GEOPHYSICAL SURVEYS
ISLAND OF MOLOKAI, HAWAII
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1.0 INTRODUCTION

This report covers the results of geophysical surveys conducted by Blackhawk Geosciences, Inc. (BGI) for Alpha U.S.A., Inc. (Alpha) on the Island of Molokai, Hawaii. The field work was performed between February 15 and March 3, 1990. Two separate geophysical surveys were used by BGI during this period. The geophysical surveys conducted and their individual objectives are as follows:

1. **Time domain electromagnetic (TDEM) surveys** were conducted to map the thickness of the fresh to brackish water lens and the location of dike-impounded ground water to better outline the geohydrologic system of Molokai's central aquifer area.

2. **Gravity surveys** were performed to outline intrusive (dense) bodies which may form a base to dike-impounded ground water and may be a source of vertical impounding dikes.
2.0 SURVEY DESIGN AND DATA ACQUISITION

2.1 TDEM

The TDEM survey was designed to outline the geohydrology of the central aquifer system. This was accomplished by mapping the depth to the saline water saturated volcanics and computing the thickness of the basal fresh water lens which underlies a large part of the area. In addition areas of high level dike impounded water in which saline water is not located at depth were identified. TDEM sounding locations were determined prior to the survey with Alpha's consulting hydrogeologist, Tom Nance. The sounding locations were modified during the survey based on initial results. These changes to the initial plan were made during consultation with Tom Nance and Bob Diffley of Alpha. The soundings were scattered throughout the central aquifer region. Fewer soundings were made within the higher elevation area which has been identified as a zone of high-level dike-impounded ground water. A greater number of soundings were located along the edge of the high-level dike-impounded ground water zone.

2.1.1 Logistics

The geophysical survey was conducted by a two man crew from BGI. Two local hires were used to assist in the field work. The equipment was transported in the field utilizing a half-ton four-wheel drive pickup and a Jeep Wrangler.

The soundings were plotted on a U.S.G.S. 1:25,000 scale map and are shown on Figure 2-1. These locations were surveyed with compass and hip-chain from known locations such as road intersections.

A daily log of field activities is given in Table 2-1. The duration of TDEM field work was 15 days. Field work could not be done on March 1 due to heavy rains which made the dirt roads impassable. A total of 29 soundings were made during the field work.

2.1.2 Data Acquisition

All soundings were made utilizing the Geonics EM-37 TDEM system with a DAS-54 data logger. Transmitter loop sizes utilized were 1,000 ft by 1,000 ft for 24 of the soundings; 1,500 ft by 1,500 ft for four soundings; and 1,500 ft by 1,000 ft for one sounding. The transmitter loop size was determined by (i) available space for laying out the loops, and (ii) required depth of exploration. The current in the loops was 19 amps. The transmitter-receiver array used consisted of center-loop soundings.
At the center of each transmitter loop the time derivative of the vertical magnetic field is measured at several different amplifier gains and opposite receiver polarities. Two different receiver coils with effective areas of 100 m² and 1000 m² were used. The base frequencies used were 3 Hz and 30 Hz. All data from the soundings were recorded on the DAS-54 data logger for later processing on a portable computer.

2.2 GRAVITY

2.2.1 Logistics

A total of 27 gravity stations were measured in a period of two field days. Two additional field days were required for an elevation survey for the gravity stations. One local hire was employed during the two days of elevation surveying. The locations of the gravity stations are shown on Figure 2-1.

A daily log of field activity is given in Table 2-2.

2.2.2 Data Acquisition

A line of gravity stations trending roughly northwest to southeast was acquired using station B-1 as a base station. The instrument used for gravity measurements was a LaCoste-Romberg Model G Gravimeter. Base station B-1 was occupied at the beginning of the survey and was reoccupied every few hours during the course of the survey, so that instrument drift could be accounted for in the data processing.

The elevation survey was run using a Lietz Set4 electronic total station. A point of known elevation indicated on the topographic map was tied to the surveyed line of gravity stations so that elevations above sea level could be computed for each gravity station.
<table>
<thead>
<tr>
<th>Date (1990)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 14</td>
<td>Mobilize from Denver, Colorado to Honolulu, Hawaii.</td>
</tr>
<tr>
<td>February 15</td>
<td>Mobilize from Honolulu to Molokai. Read loops CA1 and CA2. Site check loop locations in forest.</td>
</tr>
<tr>
<td>February 16</td>
<td>Read loops CA3, CA4 and CA5.</td>
</tr>
<tr>
<td>February 17</td>
<td>Read loops CA6, CA7 and CA8.</td>
</tr>
<tr>
<td>February 18</td>
<td>Read loops CA9, CA10 and CA11.</td>
</tr>
<tr>
<td>February 19</td>
<td>Read loops CA12 and CA13.</td>
</tr>
<tr>
<td>February 20</td>
<td>Read loops CA14 and CA15.</td>
</tr>
<tr>
<td>February 21</td>
<td>Read loops CA16, CA17 and CA18.</td>
</tr>
<tr>
<td>February 24</td>
<td>Read loop CA25.</td>
</tr>
<tr>
<td>February 25</td>
<td>Read loops CA26 and CA27.</td>
</tr>
<tr>
<td>February 26</td>
<td>Read loop CA28.</td>
</tr>
<tr>
<td>February 27</td>
<td>Read loops CA29 and CA30.</td>
</tr>
<tr>
<td>February 28</td>
<td>Read loop CA31.</td>
</tr>
<tr>
<td>March 1</td>
<td>Weather day. Heavy rains prevent access on dirt roads.</td>
</tr>
<tr>
<td>March 2</td>
<td>Read loops CA32 and CA33.</td>
</tr>
<tr>
<td>March 3</td>
<td>Read loops CA34 and CA35.</td>
</tr>
<tr>
<td>March 5</td>
<td>Pack equipment and ship to Honolulu.</td>
</tr>
<tr>
<td>March 6</td>
<td>Demobilize from Molokai, HI to Denver, CO.</td>
</tr>
</tbody>
</table>
Table 2-2. Daily Log of Field Activities  
(Gravity Survey)

<table>
<thead>
<tr>
<th>Date (1990)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 14</td>
<td>Mobilize from Denver, Colorado to Honolulu, Hawaii.</td>
</tr>
<tr>
<td>February 15</td>
<td>Mobilize from Honolulu to Molokai.</td>
</tr>
<tr>
<td>February 16</td>
<td>Read gravity stations B1, M1 through M12, and AP1.</td>
</tr>
<tr>
<td>February 17</td>
<td>Survey gravity stations B1, M1 through M5, and J1 through J7.</td>
</tr>
<tr>
<td>February 18</td>
<td>Survey gravity stations M6 through M18.</td>
</tr>
<tr>
<td>February 19</td>
<td>Read gravity stations M13 through M18, and J1 through J7.</td>
</tr>
<tr>
<td>March 3</td>
<td>Demobilize from Molokai, HI to Denver, CO.</td>
</tr>
</tbody>
</table>
MAP
GOES
HERE
## 3.0 DATA PROCESSING

### 3.1 TDEM

The processing of the TDEM data consists of the following steps:

1. The raw data at each station were edited and averaged together in pairs.

2. Data pairs were edited for each base frequency and terminated at the point where excessive noise or minimum signal occurs.

3. Data pairs and base frequencies are averaged together to form one data set over the largest time range possible.

4. The data set produced in Step 3 is entered into an Automatic Ridge Regression Transient Inversion program.

The inversion program transforms the data into apparent resistivity values versus time. A starting geoelectric model (consisting of the number of layers, resistivities and thicknesses for each layer) is entered into the program. The inversion program then automatically adjusts the model parameters to obtain the best fit between the model and the field data. For all calculations a one-dimensional (horizontally layered) model is assumed.

The results of the transient inversion program from a typical sounding (sounding 1) are shown in Figures 3-1 and 3-2. Figure 3-1 shows the experimentally measured apparent resistivity data superimposed on the computed behavior (solid line) of subsurface resistivity layering that best matches the observed data. The resistivity layering of the best match is shown on the right. Figure 3-2 lists gate number, time, measured data, computed values, and errors for each time gate, as well as overall RMS error. The results of the 29 soundings are contained in the attachment to this report.

### 3.2 GRAVITY

Data reduction consisted of the following steps: The meter dial readings were converted to milligals using the meter factors for the LaCoste–Romberg Model G Gravimeter used for this survey. Earth tides were then calculated and added to the milligal values to obtain tide-corrected gravity. The instrument drift was then removed using station B-1 as a base station. The longest period between re-occupation of the base station for the survey was 3 hours 28 minutes. After all drift factors had been accounted for, latitude, free air effect, bouguer slab, and terrain...
corrections were calculated and applied to generate bouguer gravity. From bouguer gravity, lateral variations in subsurface density can be inferred.
EXAMPLE OF INVERSION RESULTS

% ERROR: 1.78
CALIBRATION: 1
OFFSET: 61.0 M
RAMP: 50.0
Blackhawk Geosciences
# Example of Inversion Data Sheet

**FIGURE 3-2**

**Model:** 5 Layers

<table>
<thead>
<tr>
<th>Resistivity (ohm-m)</th>
<th>Thickness (m)</th>
<th>Elevation (m)</th>
<th>Conductance (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.83</td>
<td>18.5</td>
<td>67.1</td>
<td>Layer 2.4</td>
</tr>
<tr>
<td>200.64</td>
<td>63.7</td>
<td>-15.1</td>
<td>Layer 2.7</td>
</tr>
<tr>
<td>2.12</td>
<td>35.4</td>
<td>159.4</td>
<td>Layer 16.7</td>
</tr>
<tr>
<td>7.27</td>
<td>198.8</td>
<td>-49.5</td>
<td>Layer 27.3</td>
</tr>
<tr>
<td>14.08</td>
<td></td>
<td></td>
<td>Total 46.7</td>
</tr>
</tbody>
</table>

**Times** | **Data** | **Calc** | **% Error** | **Std Err**
---|---|---|---|---
1 | 1.40E-04 | 2.13E+01 | 2.13E+01 | -0.076 |
2 | 1.77E-04 | 2.12E+01 | 2.12E+01 | -0.131 |
3 | 2.20E-04 | 2.19E+01 | 2.17E+01 | -0.708 |
4 | 2.80E-04 | 2.25E+01 | 2.27E+01 | -0.836 |
5 | 3.55E-04 | 2.35E+01 | 2.34E+01 | 0.433  |
6 | 4.43E-04 | 2.32E+01 | 2.31E+01 | 0.235  |
7 | 5.64E-04 | 2.14E+01 | 2.15E+01 | -0.730 |
8 | 7.13E-04 | 1.91E+01 | 1.90E+01 | 0.602  |
9 | 8.81E-04 | 1.64E+01 | 1.65E+01 | -0.537 |
10 | 1.10E-03 | 1.43E+01 | 1.42E+01 | 0.598  |
11 | 1.41E-03 | 1.21E+01 | 1.20E+01 | 0.800  |
12 | 1.78E-03 | 1.04E+01 | 1.05E+01 | -1.328 |
13 | 2.21E-03 | 9.45E+00  | 9.47E+00  | -0.207 |
14 | 2.83E-03 | 8.79E+00  | 8.58E+00  | 2.527  |
15 | 3.55E-03 | 7.78E+00  | 7.96E+00  | -2.260 |
16 | 4.43E-03 | 7.45E+00  | 7.52E+00  | -0.950 |
17 | 5.64E-03 | 7.18E+00  | 7.17E+00  | 0.017  |
18 | 7.13E-03 | 7.12E+00  | 6.94E+00  | 2.593  |
19 | 8.81E-03 | 6.75E+00  | 6.80E+00  | -0.754 |
20 | 1.10E-02 | 6.68E+00  | 6.73E+00  | -0.795 |
21 | 1.41E-02 | 6.67E+00  | 6.72E+00  | -0.696 |
22 | 1.80E-02 | 6.78E+00  | 6.79E+00  | -0.124 |
23 | 2.22E-02 | 7.08E+00  | 6.92E+00  | 2.427  |

R: 61, X: 0, Y: 61, DL: 122, REQ: 68, CF: 1.0000
CLHZ ARRAY, 23 DATA POINTS, RAMP: 50.0 MICROSEC, DATA: 00-01

**RMS Log Error:** 7.67E-03, ANTILOG YIELDS 1.7810 %

**Late Time Parameters**

* Blackhawk Geosciences *

**Parameter Resolution Matrix:**

"F" MEANS FIXED PARAMETER

| P | 0.99 |
| P 2 | -0.02 | 0.01 |
| P 3 | 0.03 | 0.00 | 0.88 |
| P 4 | 0.02 | 0.00 | -0.07 | 0.93 |
| P 5 | 0.00 | -0.01 | -0.01 | -0.04 | 0.86 |
| T 1 | -0.02 | -0.06 | 0.05 | 0.02 | 0.00 | 0.97 |
| T 2 | 0.00 | 0.02 | 0.02 | 0.01 | 0.00 | -0.01 | 1.00 |
| T 3 | 0.05 | 0.00 | -0.19 | -0.12 | -0.03 | 0.08 | 0.03 | 0.68 |
4.0 INTERPRETATION AND RESULTS

4.1 TDEM

The general procedures in the interpretation of TDEM soundings are discussed in BGI's December 1989 report entitled, "TDEM Survey, Western Portion of the Island of Molokai, State of Hawaii", and are not be repeated in this report.

The results of the TDEM survey are addressed in terms of the central aquifer area of Molokai. Soundings are from the present survey and the December 1989 survey.

4.1.1 Central Aquifer

The results of the TDEM soundings are shown in Figures 4-1 and 4-2. Figure 4-1 shows an approximate division line of easily exploitable fresh water inland, running generally northwest-southeast through the center of the map area. It is expected that the basal ground water with an approximate hydrologic head of > 10 ft is mostly fresh northeast of the division line, and mostly brackish southwest of this line. Also shown on the map is the elevation of the top of saline water of each sounding. The depth below sea level of the top of the saline water interface is approximately equal to the thickness of the fresh to brackish water lens.

From this map several other features are detected. These are:

1. A central area at higher elevations where no saline waters were detected.
2. Thick zones of fresh water (> 700 ft) occurring close to the ocean along the north side of the island.
3. A rapid thinning of the fresh water lens along a northwest-southeast line running through the center of the map area.
4. Gradual thinning of the fresh/brackish water lens in the area of the Hoolehua Plain.

No saline water is detected in soundings CA16, CA25 and CA28 which are shown on Figure 4-2 to have resistive basements. The possible reasons for this are (i) the saline water is located far below sea level beyond the exploration limit of the TDEM system, or (ii) saline water has not migrated under this portion of the island due to dikes and/or intrusive bodies impeding the flow. In either case it is likely that dike-impounded water is present in this area. From the survey it is not possible to determine the elevation of fresh water above sea level.
Along the north side of the island from sounding CA29 at Meyers Lake to sounding CA18 north of Puu Anoano a thick fresh water lens is present. Because the proximity of this area to the ocean (less than 4,000 ft) a relatively thin lens would be expected due to drainage into the ocean. For this thickness to develop an impedance (apparent hydrologic boundary) to ground water flow towards the ocean must exist. The most probable cause of this impedance is vertical dikes. The results of the gravity survey (Fig. 4-3) implies that an intrusive body is present at depth in this area. This makes it quite likely that numerous vertical dikes occur in the area.

The area of rapid thinning of the fresh to brackish ground water lens in the center of the map may be due to a decrease in the permeability of the lavas in this area. The area of rapid thinning generally parallels several volcanic vents. These vents include Puu Luahine, Kakalahale, the area northwest of the Kualapuu vent, and possibly Eleuweuewe and Puu Anoano. From soundings performed in the areas of volcanic vents, such as sounding 39 of the 1989 survey, and sounding CA14 of this survey, clay alteration of the surrounding volcanics is inferred. This alteration lowers the permeability of the volcanics which requires a larger drop in hydrologic head for ground water to move across the lower permeability area. The zones of lower permeability were not mapped directly by the TDEM soundings due to the relatively widely spaced soundings.

The area of gradual thinning of the fresh to brackish water lens shows a fairly consistent trend. Soundings CA1 and CA2 of the present survey, however, show an anomalously thin brackish water lens. Sounding CA1 is adjacent to sounding 39 of the 1989 survey which does not detect saline water due to alteration of the volcanics. It is possible that this adjacent alteration is affecting sounding CA1 resulting in too low a value for the thickness of the brackish water lens. Sounding CA2 shows a 49 foot thick brackish water lens which is thinner than what is expected at that location. There is indication from nearby soundings that a trough of relatively thin lens may occur through this area.

4.1.2 Distortion of TDEM Soundings

In several of the TDEM soundings there was a relatively poor fit of interpreted model to portions of the data. Figure 4-4 is an example of such a sounding. In the time range 1 to 4 milliseconds the agreement between model and data is poor. The reasons for this are:

1. In certain geoelectric sections where highly resistive zones occur, it is difficult for the instrument to record the data over certain time ranges.
2. Lateral discontinuities (2-D effects), in this case a 1,200 ft cliff, make the data difficult to match utilizing 1-D modeling.

Although the stated overall error of fit of model to data is relatively high, most of the error is in a limited time range. Fortunately, the distortion of the curve does not extend into the time range that corresponds to the low resistivity zone of the saline water saturated volcanics. The primary interpreted parameter in this survey, i.e., the total depth to the saline water, is not expected to be severely affected by this type of curve distortion. The main parameter of the interpreted sounding that is affected is the magnitude of resistivity of the resistive volcanics which is probably overestimated. In addition, the resistivity of the saline water saturated volcanics may be somewhat underestimated.

Although the depth to the saline water saturated volcanics has a greater degree of uncertainty in distorted curves, these soundings are still useful in the overall interpretation of the area.

4.2 GRAVITY

The plot of the bouger gravity anomaly is shown in Figure 4-3. A large regional gradient ( >10 mgal) increasing from south to north is the main feature of the data. One likely interpretation of this gradient is a large deeply buried intrusive which is centered near the north shore of the island. Since the anomaly does not descend on the north it is difficult to place the exact position of the intrusive. The survey line does not show evidence of large intrusive bodies along the southern portion of the area covered by this line. This indicates that although small intrusive bodies with associated dikes may occur in the southern portion of the survey, the frequency of potential ground water impounding dikes should be much greater along the north side of the island.

It is difficult to outline small-scale features with one gravity line. From the present survey it is apparent that large-scale features associated with major intrusives are readily observable.
MAP
GOES
HERE
CA26

MODEL:

187
OHM-M 291 M

5555
OHM-M 489 M

1.30
OHM-M 46.7 M

57.3
OHM-M

% ERROR: 18.0
CALIBRATION: 1
OFFSET: 150 M
RAMP: 200.0

Blackhawk Geosciences

TIME RANGE
DISTORTED DATA

FIGURE 4-4
5.0 SUMMARY AND CONCLUSIONS

The TDEM and gravity surveys over the central aquifer area of Molokai were effective in outlining the geohydrology of the island. The main results of the survey are:

1. An area in which no saline waters were detected which probably is related to high-level dike impoundment.

2. An area along north Molokai adjacent to the coast in which a much thicker than expected fresh water lens is present. This is most likely related to dike impoundment (apparent hydrologic boundary).

3. A transition zone of rapid hydrologic head decline between the interpreted high-level dike-impounded water and the gradual decline in hydrologic head which occurs on the Hoolehua plain.