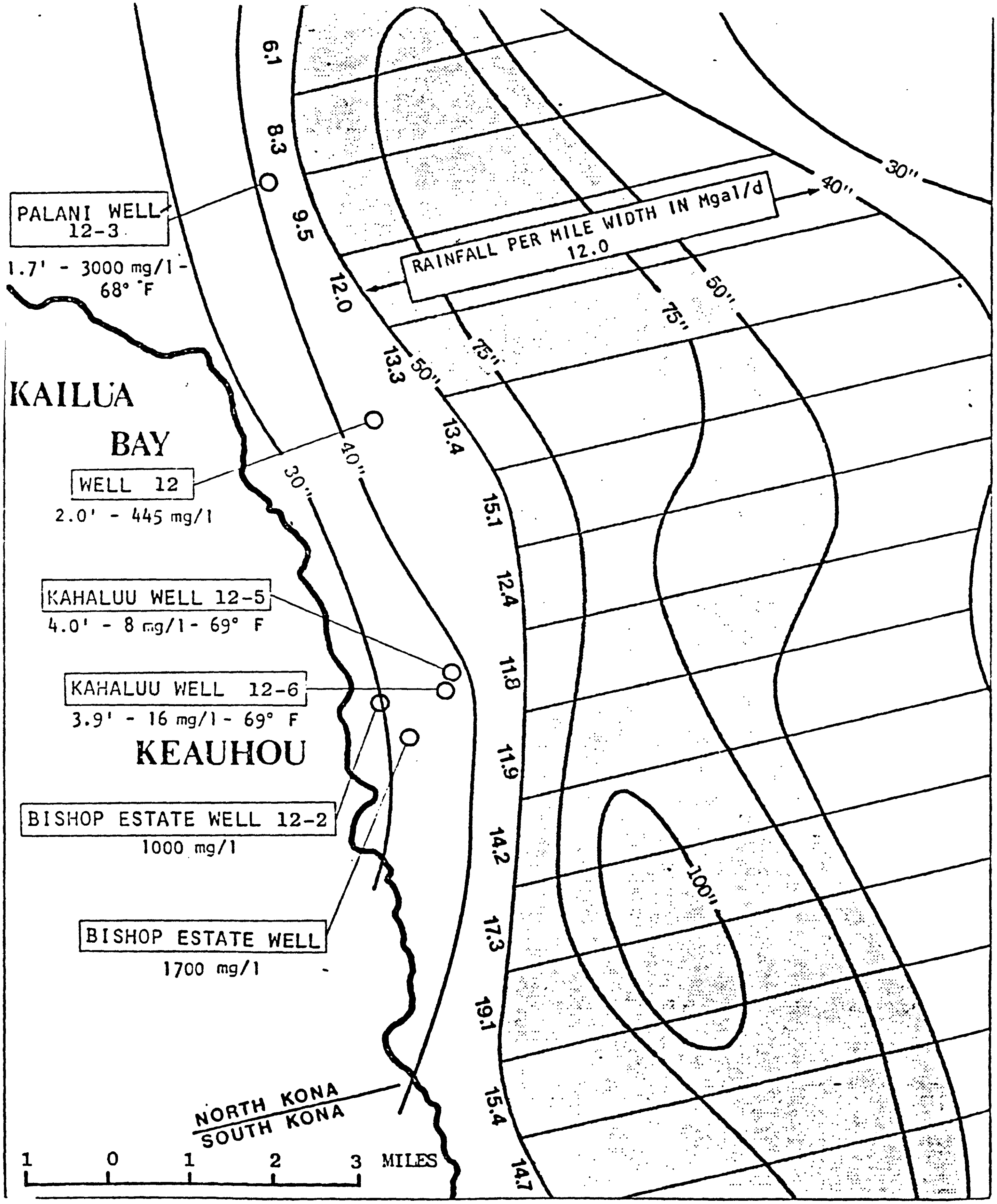



Figure 1. Map showing wells, water levels, chloride contents and temperatures of well water, lines of equal rainfall, and the rainfall per mile width.

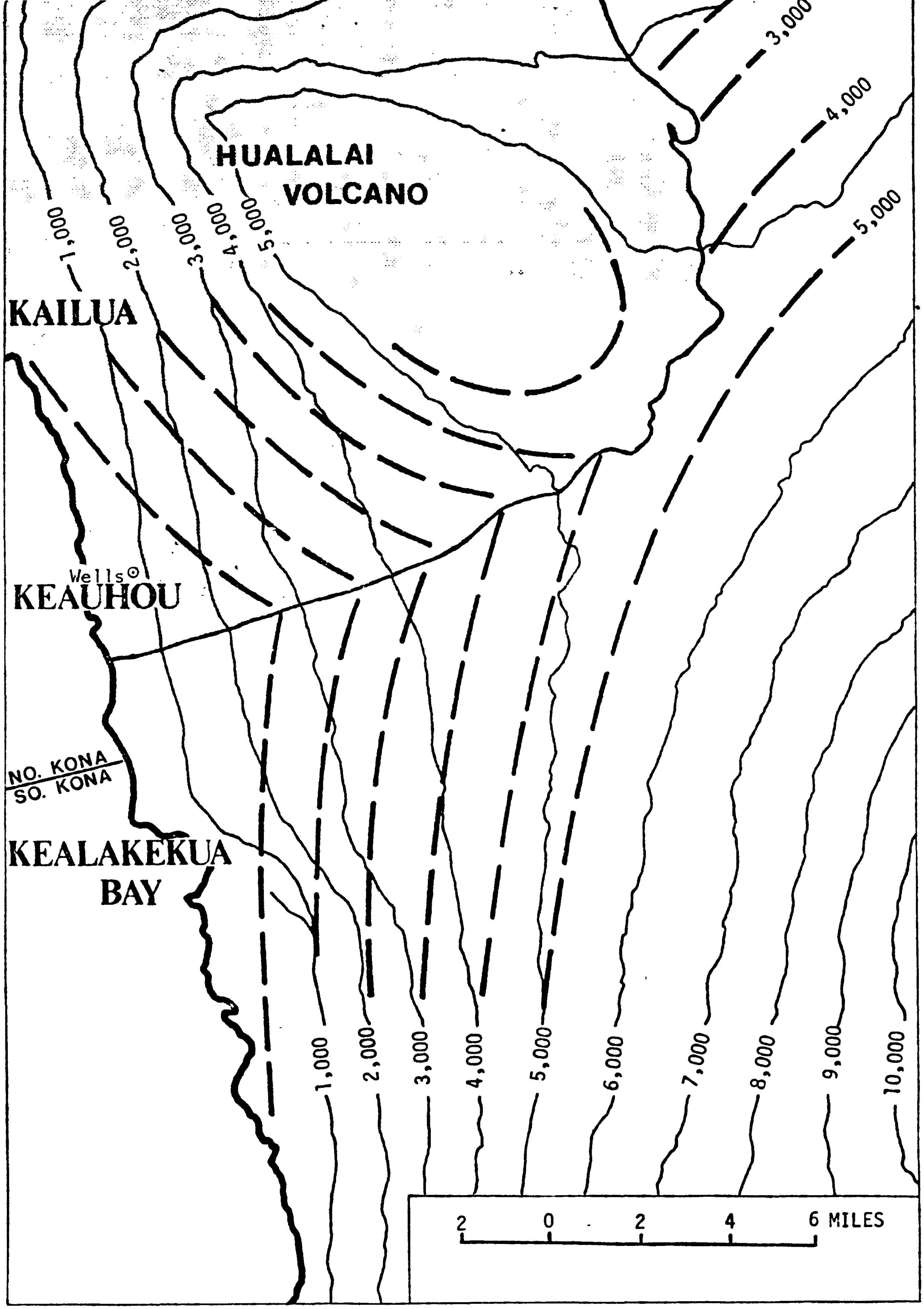



Figure 2. Map showing land contours and hypothetical land contours described in text.

significantly lowering the high permeabilities found in unrestricted lava flows. Such lower-than-normal permeable rocks likely extend south of Keauhou where rainfall increases. The combination of these lavas and high rainfall, make the area south of Keauhou very favorable for the exploration of ground water, especially at lower elevations than the currently producing wells.

## ELECTRICAL GEOPHYSICS

The application of electrical geophysics to ground water problems is fairly straightforward, since under favorable circumstances electrical-resistivity techniques can determine the depth to saltwater-saturated rock by sounding the earth for changes in resistivity with depth below ground surface. The resistivity of rocks is greatly lowered by saturation with water, especially brackish or saline water. The resistivity decrease caused by saltwater saturation is quite distinct and the thickness of a freshwater basal lens (Ghyben-Herzberg lens) overlying the saltwater may be estimated from the depth below sea level to which the interpreted saltwater has been depressed.

Electrical geophysics were applied in Kailua-Kona specifically to map the depth to saltwater along the coast from Keahole Point (north of Kailua-Kona) to the North Kona/South Kona district boundary. Thickness of the freshwater lens is computed by subtracting the local elevation from the depth to saltwater. Several problems were anticipated: 1) most accessible areas were heavily populated and had to be avoided because of the probable presence of buried pipes, power lines and telephone lines which may cause confusion when interpreting the results of an electrical survey, and 2) the study area was bordered on one side by the ocean which is an excellent electrical conductor and any deep sounding near the coast might be confused by the presence of the ocean nearby. By limiting field work to unpopulated areas away from the coast that were still accessible by vehicle, coverage was severely restricted. Because of these factors, an experimental two-pronged application of electrical resistivity techniques seemed prudent to obtain the broadest possible areal coverage for Kailua-Kona. The first prong consists of detailed reconnaissance at low elevation using shallow electromagnetic techniques to sound the depth to saltwater. The second prong consists of deep Schlumberger soundings at higher elevations.

## Reconnaissance using Shallow Electromagnetic Methods

The first step was to profile the coast at low elevations with shallow-penetration electromagnetic equipment because shallow soundings could be located closer to pipes, power lines, and the coast than deep soundings without serious adverse effects. The relative freedom to locate shallow soundings should allow denser coverage and better resolution of the basal lens, making it possible to detect more subtle variations in its character and thickness. We hypothesized that if an anomalously thick lens were found at a low elevation, then it should continue farther inland; however, if a thin lens were found at low elevation, this would not necessarily preclude the existence of a thicker lens farther inland.

Two different sets of equipment were used for reconnaissance in Kailua-Kona. Most of the coast was mapped with a Geonics EM16R Very Low Frequency (VLF) handheld, electrical-resistivity unit; several of the locations were also mapped with Max/Min loop-loop electromagnetic (EM) profiling equipment using a 244 m (800 ft) spacing. Each set of equipment was capable of 50 to 150 m penetration in the resistive volcanic terrain of the Kona coast, and, with one exception, was used at elevations less than 100 m. The VLF was easier and quicker to use and required only one person but it yielded only two data points per location. The loop-loop EM profiling required two people and took longer than the VLF, but it was capable of better subsurface resolution than the VLF because of its capability to obtain 10 data points per location. Each of these techniques is described in detail in Parasnis (1979, p. 154-165).

### <u>VLF</u>

Thirty VLF measurements were obtained at elevations between 6 and 59 m (Figure 3). Four parameters were measured at each location and are listed in Appendix A; however, only the apparent

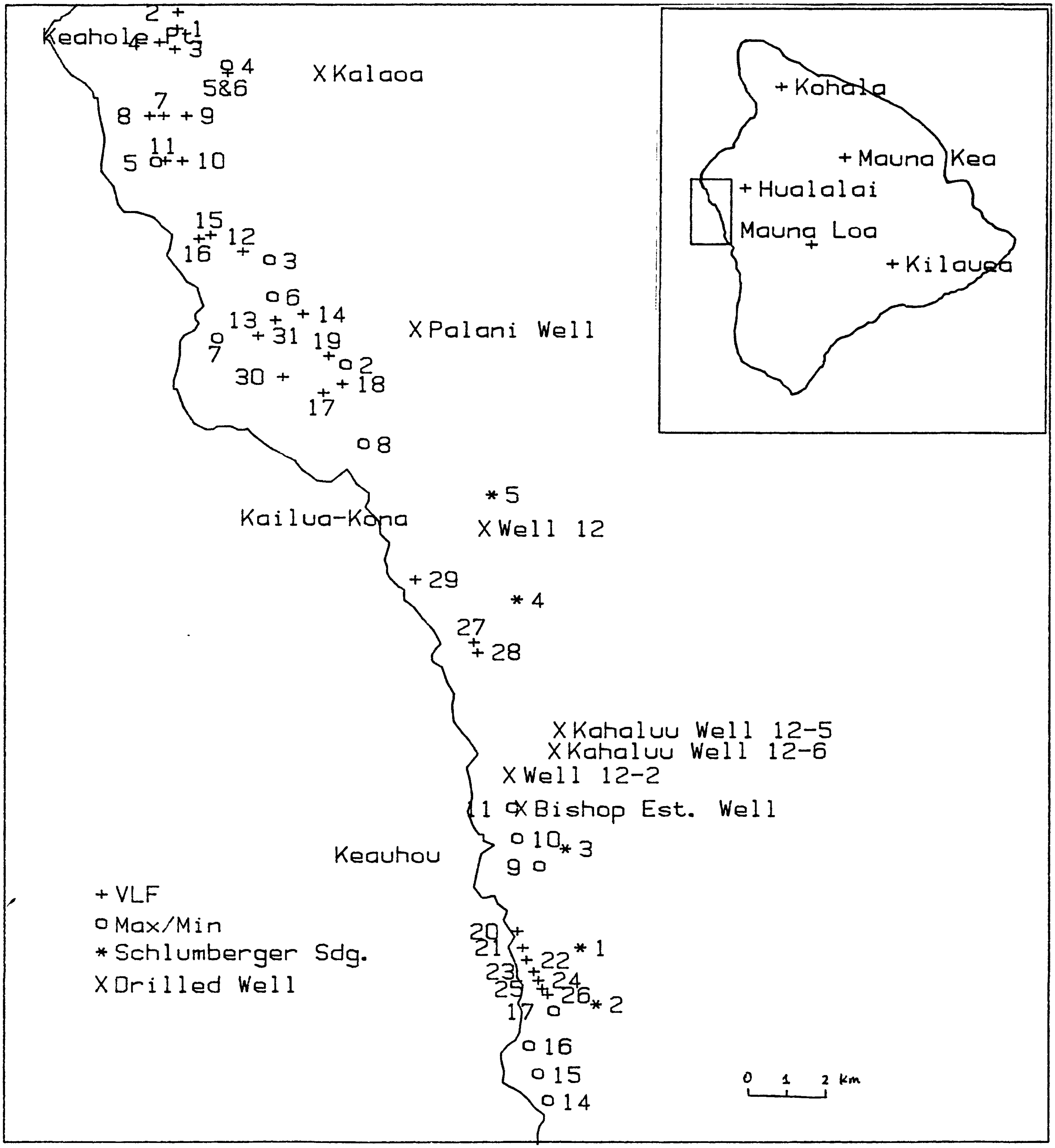



Figure 3. Map of the Kailua-Kona area showing the electrical geophysics station locations. Also shown are prominent geographical and well locations for reference.

resistivity and phase can be used to determine presence and depth to a subhorizontal conductor assumed for our purposes to be saltwater-saturated rock. The other two, dip angle and ellipticity, are useful for determining whether the measurement is distorted by nearby structures not related to ground water. If the dip angle and ellipticity are relatively small (values of 8 or less), then we assume that the apparent resistivity and phase measurements are relatively undistorted and therefore useable.

If we assume a very simple resistivity model for the earth at each measurement location along the Kona coast, we can use a fairly simple algorithm (Frignet, 1981) for directly interpreting the data. The earth model we assume consists of two layers with a horizontal interface between them. The surface layer is very resistive and the lower layer is very conductive. If we assume this model is valid and further assume an actual resistivity value for the surface layer, the algorithm of Frignet may be used to convert each apparent resistivity and phase data pair into the thickness of the surface layer (ground surface to lower layer surface) and the resistivity of the lower layer. Table I shows the results of applying Frignet's algorithm to each of the 30 data sets for three assumed values of surface layer resistivity. The values of 600, 1000, and 6000 ohm-m bracket the resistivities determined in this area for the rocks above sea level (Kauahikaua and Mattice, 1981) and should suffice for demonstrating any dependence of the interpreted conductor depth on assumed surface resistivity. Where no entry has been made for a rho2, t1 pair, the apparent resistivity and phase were not a theoretically-possible response for the assumed model for any values of rho2 and t1. Elevations were estimated from USGS 1:24,000 scale maps.

Table I. VLF Interpretations

| | rho1 = | 600 | | 1000 | | 6000 ohm-m | |
|---|---|---|---|---|---|---|---|
| No. | elevation (m) | rho2 (ohm-m) | t1 (m) | rho2 (ohm-m) | t1 (m) | rho2 (ohm-m) | t1 (m) |
| 1 | 37 | | | | | 1.7 | 39 |
| 2 | 34 | 10 | 28 | 16 | 26 | 24 | 23 |
| 3 | 40 | | | .6 | 32 | 4 | 30 |
| 4 | 30 | 52 | 22 | 62 | 19 | 72 | 17 |
| 5 | 58 | | | | | 3 | 44 |
| 6 | 58 | | | | | 10 | 51 |
| 7 | 27 | 4 | 26 | 6 | 25 | 10 | 23 |
| 8 | 21 | 25 | 14 | 27 | 13 | 29 | 12 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 9 | 44 | | | .3 | 43 | 10 | 38 |
| 10 | 23 | .4 | 16 | .5 | 15 | .7 | 15 |
| 11 | 23 | 8 | 21 | 10 | 20 | 13 | 19 |
| 12 | 49 | | | | | 0 | 37 |
| 13 | 24 | | | | | .03 | 19 |
| 14 | 40 | | | | | .03 | 20 |
| 15 | 15 | | | | | .02 | 17 |
| 16 | 11 | 0 | 12 | 0 | 12 | .01 | 11 |
| 17 | 40 | | | | | .6 | 30 |
| 18 | 59 | | | .3 | 43 | 10 | 38 |
| 20 | 6 | 3 | 18 | 4 | 17 | 4 | 17 |
| 21 | 11 | .3 | 10 | .3 | 10 | .3 | 10 |
| 22 | 38 | .04 | 23 | .3 | 22 | .8 | 22 |
| 23 | 47 | | | | | 12 | 43 |
| 24 | 47 | | | 2 | 39 | 12 | 34 |
| 25 | 49 | 3 | 31 | 7 | 29 | 13 | 27 |
| 26 | 49 | 6 | 46 | 30 | 40 | 69 | 31 |
| 27 | 30 | 3 | 26 | 5 | 25 | 8 | 23 |
| 28 | 30 | 2 | 31 | 5 | 29 | 10 | 26 |
| 29 | 14 | 2 | 7 | 2 | 7 | 2 | 7 |
| 30 | 12 | 6 | 14 | 7 | 13 | 8 | 13 |
| 31 | 18 | 0 | 10 | 0 | 10 | .01 | 10 |

If a freshwater lens exists beneath one of the measurement locations, the estimated value of t1 should be significantly greater than the elevation of that location. With the exception of locations 1, 7, 9, 11, 15, 16, 20, 21, 28, and 30, the determined values of t1 were significantly less than the elevation. Of the exceptions, the t1 values for all but location 20 were less than 2 m different from the estimated elevation. Because of the lack of precision inherent in VLF measurements, only the results of No. 20 can be taken as clear evidence of an appreciable thickness of freshwater beneath that measurement location.

Because many of the t1 values in Table I were significantly less than the site elevation does not indicate that saltwater has risen some distance above sea level, but rather that the greatly-simplified interpretation procedure is too simple for these areas. Unfortunately, a more elaborate interpretation is not practical with only two data points obtained per location. The results may still be used, but only in an empirical sense to indicate where a basal lens might be thickest.

Loop-Loop EM profiling

Seventeen loop-loop EM data sets were obtained in the study area of which thirteen are interpretable with horizontally-layered earth models. In Appendix B, ten values are given for each location consisting of two parameters at each of five frequencies. The two parameters are the in-phase (real) and out-of-phase (imaginary) portions of the electromagnetic coupling between the two wire loops separated a distance of 244 m (800 ft). The interpretation consisted of matching these ten parameters to theoretically calculated ones which would be obtained over a two layer earth model with the first layer being infinitely resistive (or at least so highly resistive as to have no effect on the measured coupling). Similar to the VLF interpretation, the derived values at each location are depth (from the ground surface) to and resistivity of the lower, more-conductive layer. The interpretations are summarized in Table II.

Table II. Loop-Loop EM Interpretations

| No. | elevation (m) | rho2 (ohm-m) | t1 (m) | elevation-t1 (m) |
|---|---|---|---|---|
| 2 | 73 | 3.1-4.2 | 77-81 | (-4)-(-8) |
| 3 | 91 | 0.9-3.3 | 86-97 | 5 -(-6) |
| 4 | 58 | 2.9-3.4 | 52-55 | 6 - 3 |
| 5 | 18 | 4.1-4.4 | 17-19 | 1 -(-1) |
| 6 | 55 | 2.5-3.3 | 67-71 | (-12)-(-16) |
| 7 | 9 | 1.9-2.0 | 9-12 | 0 -(-3) |
| 9 | 128 | 17 - 52 | 219-259 | (-91)-(-131) |
| 10 | 73 | 5.1-7.8 | 88-98 | (-15)-(-25) |
| 11 | 98 | 19 - 45 | 106-146 | (-8)-(-48) |
| 14 | 24 | 2.8-3.1 | 23-25 | 1 -(-1) |
| 15 | 18 | 2.6-2.9 | 21-24 | (-3)-(-6) |
| 16 | 11 | 3.1-3.3 | 11-13 | 0 -(-2) |
| 17 | 73 | 4.5-6.4 | 69-76 | 4 -(-3) |

At locations 2, 3, 4, 5, 7, 14, 15, 16, and 17, the conductive interface is less than 10 m below sea level and at locations 6, 9, 10, and 11, the interface is greater than 10 m below sea level. Of the latter four, location 9 was at a rather high elevation compared to its optimal depth of penetration and is probably not a reliable determination. Of the other locations, 6, 10, and 11 appear to be the best indications thus far obtained for anomalously large ground water lens thickness.

## Deep Schlumberger Sounding

On the basis of the reconnaissance work, five deep (AB/2 up to 1830 m) Schlumberger soundings were located along an abandoned railroad bed that ran parallel to the coast at an approximately constant 210 m elevation (Figure 3). The soundings spanned almost the entire coastline from Kailua-Kona town southward to the North Kona/South Kona district boundary. Details on the application of this technique can be found in Parasnis (1979, p. 98-130).

The data sets were interpreted with the aid of a version of computer program MARQDCLAG (Anderson, 1979a) adapted to a Hewlett-Packard 9826 microcomputer in BASIC 2.1. The program automatically fits a horizontally-layered model with a user-specified number of layers. As in the simpler interpretation schemes applied to the reconnaissance survey, we are only interested in the depth to the deep conductor expected to be saltwater-saturated rock underlying freshwater-saturated rock. To this end, each of the sounding data sets were computer inverted using an 8-layer model, the thicknesses of the upper 6 layers were fixed so that their total thickness equalled the elevation. The two layers below sea level were intended to represent freshwater-saturated rock (layer 7) and saltwater-saturated rock (layer 8). As applied, Schlumberger sounding allows deeper penetration than the VLF or the loop-loop EM profiling using a 244 m separation, but it has poorer resolution of the resistivity of that deep conductor (layer 8) than the VLF or loop-loop EM profiling. Table III summarizes the portions of the sounding interpretations below sea level. The raw field data and the output from the computer interpretations are reproduced in Appendix C.

Table III. Schlumberger Sounding Interpretations
- Below Sea Level Portion, Soundings listed South to North -

| Sounding No. | rho7 (ohm-m) | t7 (m below sea level) |
|---|---|---|
| 2 | 145 | 266 |
| 1 | 605 | 113 |
| 3 | 485 | 180 |
| 4 | 214 | 46 |
| 5 (insufficient penetration) | | |

Only soundings 1, 2, and 3, appear to have detected a significant depression of the basement conductor below sea level. The conductor did not appear depressed below sea level in sounding 4 and data distortion for the deeper portions of sounding 5 did not permit interpretation of the deeper part in terms of a simple layered medium. As before, the basement conductor is assumed to be saltwater-saturated rock. If the surface of that unit is depressed a significant distance below sea level, then the unit above the basement conductor is interpreted to be rock saturated with less saline water. The resistivity values determined for the freshwater-saturated rock beneath soundings 1 and 3 are very similar to values determined previously for this hydrogeologic unit (Zohdy and Jackson, 1969; Kauahikaua and Jackson, 1983); therefore, the results of these two soundings are consistent with the interpretation as a freshwater lens floating upon saltwater. The lower resistivity determined beneath sounding 2 might indicate a more brackish lens or a very thick transition zone.

## DISCUSSION

The electrical geophysics results indicate that freshwater anomalies may be found in two areas: the first is defined by loop-loop EM profile site 6 which is located about 6 km north of Kailua-Kona town, and the second is defined by Schlumberger soundings 1 and 3, loop-loop EM sites 10 and 11, and VLF site 20 which are located between the Keauhou wells (12-5 and 12-6 on

Figure 1) and a point 4 km south. The hydrogeologic data support lower-than-normal permeability also in the latter area.

Although the area north of Kailua-Kona is represented by an anomalous loop-loop EM site, it is also represented by several unanomalous loop-loop EM and VLF sites (Figure 3). The anomalous loop-loop EM site is either affected by factors other than hydrogeologic ones, or they indicate a very local thickening of the basal lens. In either case, it does not indicate a broad area with anomalous ground water reserves.

On the other hand, the area immediately south of the Keauhou wells is represented by anomalies in all electrical geophysical techniques as well as a hypothesized lower permeability. Each indication is consistent with the other in that a locally lower permeability would cause a locally thicker basal lens which may be seen using electrical geophysics measurements.

On the basis of the results of this study, the area between the Keauhou wells and a point about 4 km south is well worth exploring by test borings. The drilling may show that domestic-quality water is developable by wells located at elevations as low as 200 m.

## APPENDIX A: VLF Data

The VLF data were taken with a Geonics EM16R unit using station NPM (23.4 kHz) located at Lualualei, O'ahu. The dip angle (dip) and ellipticity (ellip) of the VLF magnetic field and the apparent resistivity (rhoa) and phase angle (phase) of the VLF electromagnetic field were measured. Site 19 was located in a County garbage dump/landfill; the large dip angle and ellipticity were probably due to metal buried in the landfill.

Table IV. VLF Field Data

| No. | dip degrees | ellip | rhoa ohm-m | phase degrees |
|---|---|---|---|---|
| 1 | -5.5 | 2 | 310 | 86 |
| 2 | 7 | 0 | 190 | 75 |
| 3 | 2.5 | 0.5 | 200 | 84 |
| 4 | 4.5 | 0.2 | 205 | 65 |
| 5 | 3.5 | 0.1 | 400 | 85 |
| 6 | 3.5 | 0 | 580 | 83 |
| 7 | 0 | 0.2 | 150 | 79 |
| 8 | 5 | 0.2 | 95 | 67 |
| 9 | 7.5 | 1.0 | 350 | 82 |
| 10 | 4 | 0 | 50 | 85 |
| 11 | 1 | 0 | 120 | 76 |
| 12 | 5 | -0.1 | 260 | 89 |
| 13 | 4 | 0 | 70 | 89 |
| 14 | 4 | -0.5 | 50-100 | 89 |
| 15 | 3 | 0 | 55 | 89 |
| 16 | 3 | 0 | 25 | 89 |
| 17 | 3 | -0.8 | 180 | 87 |
| 18 | 4 | -0.5 | 350 | 82 |
| 19 | 25 | 22.5 | | |
| 20 | 5 | 0 | 78 | 80 |
| 21 | 3 | -0.3 | 23 | 85 |
| 22 | 2 | 0 | 100 | 86 |
| 23 | 2 | -2 | 430 | 82 |
| 24 | 2.5 | -2 | 300 | 81 |
| 25 | 2 | -1 | 200 | 79 |
| 26 | 2 | -6 | 400 | 72 |
| 27 | 4 | -1.4 | 150 | 80 |
| 28 | 3 | 0 | 190 | 80 |
| 29 | 3 | 1.2 | 17 | 75 |
| 30 | 2.5 | 0.7 | 60 | 75 |
| 31 | 3.5 | 0 | 20 | 89 |

## APPENDIX B: Loop-loop EM Data

All loop-loop EM data were taken in the horizontal, coplanar loop mode (Parasnis, 1979) with the transmitter and receiver loops separated 244 m (800 ft). The in-phase or real (R) portion and the out-of-phase or imaginary (I) portion of the loop coupling at each of five frequencies - 222, 444, 888, 1777, 3555 Hz were measured. The data units are in percent of the coupling that would be observed in the absence of all conductive material. Note that the R measurement is actually equal to the real portion of the coupling minus 100 percent and that R values significantly greater than about 35 are theoretically impossible for any horizontally-layered earth model and are indicative of distortion.

Interpretation was done with the aid of computer program MARQMAXMIN, a Hewlett-Packard 9826 BASIC 2.1 version of program MARQLOOPS (Anderson, 1979b), which finds the best-fitting, horizontally-layered earth model for a given loop-loop EM profile data set. Input to the program consists of the data set, the number of layers, and a first guess at the resistivities and thicknesses of those layers. The program automatically adjusts the model approximately for possible errors in loop spacing by automatically varying this quantity (not to exceed 244 m) to achieve the best possible fit to the data set.

Table V. Loop-Loop EM Field Data

| Frequency | 222 | | 444 | | 888 | | 1777 | | 3555 | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | R | I | R | I | R | I | R | I | R | I |
| 2 | 38 | -5 | 31 | -10 | 16 | -10 | 10 | -8 | 9 | -5 |
| 3 | 13.5 | -5.5 | 8 | -8.5 | 3 | -7 | -2.5 | -4.5 | -4.5 | -3.5 |
| 4 | 27.5 | -21 | 9 | -25 | -4 | -19 | -13 | -13.5 | -18 | -10 |
| 5 | -11 | -57.5 | -42 | -53 | -55 | -33.5 | -62.5 | -20 | -72.5 | -12 |
| 6 | 35 | -11 | 26.5 | -15 | 12 | -13 | 4 | -9 | 2.5 | -6.5 |
| 7 | -79 | -53 | -88.5 | -28 | -80.5 | -16 | -78 | -10 | -83 | -4.5 |
| 8 | 78 | -17.5 | 64 | -27 | 36 | -24 | 16 | -15 | 12.5 | -11 |
| 9 | 25 | 4 | 28 | 3.5 | 25 | 3.5 | 23.5 | 4 | 27.5 | 4.5 |
| 10 | 36 | 2.5 | 36 | 0 | 28.5 | -8 | 23.5 | -4 | 28.5 | -4.5 |
| 11 | 40 | 9.5 | 40 | 11 | 33 | 4 | 34.5 | 4 | 38 | 3.5 |
| 14 | -6.5 | -51.5 | -29 | -43 | -40.5 | -27.5 | -46 | -17 | -51.5 | -10 |
| 15 | -17.5 | -52.5 | -44.5 | -42.5 | -50 | -25 | -55 | -14.5 | -60 | -8.5 |
| 16 | -22 | -67 | -53 | -48 | -58 | -25.5 | -62 | -15 | -68.5 | -10 |
| 17 | 48 | -4 | 44 | -8.5 | 33.5 | -9 | 26.5 | -10 | 25 | -13 |

resistivities and thicknesses of each of the layers in the earth model. Of course, approximate matching can be done by manually comparing the sounding data to theoretical curves in a standard album; however, the computer inversion offers an additional advantage, besides speed and automation, of parameter resolution estimates. They offer a means of assessing the reliability of parameters they estimate.

MARQDCLAG_HP automatically minimizes the following quantity:

$$PHI = \sum_{i=1}^{N} \left[ \frac{y_i - f(x_i)}{w_i} \right]^2$$

where

N is the number of data in the sounding data set,
$x_i$ is the $i^{th}$ current electrode spacing,
$y_i$ is the apparent resistivity measured at $x_i$,
$w_i$ is the apparent resistivity measurement error ($=y_i/100$), and
$f(x)$ is the theoretical calculated apparent resistivity.

Along with the sounding data set, the program also requires a starting guess of the model parameters.

The number of layers cannot be automatically varied by the program so it is a common practice to invert each sounding data set for several models, each having a different number of layers. The best-fitting model is chosen to be the one which minimizes the following quantity, called the reduced chi-squared statistic:

$$X^2 = PHI / (N - 1 - K)$$

where K is the number of parameters in the model being fitted to the data. In general applications, K = 2 * m - 1 where m is the number of layers in the theoretical model and * denotes multiplication.

During the inversions of the sounding data sets, the natural logarithm of the model parameters were actually manipulated to avoid the possibility of negative resistivities or thicknesses

MARQUARDT STATISTICS: KONA VES 1, ELEVATION=660 FT

| | X | OBSERVED | PREDICTED | %RESIDUALS | WEIGHT FN |
|---|---|---|---|---|---|
| 1 | +3.0480E+01 | +2.9120E+03 | +2.7651E+03 | +5.0451E+00 | +4.1012E-02 |
| 2 | +3.9624E+01 | +2.5210E+03 | +2.6636E+03 | -5.6578E+00 | +5.4720E-02 |
| 3 | +4.8768E+01 | +2.5640E+03 | +2.6236E+03 | -2.3232E+00 | +5.2900E-02 |
| 4 | +6.0960E+01 | +2.5690E+03 | +2.5247E+03 | +1.7239E+00 | +5.2694E-02 |
| 5 | +7.6200E+01 | +2.3800E+03 | +2.3368E+03 | +1.8141E+00 | +6.1396E-02 |
| 6 | +9.1440E+01 | +2.2120E+03 | +2.1457E+03 | +2.9994E+00 | +7.1076E-02 |
| 7 | +1.2192E+02 | +1.7360E+03 | +1.8270E+03 | -5.2427E+00 | +1.1540E-01 |
| 8 | +1.5240E+02 | +1.6540E+03 | +1.5634E+03 | +5.4769E+00 | +1.2712E-01 |
| 9 | +1.9812E+02 | +1.2430E+03 | +1.2537E+03 | -8.5862E-01 | +2.2509E-01 |
| 10 | +2.4384E+02 | +9.9900E+02 | +1.0323E+03 | -3.3371E+00 | +3.4847E-01 |
| 11 | +3.0480E+02 | +8.1000E+02 | +8.1156E+02 | -1.9221E-01 | +5.3006E-01 |
| 12 | +3.9624E+02 | +6.1000E+02 | +6.0620E+02 | +6.2336E-01 | +9.3462E-01 |
| 13 | +4.8768E+02 | +4.7200E+02 | +4.5457E+02 | +3.6919E+00 | +1.5610E+00 |
| 14 | +6.0960E+02 | +3.1800E+02 | +3.2589E+02 | -2.4817E+00 | +3.4390E+00 |
| 15 | +7.6200E+02 | +2.1700E+02 | +2.1824E+02 | -5.7112E-01 | +7.3854E+00 |

CORRELATION MATRIX:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | +1.00 | -.83 | +.77 | -.74 | +.48 | -.58 | +.48 | -.15 | -.49 |
| 2 | -.83 | +1.00 | -.99 | +.97 | -.76 | +.80 | -.68 | -.10 | +.68 |
| 3 | +.77 | -.99 | +1.00 | -.99 | +.84 | -.85 | +.74 | +.18 | -.73 |
| 4 | -.74 | +.97 | -.99 | +1.00 | -.89 | +.90 | -.79 | -.24 | +.79 |
| 5 | +.48 | -.76 | +.84 | -.89 | +1.00 | -.98 | +.92 | +.54 | -.91 |
| 6 | -.58 | +.80 | -.85 | +.90 | -.98 | +1.00 | -.97 | -.56 | +.96 |
| 7 | +.48 | -.68 | +.74 | -.79 | +.92 | -.97 | +1.00 | +.73 | -1.00 |
| 8 | -.15 | -.10 | +.18 | -.24 | +.54 | -.56 | +.73 | +1.00 | -.74 |
| 15 | -.49 | +.68 | -.73 | +.79 | -.91 | +.96 | -1.00 | -.74 | +1.00 |

REDUCED CHI-SQUARED=33.6
PHI=168.02

DCLAG: ******** END ********          KONA VES 1, ELEVATION=660 FT

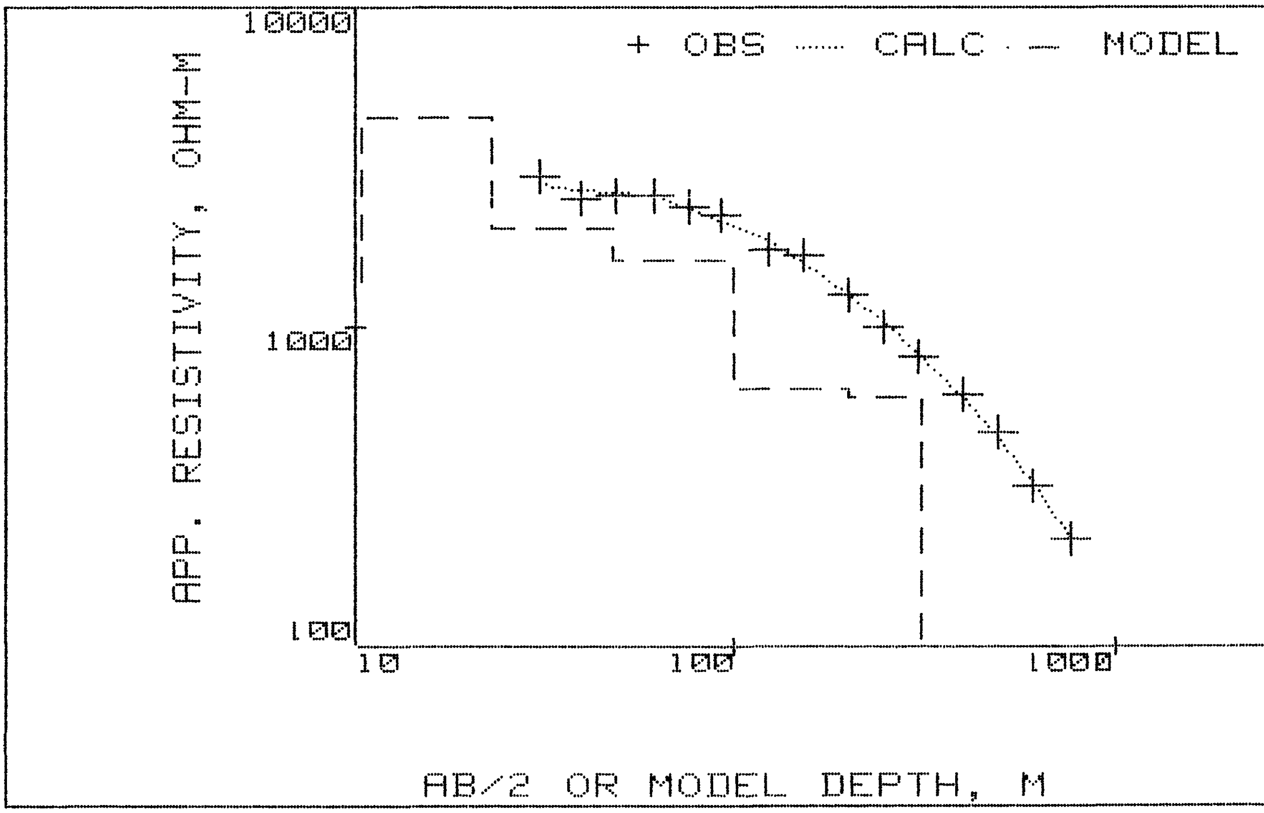
COORDINATES: 0 0  UTM4
ELEVATION  : 201  METER
AZIMUTH    : N10W

| B-SD | B | B+SD |
|---|---|---|
| 1.075E+005 | 1.693E+005 | 2.666E+005 |
| 1.021E+003 | 1.265E+003 | 1.567E+003 |
| 3.305E+003 | 4.424E+003 | 5.922E+003 |
| 1.410E+003 | 2.008E+003 | 2.860E+003 |
| 1.323E+003 | 1.603E+003 | 1.942E+003 |
| 3.941E+002 | 6.424E+002 | 1.047E+003 |
| 1.023E+002 | 6.051E+002 | 3.579E+003 |
| 1.484E+001 | 3.355E+001 | 7.583E+001 |
| | 4.100E+000 | |
| | 6.280E+000 | |
| | 1.248E+001 | |
| | 2.510E+001 | |
| | 5.100E+001 | |
| | 9.900E+001 | |
| 1.799E+001 | 1.128E+002 | 7.068E+002 |

FINAL UNSCALED PARAMETERS--
(* denotes fixed value)

| | | | RESISTIVITY | | DEPTH | |
|---|---|---|---|---|---|---|
| 1 | | 1.69310191E+05 | 1 | 1.693102E+05 | | |
| 2 | | 1.26532703E+03 | 2 | 1.265327E+03 | | |
| 3 | | 4.42404928E+03 | 3 | 4.424049E+03 | | |
| 4 | | 2.00793465E+03 | 4 | 2.007935E+03 | | |
| 5 | | 1.60264354E+03 | 5 | 1.602644E+03 | | |
| 6 | | 6.42423629E+02 | 6 | 6.424236E+02 | | |
| 7 | | 6.05055499E+02 | 7 | 6.050555E+02 | | |
| 8 | | 3.35510741E+01 | 8 | 3.355107E+01 | | |
| 9 | * | 4.10000000E+00 | | | 1 | 4.100000E+00 |
| 10 | * | 6.28000000E+00 | | | 2 | 1.038000E+01 |
| 11 | * | 1.24800000E+01 | | | 3 | 2.286000E+01 |
| 12 | * | 2.51000000E+01 | | | 4 | 4.796000E+01 |
| 13 | * | 5.10000000E+01 | | | 5 | 9.896000E+01 |
| 14 | * | 9.90000000E+01 | | | 6 | 1.979600E+02 |
| 15 | | 1.12752083E+02 | | | 7 | 3.107121E+02 |

KONA VES 1, ELEVATION=660 FT



MARQUARDT STATISTICS: KONA VES 2, ELEVATION=680 FT

| | X | OBSERVED | PREDICTED | %RESIDUALS | WEIGHT FN |
|---|---|---|---|---|---|
| 1 | +3.0480E+01 | +1.5420E+03 | +1.5459E+03 | -2.5057E-01 | +2.5956E-02 |
| 2 | +3.9624E+01 | +1.3980E+03 | +1.4016E+03 | -2.5575E-01 | +3.1578E-02 |
| 3 | +4.8768E+01 | +1.3520E+03 | +1.3181E+03 | +2.5058E+00 | +3.3764E-02 |
| 4 | +6.0960E+01 | +1.2450E+03 | +1.2567E+03 | -9.3622E-01 | +3.9817E-02 |
| 5 | +7.6200E+01 | +1.1560E+03 | +1.2048E+03 | -4.2256E+00 | +4.6184E-02 |
| 6 | +9.1440E+01 | +1.1510E+03 | +1.1530E+03 | -1.7038E-01 | +4.6586E-02 |
| 7 | +1.2192E+02 | +1.0730E+03 | +1.0312E+03 | +3.8940E+00 | +5.3605E-02 |
| 8 | +1.5240E+02 | +9.2400E+02 | +8.9751E+02 | +2.8667E+00 | +7.2287E-02 |
| 9 | +1.9812E+02 | +7.1200E+02 | +7.0926E+02 | +3.8445E-01 | +1.2174E-01 |
| 10 | +2.4384E+02 | +5.3300E+02 | +5.5748E+02 | -4.5920E+00 | +2.1724E-01 |
| 11 | +3.0480E+02 | +4.0200E+02 | +4.1427E+02 | -3.0517E+00 | +3.8190E-01 |
| 12 | +3.9624E+02 | +3.1000E+02 | +2.8838E+02 | +6.9756E+00 | +6.4221E-01 |
| 13 | +4.8768E+02 | +1.8000E+02 | +2.1842E+02 | -2.1343E+01 | +7.6194E-02 |
| 14 | +6.0960E+02 | +1.5800E+02 | +1.6202E+02 | -2.5430E+00 | +2.4722E+00 |
| 15 | +7.6200E+02 | +1.2000E+02 | +1.1837E+02 | +1.3558E+00 | +4.2859E+00 |
| 16 | +9.1440E+02 | +9.1000E+01 | +9.1214E+01 | -2.3468E-01 | +7.4528E+00 |

CORRELATION MATRIX:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | +1.00 | -.96 | +.97 | -.93 | +.90 | -.35 | +.36 | +.27 | -.33 |
| 2 | -.96 | +1.00 | -1.00 | +.98 | -.96 | +.46 | -.45 | -.34 | +.42 |
| 3 | +.97 | -1.00 | +1.00 | -.99 | +.96 | -.48 | +.47 | +.35 | -.43 |
| 4 | -.93 | +.98 | -.99 | +1.00 | -.99 | +.58 | -.56 | -.42 | +.52 |
| 5 | +.90 | -.96 | +.96 | -.99 | +1.00 | -.68 | +.65 | +.51 | -.62 |
| 6 | -.35 | +.46 | -.48 | +.58 | -.68 | +1.00 | -.97 | -.84 | +.95 |
| 7 | +.36 | -.45 | +.47 | -.56 | +.65 | -.97 | +1.00 | +.93 | -1.00 |
| 8 | +.27 | -.34 | +.35 | -.42 | +.51 | -.84 | +.93 | +1.00 | -.96 |
| 15 | -.33 | +.42 | -.43 | +.52 | -.62 | +.95 | -1.00 | -.96 | +1.00 |

REDUCED CHI-SQUARED=25.72
PHI=154.34

DCLAG: ******** END ********      KONA VES 2, ELEVATION=680 FT

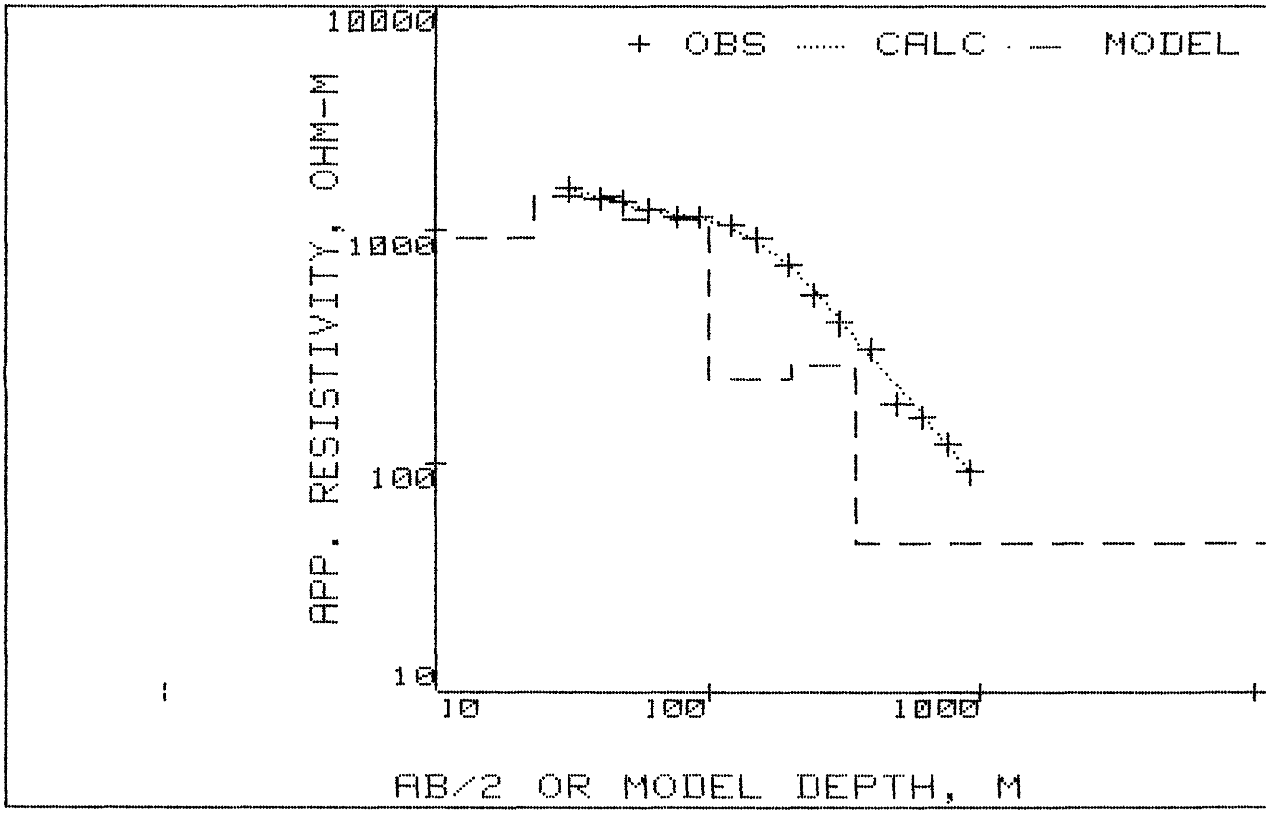
COORDINATES: 0 0  UTM4
ELEVATION  : 207  METER
AZIMUTH    : N10W

| B-SD | B | B+SD |
|---|---|---|
| 1.298E+002 | 1.264E+003 | 1.231E+004 |
| 1.568E+003 | 2.873E+003 | 5.265E+003 |
| 3.744E+002 | 9.262E+002 | 2.291E+003 |
| 7.897E+002 | 1.442E+003 | 2.634E+003 |
| 6.749E+002 | 1.139E+003 | 1.923E+003 |
| 1.283E+002 | 2.303E+002 | 4.133E+002 |
| 5.191E+001 | 2.657E+002 | 1.360E+003 |
| 2.500E+001 | 4.462E+001 | 7.964E+001 |
| | 3.234E+000 | |
| | 6.469E+000 | |
| | 1.294E+001 | |
| | 2.587E+001 | |
| | 5.175E+001 | |
| | 1.035E+002 | |
| 2.051E+001 | 1.446E+002 | 1.019E+003 |

FINAL UNSCALED PARAMETERS-- (* denotes fixed value)

| | | | RESISTIVITY | | DEPTH | |
|---|---|---|---|---|---|---|
| 1 | | 1.26399293E+03 | 1 | 1.263993E+03 | | |
| 2 | | 2.87313418E+03 | 2 | 2.873134E+03 | | |
| 3 | | 9.26163821E+02 | 3 | 9.261638E+02 | | |
| 4 | | 1.44228684E+03 | 4 | 1.442287E+03 | | |
| 5 | | 1.13910185E+03 | 5 | 1.139102E+03 | | |
| 6 | | 2.30294458E+02 | 6 | 2.302945E+02 | | |
| 7 | | 2.65666517E+02 | 7 | 2.656665E+02 | | |
| 8 | | 4.46201899E+01 | 8 | 4.462019E+01 | | |
| 9 | * | 3.23437500E+00 | | | 1 | 3.234375E+00 |
| 10 | * | 6.46875000E+00 | | | 2 | 9.703125E+00 |
| 11 | * | 1.29375000E+01 | | | 3 | 2.264062E+01 |
| 12 | * | 2.58750000E+01 | | | 4 | 4.851562E+01 |
| 13 | * | 5.17500000E+01 | | | 5 | 1.002656E+02 |
| 14 | * | 1.03500000E+02 | | | 6 | 2.037656E+02 |
| 15 | | 1.44615409E+02 | | | 7 | 3.483810E+02 |

KONA VES 2, ELEVATION=680 FT



MARQUARDT STATISTICS: KONA VES 3, ELEVATION=660 FT

| | X | OBSERVED | PREDICTED | %RESIDUALS | WEIGHT FN |
|---|---|---|---|---|---|
| 1 | +3.0480E+01 | +1.8190E+03 | +1.8159E+03 | +1.7098E-01 | +6.0437E-02 |
| 2 | +4.8768E+01 | +1.7400E+03 | +1.7247E+03 | +8.7664E-01 | +6.6050E-02 |
| 3 | +6.0960E+01 | +1.8080E+03 | +1.8411E+03 | -1.8318E+00 | +6.1175E-02 |
| 4 | +7.6200E+01 | +1.9300E+03 | +1.9593E+03 | -1.5201E+00 | +5.3686E-02 |
| 5 | +9.1440E+01 | +2.1200E+03 | +2.0246E+03 | +4.4979E+00 | +4.4494E-02 |
| 6 | +1.2192E+02 | +2.0070E+03 | +2.0386E+03 | -1.5739E+00 | +4.9645E-02 |
| 7 | +1.5240E+02 | +1.9660E+03 | +1.9644E+03 | +7.9252E-02 | +5.1737E-02 |
| 8 | +1.9812E+02 | +1.7620E+03 | +1.7864E+03 | -1.3854E+00 | +6.4411E-02 |
| 9 | +2.4384E+02 | +1.5940E+03 | +1.5859E+03 | +5.0606E-01 | +7.8704E-02 |
| 10 | +3.0480E+02 | +1.3430E+03 | +1.3276E+03 | +1.1473E+00 | +1.1087E-01 |
| 11 | +3.9624E+02 | +9.9200E+02 | +9.9189E+02 | +1.0782E-02 | +2.0321E-01 |
| 12 | +4.8768E+02 | +7.2000E+02 | +7.2584E+02 | -8.1092E-01 | +3.8575E-01 |
| 13 | +6.0960E+02 | +4.6700E+02 | +4.6650E+02 | +1.0796E-01 | +9.1693E-01 |
| 14 | +7.6200E+02 | +2.6100E+02 | +2.6030E+02 | +2.6724E-01 | +2.9356E+00 |
| 15 | +9.1440E+02 | +1.4200E+02 | +1.4206E+02 | -4.4916E-02 | +9.9173E+00 |

CORRELATION MATRIX:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | +1.00 | -.66 | +.76 | -.71 | +.63 | -.41 | +.33 | +.01 | -.20 |
| 2 | -.66 | +1.00 | -.91 | +.86 | -.82 | +.68 | -.66 | -.53 | +.60 |
| 3 | +.76 | -.91 | +1.00 | -.98 | +.93 | -.76 | +.71 | +.47 | -.60 |
| 4 | -.71 | +.86 | -.98 | +1.00 | -.98 | +.84 | -.79 | -.54 | +.68 |
| 5 | +.63 | -.82 | +.93 | -.98 | +1.00 | -.93 | +.88 | +.63 | -.78 |
| 6 | -.41 | +.68 | -.76 | +.84 | -.93 | +1.00 | -.98 | -.81 | +.94 |
| 7 | +.33 | -.66 | +.71 | -.79 | +.88 | -.98 | +1.00 | +.89 | -.98 |
| 8 | +.01 | -.53 | +.47 | -.54 | +.63 | -.81 | +.89 | +1.00 | -.96 |
| 15 | -.20 | +.60 | -.60 | +.68 | -.78 | +.94 | -.98 | -.96 | +1.00 |

REDUCED CHI-SQUARED=6.683
PHI=33.413

DCLAG: ******** END ********        KONA VES 3, ELEVATION=660 FT

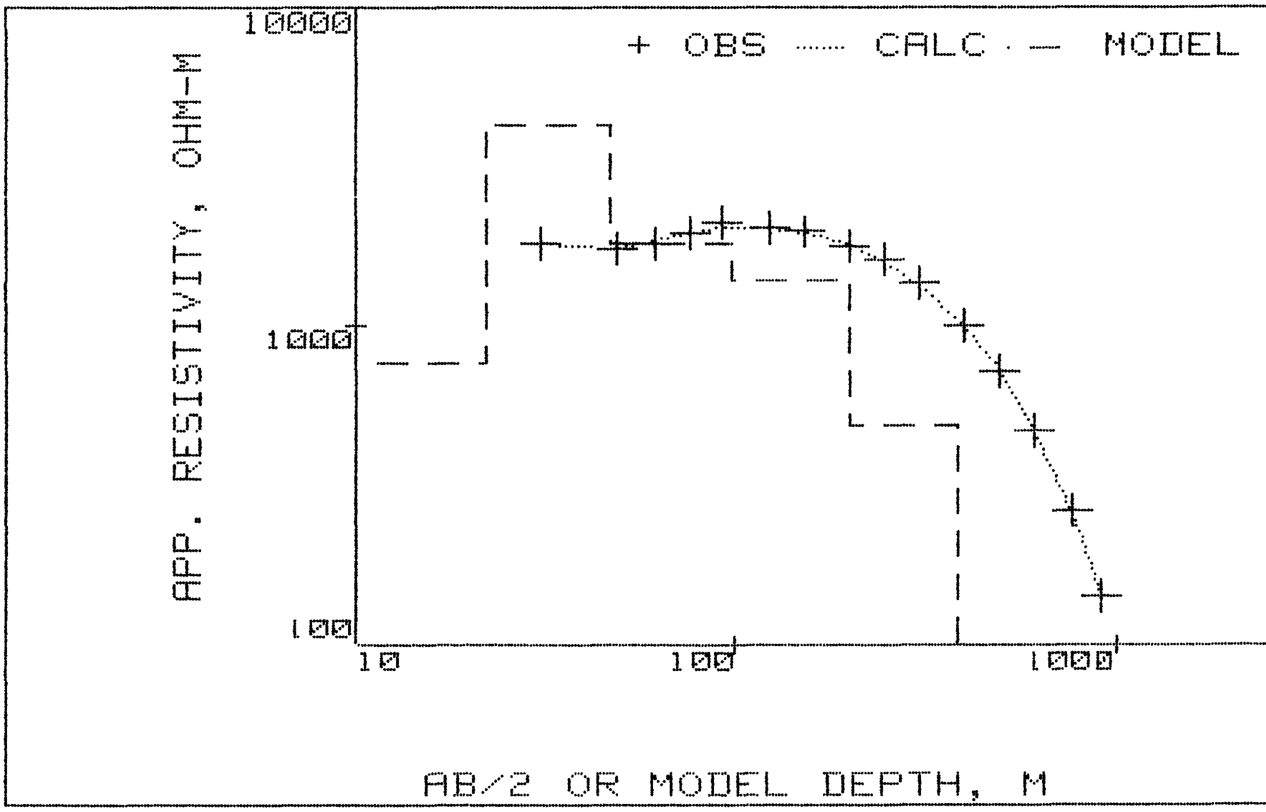
COORDINATES: 0 0  UTM4
ELEVATION  : 201  METER
AZIMUTH    : N10W

| B-SD | B | B+SD |
|---|---|---|
| 4.295E+003 | 4.518E+003 | 4.753E+003 |
| 4.313E+003 | 4.430E+003 | 4.549E+003 |
| 7.197E+002 | 7.587E+002 | 7.998E+002 |
| 3.647E+003 | 4.232E+003 | 4.910E+003 |
| 1.438E+003 | 1.789E+003 | 2.225E+003 |
| 1.145E+003 | 1.389E+003 | 1.685E+003 |
| 2.632E+002 | 4.853E+002 | 8.946E+002 |
| 1.641E-001 | 5.137E+000 | 1.609E+002 |
| | 3.141E+000 | |
| | 6.281E+000 | |
| | 1.256E+001 | |
| | 2.512E+001 | |
| | 5.025E+001 | |
| | 1.005E+002 | |
| 1.127E+002 | 1.804E+002 | 2.889E+002 |

FINAL UNSCALED PARAMETERS--
(* denotes fixed value)

| | | | RESISTIVITY | | | DEPTH |
|---|---|---|---|---|---|---|
| 1 | | 4.51829933E+03 | 1 | 4.518299E+03 | | |
| 2 | | 4.42960809E+03 | 2 | 4.429608E+03 | | |
| 3 | | 7.58695777E+02 | 3 | 7.586958E+02 | | |
| 4 | | 4.23178510E+03 | 4 | 4.231785E+03 | | |
| 5 | | 1.78900222E+03 | 5 | 1.789002E+03 | | |
| 6 | | 1.38901114E+03 | 6 | 1.389011E+03 | | |
| 7 | | 4.85252321E+02 | 7 | 4.852523E+02 | | |
| 8 | | 5.13744677E+00 | 8 | 5.137447E+00 | | |
| 9 | * | 3.14062500E+00 | | | 1 | 3.140625E+00 |
| 10 | * | 6.28125000E+00 | | | 2 | 9.421875E+00 |
| 11 | * | 1.25625000E+01 | | | 3 | 2.198437E+01 |
| 12 | * | 2.51250000E+01 | | | 4 | 4.710937E+01 |
| 13 | * | 5.02500000E+01 | | | 5 | 9.735937E+01 |
| 14 | * | 1.00500000E+02 | | | 6 | 1.978594E+02 |
| 15 | | 1.80421240E+02 | | | 7 | 3.782806E+02 |

KONA VES 3, ELEVATION=660 FT



MARQUARDT STATISTICS: KONA VES 4, ELEVATION=700 FT.

| | X | OBSERVED | PREDICTED | %RESIDUALS | WEIGHT FN |
|---|---|---|---|---|---|
| 1 | +3.0480E+01 | +2.8980E+03 | +2.8639E+03 | +1.1758E+00 | +3.2346E-01 |
| 2 | +3.9624E+01 | +2.4150E+03 | +2.4317E+03 | -6.8982E-01 | +4.6579E-01 |
| 3 | +4.8768E+01 | +2.2230E+03 | +2.2154E+03 | +3.4348E-01 | +5.4972E-01 |
| 4 | +6.0960E+01 | +2.0560E+03 | +2.0898E+03 | -1.6420E+00 | +6.4265E-01 |
| 5 | +7.6200E+01 | +2.0470E+03 | +2.0107E+03 | +1.7715E+00 | +6.4832E-01 |
| 6 | +9.1440E+01 | +1.9900E+03 | +1.9390E+03 | +2.5650E+00 | +6.8599E-01 |
| 7 | +1.2192E+02 | +1.7280E+03 | +1.7830E+03 | -3.1805E+00 | +9.0978E-01 |
| 8 | +1.5240E+02 | +1.6350E+03 | +1.6374E+03 | -1.4772E-01 | +1.0162E+00 |
| 9 | +1.9812E+02 | +1.4550E+03 | +1.4594E+03 | -3.0091E-01 | +1.2832E+00 |
| 10 | +2.4384E+02 | +1.3260E+03 | +1.3097E+03 | +1.2260E+00 | +1.5450E+00 |
| 11 | +3.0480E+02 | +9.6300E+02 | +1.1213E+03 | -1.6434E+01 | +3.3538E-02 |
| 12 | +3.9624E+02 | +8.3500E+02 | +8.4717E+02 | -1.4572E+00 | +3.8963E+00 |

CORRELATION MATRIX:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | +1.00 | -.96 | +.96 | -.93 | +.87 | -.77 | +.69 | +.60 | -.67 |
| 2 | -.96 | +1.00 | -1.00 | +.99 | -.95 | +.87 | -.79 | -.70 | +.77 |
| 3 | +.96 | -1.00 | +1.00 | -.99 | +.96 | -.88 | +.80 | +.72 | -.79 |
| 4 | -.93 | +.99 | -.99 | +1.00 | -.99 | +.93 | -.86 | -.78 | +.85 |
| 5 | +.87 | -.95 | +.96 | -.99 | +1.00 | -.98 | +.93 | +.86 | -.92 |
| 6 | -.77 | +.87 | -.88 | +.93 | -.98 | +1.00 | -.99 | -.95 | +.98 |
| 7 | +.69 | -.79 | +.80 | -.86 | +.93 | -.99 | +1.00 | +.99 | -1.00 |
| 8 | +.60 | -.70 | +.72 | -.78 | +.86 | -.95 | +.99 | +1.00 | -.99 |
| 15 | -.67 | +.77 | -.79 | +.85 | -.92 | +.98 | -1.00 | -.99 | +1.00 |

REDUCED CHI-SQUARED=15.67
PHI=31.337

DCLAG: ******** END ********          KONA VES 4, ELEVATION=700 FT.

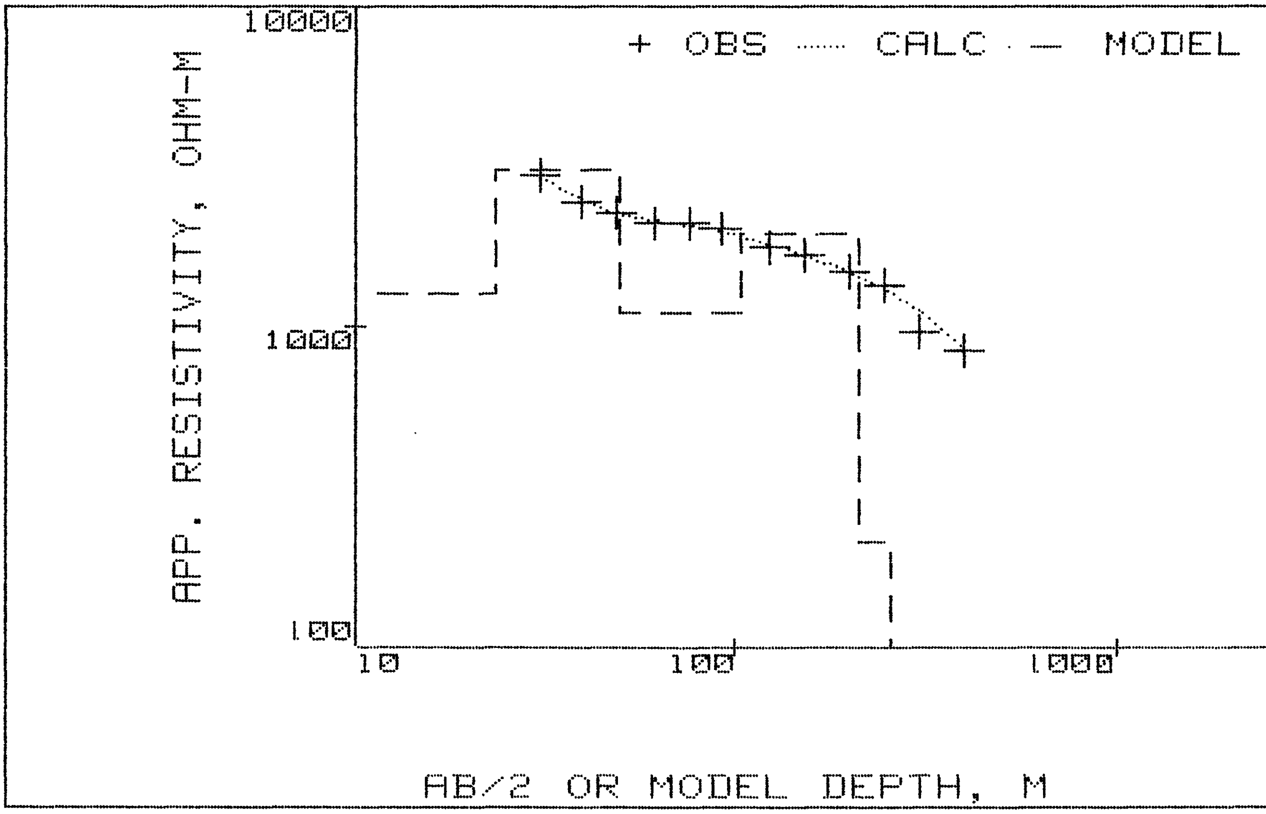
COORDINATES: 0 0   UTM4
ELEVATION   : 213   METER
AZIMUTH     : N10W

| B-SD | B | B+SD |
|---|---|---|
| 2.587E+003 | 3.083E+003 | 3.674E+003 |
| 6.013E+003 | 6.440E+003 | 6.897E+003 |
| 1.009E+003 | 1.239E+003 | 1.521E+003 |
| 2.230E+003 | 3.045E+003 | 4.160E+003 |
| 4.293E+002 | 1.088E+003 | 2.758E+003 |
| 9.272E+000 | 1.904E+003 | 3.910E+005 |
| 0.000E+000 | 2.138E+002 | 1.000E+100 |
| 0.000E+000 | 5.000E+000 | 1.000E+100 |
| | 3.328E+000 | |
| | 6.656E+000 | |
| | 1.331E+001 | |
| | 2.662E+001 | |
| | 5.325E+001 | |
| | 1.065E+002 | |
| 0.000E+000 | 4.558E+001 | 1.000E+100 |

FINAL UNSCALED PARAMETERS-- RESISTIVITY DEPTH
(* denotes fixed value)

| | | | | RESISTIVITY | | DEPTH |
|---|---|---|---|---|---|---|
| 1 | | 3.08319904E+03 | 1 | 3.083199E+03 | | |
| 2 | | 6.43981522E+03 | 2 | 6.439815E+03 | | |
| 3 | | 1.23858339E+03 | 3 | 1.238583E+03 | | |
| 4 | | 3.04548181E+03 | 4 | 3.045482E+03 | | |
| 5 | | 1.08803562E+03 | 5 | 1.088036E+03 | | |
| 6 | | 1.90401048E+03 | 6 | 1.904010E+03 | | |
| 7 | | 2.13834818E+02 | 7 | 2.138348E+02 | | |
| 8 | | 5.00000000E+00 | 8 | 5.000000E+00 | | |
| 9 | * | 3.32812500E+00 | | | 1 | 3.328125E+00 |
| 10 | * | 6.65625000E+00 | | | 2 | 9.984375E+00 |
| 11 | * | 1.33125000E+01 | | | 3 | 2.329687E+01 |
| 12 | * | 2.66250000E+01 | | | 4 | 4.992187E+01 |
| 13 | * | 5.32500000E+01 | | | 5 | 1.031719E+02 |
| 14 | * | 1.06500000E+02 | | | 6 | 2.096719E+02 |
| 15 | | 4.55802982E+01 | | | 7 | 2.552522E+02 |

KONA VES 4, ELEVATION=700 FT.



# REFERENCES

Anderson, W.A., 1979a, Program MARQDCLAG -- Marquardt inversion of Dc-Schlumberger soundings by lagged-convolution: U.S. Geological Survey Open-File Report 79-1432, 58 p.

Anderson, W.A., 1979b, Program MARQLOOPS -- Marquardt inversion of loop-loop frequency soundings: U.S. Geological Survey Open-File Report 79-240, 75 p.

Davis, D.A. and Yamanaga, G., 1968, Preliminary Report on the Water Resources of the Kona Area, Hawaii : U.S. Geological Survey Circular C46, 22 p.

Frignet, B., 1981, Two-layer inversion for E-mode VLF: in Manual of Geophysical Hand-Calculator Programs, Program EM3, Society of Exploration Geophysicists, 4 p.

Kauahikaua, J. and Jackson, D.B., 1983, Ground water exploration in the South Kohala District using vertical electrical sounding: U.S. Geological Survey Open-File Report 83-67, 20 p.

Kauahikaua, J. and Mattice, M.D., 1981, Geophysical reconnaissance of prospective geothermal areas on the Island of Hawai'i using electrical methods: U.S. Geological Survey Open-File Report 81-1044, 50 p.

Parasnis, D.S., 1979, Principles of Applied Geophysics : John Wiley & Sons, New York, 275 p.

Stearns, H.T. and Macdonald, G.A., 1946, Geology and Ground water Resources of the Island of Hawaii : Hawaii Div. of Hydrography Bull. 9, 363 p.

Zohdy, A.A.R. and Jackson, D.B., 1969, Application of deep electrical soundings for ground water exploration in Hawaii: Geophysics, v. 34, p. 584-600.