TIME DOMAIN ELECTROMAGNETIC SURVEYS FOR ASSISTING IN DETERMINING THE GROUNDWATER RESOURCES ON KULA 1800 PROPERTY ISLAND OF MAUI, HAWAII

Project Number 5038

May 2006

Prepared For:

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TABLE OF CONTENTS

LIST OF FIGURES AT THE END OF THE TEXT

LIST OF TABLES

APPENDICES

1.0 INTRODUCTION

This report contains the results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation at the Kula 1800 Property located on the Island of Maui, Hawaii. Blackhawk, a Division of ZAPATA ENGINEERING (Blackhawk) conducted the surveys from May 2 through May 5, 2006 for Kula 1800 Investment Partners, LLC (Kula 1800 Partners) of Maui and Tom Nance Water Resource Engineering (TNWRE) of Honolulu, Hawaii.

The main objectives of the TDEM surveys on Maui were to explore for possible basal and high-level groundwater occurrences at the project site. The surveys were conducted at six TDEM sounding locations. This allowed for the creation of two survey lines, one positioned along the Pulehu Road and the second located along the Naalae Road near the Waiakoa Gulch. Figure 1-1 shows the locations of the TDEM soundings taken during this survey on the Kula 1800 Property.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, the degree of saturation, and concentration of dissolved solids in the groundwater. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. intrusives, dikes, etc).

The basic geologic and hydrologic framework of the Island of Maui and the two modes of groundwater occurrences are illustrated in Figure 2-1. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM surveys previously run on Hawaii have reliably mapped the basal mode groundwater occurrence and the boundary between fresh water in the basal mode and high-level water occurrences. Basal mode groundwater is resting approximately at sea level near the ocean surrounding the Island of Maui. This is generally due to the fact that the volcanic rocks, which comprise the island, allow rainfall to percolate with little impedance directly downward through the rock mass (reference Figure 2-1). The fresh water floats directly on the seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the ocean. When groundwater is under conditions of static equilibrium, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level, approximately 40 feet of fresh water will exist below sea level as shown in Figure 2-2. The transition from fresh water to seawater at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual, depending upon hydrologic flux, horizontal to vertical permeability contrast, and other geologic factors. It is assumed, when resolving TDEM data, that seawater saturated volcanics begin at the midpoint of the transition zone.

TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous previous TDEM surveys and calibration at well sites, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity occurs between the units; however, other factors (such as elevation) can be used to separate the units. Therefore the main geologic/hydrologic units that can be derived from TDEM surveys are:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg Principle, the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterites). These lower resistivity units are generally relatively thin (100 ft to 200 ft) layers that occur mainly at or near the ground surface.
- Clay poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values. Note that the extent of fresh water saturation is normally based on geographic and elevation information, and that the fresh water cannot usually be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM by uncharacteristic sounding curves (distorted by 2-D structures), and by soundings that transition between detection of seawater at depth (indicating basal mode groundwater) and soundings that map high resistivities to depths below sea level (indicating possible high-level groundwater).

3.0 DATA ACQUISITION AND LOGISTICS

Blackhawk mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys. The crew and equipment were mobilized from Golden, Colorado. During the TDEM field surveys on Maui, Kula 1800 Partners personnel provided field site orientation and access (key to locked gates) to the property while TNWRE personnel provided project direction and oversight. A daily log of field activities during the TDEM surveys is presented in Table 3-1.

The geophysical equipment utilized for the TDEM surveys was the Geonics EM37 system. The EM37 system consists of both a portable motor-generator powered transmitter and a PROTEM digital receiver. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section of the subsurface. To accomplish this, the TDEM measurements were acquired using a central-loop array at each sounding site. The square transmitter loops were constructed using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1. The dimensions for the transmitter wire loops were 1,000 ft by 1,000 ft. The transmitter was placed at a corner of the wire-loop and square-wave current pulses were driven through the wire utilizing a current of 14 amperes. The current pulses induce eddy current flow in the subsurface. A receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of the wire-loop and used to record the decay of the secondary magnetic field due to the eddy currents induced in the subsurface. The effective exploration depth with a 1,000 ft by 1,000 ft transmitter wire-loop array is determined to be approximately 2,500 ft. Greater exploration depths are reached with larger wire-loops and factors that affect the depth of investigation include ground resistivity (ohm-m) and ambient noise (i.e. 60-cycle power line).

The TDEM data acquired at each sounding consisted of measurements utilizing several receiver gain settings and two transmitter frequencies in order to ensure data quality and to obtain data over the longest possible time interval. The data were recorded at base frequencies of 3 Hz and 30 Hz for the TDEM soundings at the Kula 1800 Property. For data quality control purposes, additional offset data sets were collected at designated locations, from the center of each sounding, for comparison to the center loop data. The data from each sounding were stored in a solid-state memory logger in the PROTEM receiver and transferred at the end of each day to a PC for processing. The TDEM data collected for all of the soundings were of excellent quality with no measured cultural interference (i.e. 60-cycle noise) from nearby power lines and/or pipelines located along the roadways. A technical note describing the principles of TDEM with case histories is given in Appendix A.

The transmitter wire-loop corners and centers were registered to road junctions, gates and fences located on the property. Other landmarks, such as water tanks and gulches, were also used to locate the corners of the wire-loops on the map with a hip-chain and compass. In addition, a hand-held Global Positioning System (GPS) was utilized to map both the centers and elevations of the soundings and were placed on the topographic map. A total of six soundings were measured on the Kula 1800 Property during the four days of fieldwork. The GPS coordinates and elevations of the TDEM soundings are given in Table 3-2 in Appendix B.

Table 3-1
Daily Log of Field Activities
Kula 1800 Property TDEM Survey

Date (2006)	Activity
April 26	Ship TDEM geophysical equipment from Golden, CO to Kahalui, Maui.
May 1	Mobilize Blackhawk field crew from Golden, CO to Kahalui, Maui. Meet with client and discuss Kula 1800 project and receive key to property gates.
May 2	Unpack TDEM geophysical equipment at Kamaole Sands hotel. Test motor-generator and organize equipment into 4WD vehicle. Begin geophysical survey. Collect TDEM data on Soundings K-1 and K-2. Download data to PC and perform preliminary data analysis in hotel. Discuss results with TNWRE.
May 3	Acquire TDEM data on Soundings K-3 and K-4. Download data to PC and perform preliminary data analysis in hotel. Discuss results with TNWRE.
May 4	Take TDEM data on Sounding K-5. Download data to PC in field and perform preliminary data analysis. Discuss results with TNWRE and client. Decision is made by client to continue data collection. Perform recon for Sounding K-6 and access across Waiakoa Gulch.
May 5	Remove boulders and grade power line road to gain access through Waiakoa Gulch with 4WD ATV. Collect TDEM data on Sounding K-6. Download data and perform data analysis in hotel.
May 6	Discuss Sounding K-6 results with TNWRE. Pack up TDEM equipment and store shipping boxes at hotel. Demobilize one person from Blackhawk crew from Kahalui, Maui to Golden, CO.
May 7	Day off.
May 8-9	Deliver TDEM equipment to FedEx office in Kahalui. Demobilize remaining Blackhawk personnel from Kahalui, Maui to Golden, CO.

4.0 DATA PROCESSING

The field data collected at each TDEM sounding was transferred from the Geonics PROTEM digital receiver to a PC for editing and processing. Processing of the TDEM data begins with averaging of the electromotive forces recorded at positive and negative receiver polarities. Next, the measurements collected at the two base frequencies (3 and 30 Hz) and different amplifier gains were combined to give one voltage decay curve (transient). The electromotive forces in the various time gates of the decay curves were subsequently entered into the TEMIXXL (Interpex Ltd.) inversion program to obtain a one-dimensional (1-D) geoelectric section that best matches the observed decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers and the resistivities and thickness for each of the layers. This model is usually derived from general knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown on Figure 4-1 for Sounding K-1 on the Kula 1800 Property. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A three-layer inversion model is shown for Sounding K-1. The model displays a relatively thin (91 ft) moderately resistive (73 ohm-m) surface layer of clay soil (laterite) with a thick (1106 ft) resistive (449 ohm-m) second layer overlying a third conductive (9 ohm-m) layer. The depth to the top of the third layer is located at about 103 ft above sea level (asl) in the section.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Figures 4-1 and 4-2 also show the equivalence analysis for Sounding K-1. This sounding is typical of the TDEM data and shows about a +/-5% equivalence in depth determinations and +/-10% in individual layer resistivities. The inversion results for each sounding of this project are given in Appendix B.

5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion of the individual TDEM soundings can be linked together (layers with similar resistivities) to create a 2-D geoelectric cross-section along a survey line. For this survey, a total of six (6) TDEM soundings were collected along the Pulehu and Naalae roads at the Kula 1800 Property. The survey data allowed for construction of two geoelectric cross-sections that trend from west to east as shown on Figure 1-2. The correlations between geoelectric layers and lithologic units established in Figure 2-3 were used to guide the interpretations on these geoelectric cross-sections.

5.2 GEOELECTRIC CROSS-SECTION - LINE 1 (A-A')

Figure 5-1 shows the layered geoelectric cross-section from the TDEM data taken along Line 1 on the Kula 1800 Property. The TDEM soundings were located along Pulehu Road in an approximate west to east direction with the center of Sounding K-1 at an elevation of 1,300 ft, and Sounding K-2 at 1,650 ft elevation. The soundings were positioned south of Pulehu Road due to property access and location of powerlines and metal pipelines along the road.

A three-layer cross-section is interpreted for the two soundings along Line 1. The upper layer in the geoelectric cross-section exhibits intermediate to high resistivities ranging from 74 to 131 ohm-m and is interpreted as a relatively thick (90 to 150 ft) laterite surface layer. The second layer in the section exhibits high resistivities that range from 157 to 449 ohm-m and is interpreted as dry clay poor volcanic formations above sea level. The third layer in the section displays low resistivity values (9 to 11 ohm-m) and is interpreted to be influenced by geologic structures (i.e. intrusives, dikes) at depth beneath the soundings. The top of the third layer is interpreted to occur at an elevation of about 103 ft above sea level at Sounding K-1 and about 712 ft above sea level at Sounding K-2. The third layer of the section is expected to be influenced by 2-D geologic structures (i.e. intrusives, dikes), the presences of significant amounts of fine-grained materials (clay layers) in these areas, or possible saturation of this portion of the geologic section with brackish groundwater. Therefore, both of these TDEM soundings are interpreted to be located within areas that are controlled by structures that have distorted the true formation resistivities. Because these two soundings did not detect seawater saturated volcanic formations (i.e. 3 ohm-m values) below sea level in the section, a calculation cannot be made for the thickness of the fresh-brackish water lens in these areas.

5.3 GEOELECTRIC CROSS-SECTION - LINE 2 (B-B')

The geoelectric cross-section from the TDEM data taken along Line 2 is shown in Figure 5-2. The soundings were situated along Naalae Road in a roughly west to east trend with the center of Sounding K-3 at an elevation of 1,300 ft, and Sounding K-6 at an elevation of 1,700 ft. on the east end of the line. During the survey, it was necessary to reposition the soundings both north and south of Naalae Road, to avoid interference from powerlines and metal pipelines in the area.

A three-layer section is interpreted for the four soundings along Line 2. The upper layer in the geoelectric cross-section shows intermediate to high resistivities that range from 101 to 163 ohm-m and is interpreted as a thick (188 to 410 ft) laterite surface layer. The second layer in the cross-section exhibits high resistivities that range from 106 to >1000 ohm-m and is interpreted as dry clay poor volcanic formations both above and below sea level. Where the second layer occurs below sea level it is expected to be saturated with fresh-brackish basal mode water. The third layer in the section with low resistivities (2.5 to 4.7 ohm-m) is interpreted to represent seawater saturated volcanic layers at depth beneath Soundings K-3, K- 4 and K-5. The calculated thickness of the fresh-brackish water lens ranges from 156 ft beneath Sounding K-3 to 109 ft beneath Sounding K-5.

Sounding K-6 exhibits a high resistivity value (336 ohm-m) throughout the effective exploration depth of the TDEM measurement (about 750 ft below sea level). Therefore, this sounding is interpreted to be located above the geologic/hydrologic structure (i.e. intrusive, dikes) that is observed beneath Soundings K-1 and K-2 on Line 1. With the existing TDEM data density, the geologic/hydrologic boundary is interpreted midway between Soundings K-5 and K-6, and the potential for high-level groundwater may exist beneath Sounding K-6. Also, the exact position and width of the structure is uncertain due to the data density in this area.

5.4 HYDROGEOLOGIC INTERPRETATIONS

Table 5-1 contains the approximate thickness of the fresh-brackish water lens calculated from the elevation of the seawater interface interpreted from the TDEM soundings taken at the Kula 1800 Property. The table includes the value of static water level (head) calculated by using the Ghyben-Herzberg Principle.

Table 5-1
Hydrogeologic Information Derived From TDEM Soundings
Kula 1800 Property
(Values in Feet)

Sounding Number	Surface Elevation	Elevation of Top of the Conductive Layer	Calculated Static Water Level (Head) Using Ghyben-Herzberg Principle	Approximate Thickness of Fresh-Brackish Water Lens
K-1	1300	*	*	*
K-2	1650	*	*	*
K-3	1300	-156	3.9	160
K-4	1500	-149	3.7	153
K-5	1680	-109	2.7	112
K-6	1700	*	*	*

*The TDEM sounding did not detect seawater-saturated layers at depth in the section; therefore, a calculation cannot be made for the thickness of the fresh-brackish water lens for this data.

The TDEM data is further summarized on the interpretation map shown in Figure 5-3. On this map the soundings are separated into three groups and are color coded:

1. Three soundings K-3, K-4 and K-5 (blue), in which a layer of low resistivity was detected below sea level. A fresh-brackish water lens is expected to occur in the basal mode beneath these soundings.
2. Two soundings K-1 and K-2 (green), which are interpreted to be influenced by lateral discontinuities (i.e. intrusives) and geologic/hydrogeologic groundwater damming structures are inferred. Low resistivity values occur above sea level and groundwater levels, water quality and production are expected to be variable in these areas.
3. Sounding K-6 (yellow), where a high resistivity value was interpreted to the effective exploration depth of the sounding (about 750 ft below sea level). The potential for high-level groundwater likely exists in the area of this sounding.

The accuracy of determining the depth to the saltwater interface from TDEM soundings is estimated to be +/-5% of the total depth calculated in the sounding measurement, (e.g. from the ground surface to the salt water interface). The accuracy of determining the groundwater damming structures at the Kula 1800 Property is mainly determined by the TDEM data density (sounding spacing).

From the summary map, the boundary of the inferred geologic/hydrologic discontinuity appears to be located between Soundings K-4 and K-6 on the west; and between Soundings K-5 and K-6 on the south, roughly along the Waiakoa Gulch. From there, the results from Soundings K-1 and K-2 suggest that it extends to the northwest between K-1 and K-3 and northeast between K-2 and K-6. Due to the sparse TDEM data density, the discontinuity boundary is not well defined in these areas of the property.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objectives of the TDEM surveys on the Kula 1800 Property on Maui were to explore for basal and high-level groundwater resources. The optimum locations for groundwater in the basal mode are expected to occur where the thickest lens of fresh-brackish water is detected floating on seawater. The optimum locations for high-level groundwater are expected to occur within dike-confined areas detected at relatively low surface elevations.

The results from the surveys are shown on the summary map in Figure 5-3. The TDEM data indicate:

- That beneath Soundings K-3, K-4 and K-5, a lens of basal mode fresh-brackish water occurs. The thickest lens of potential fresh-brackish water resource is interpreted to occur beneath Sounding K-3, and is estimated to be 160 ft thick.
- In areas beneath Soundings K-1 and K-2, the data are interpreted to be influenced by lateral discontinuities (i.e. intrusives) and groundwater-damming structures are inferred. The groundwater regime is expected to be structurally complicated in these areas and groundwater yield and quality is expected to be variable.
- Beneath Sounding K-6, the potential for high-level groundwater is expected to exist. Groundwater damming structures are interpreted on three sides of Sounding K-6 (south, west and north) and therefore, this appears to be the best location for high-level groundwater occurrence.

The groundwater resources within areas controlled by geologic/hydrogeologic structures cannot be determined directly from TDEM sounding data.

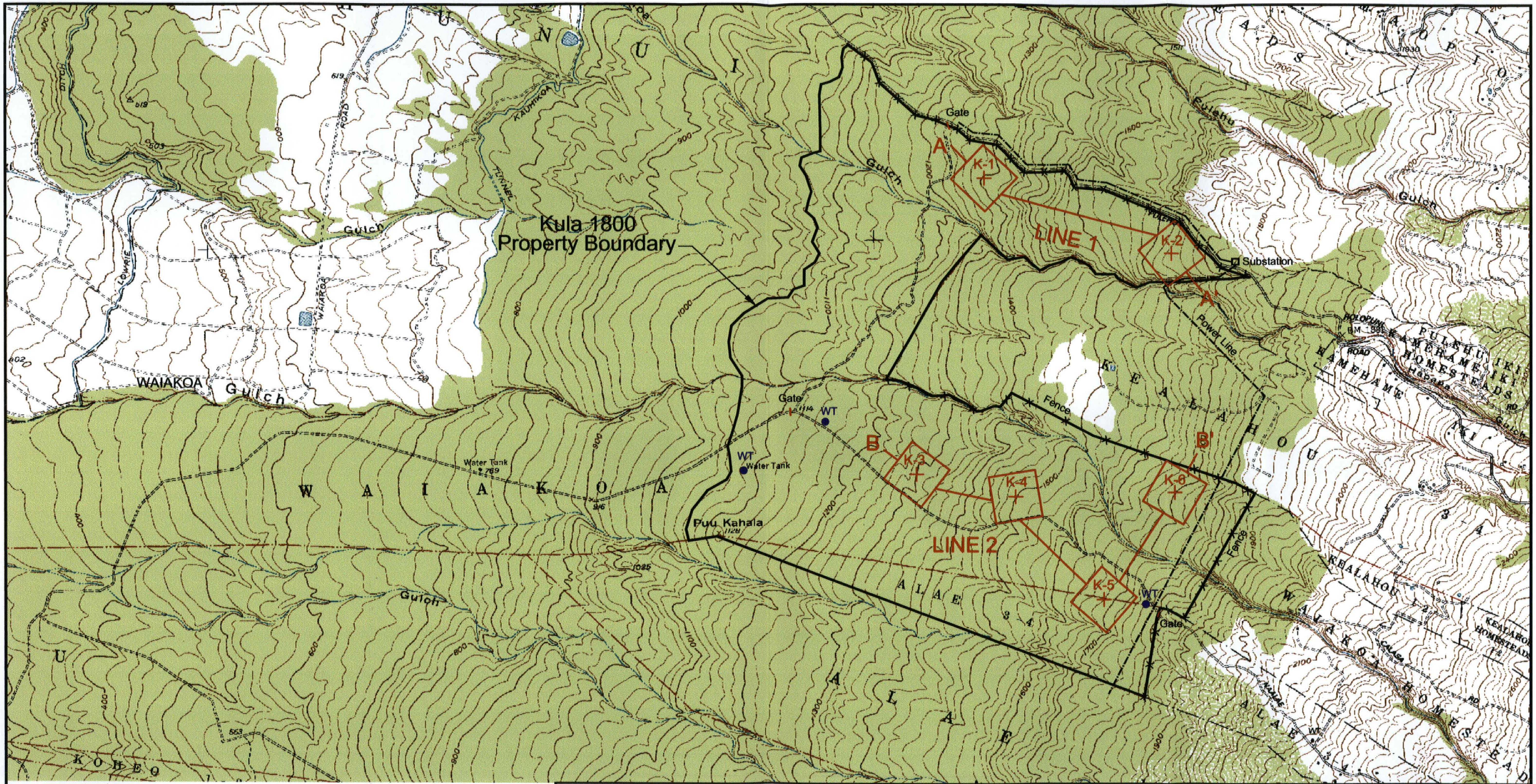
Due to the location of the existing power line and limited road access on the east portion of the property boundary, it was necessary to move Sounding K-6 to a lower elevation than originally planned to avoid cultural interference (i.e. 60-cycle noise) to the data. Therefore, additional TDEM soundings located above the power line and east (upslope) of the property boundary fence line will help define the extent of potential high-level groundwater in this area of the site.

7.0 CERTIFICATION

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk, a Division of ZAPATA ENGINEERING, Senior Geophysicists.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.



Explanation

K-1	TDEM Soundings
A-A'	Section Line
WT ●	Water Tank

Maui
Hawaiian Islands

N

0 2000 4000
Scale in Feet

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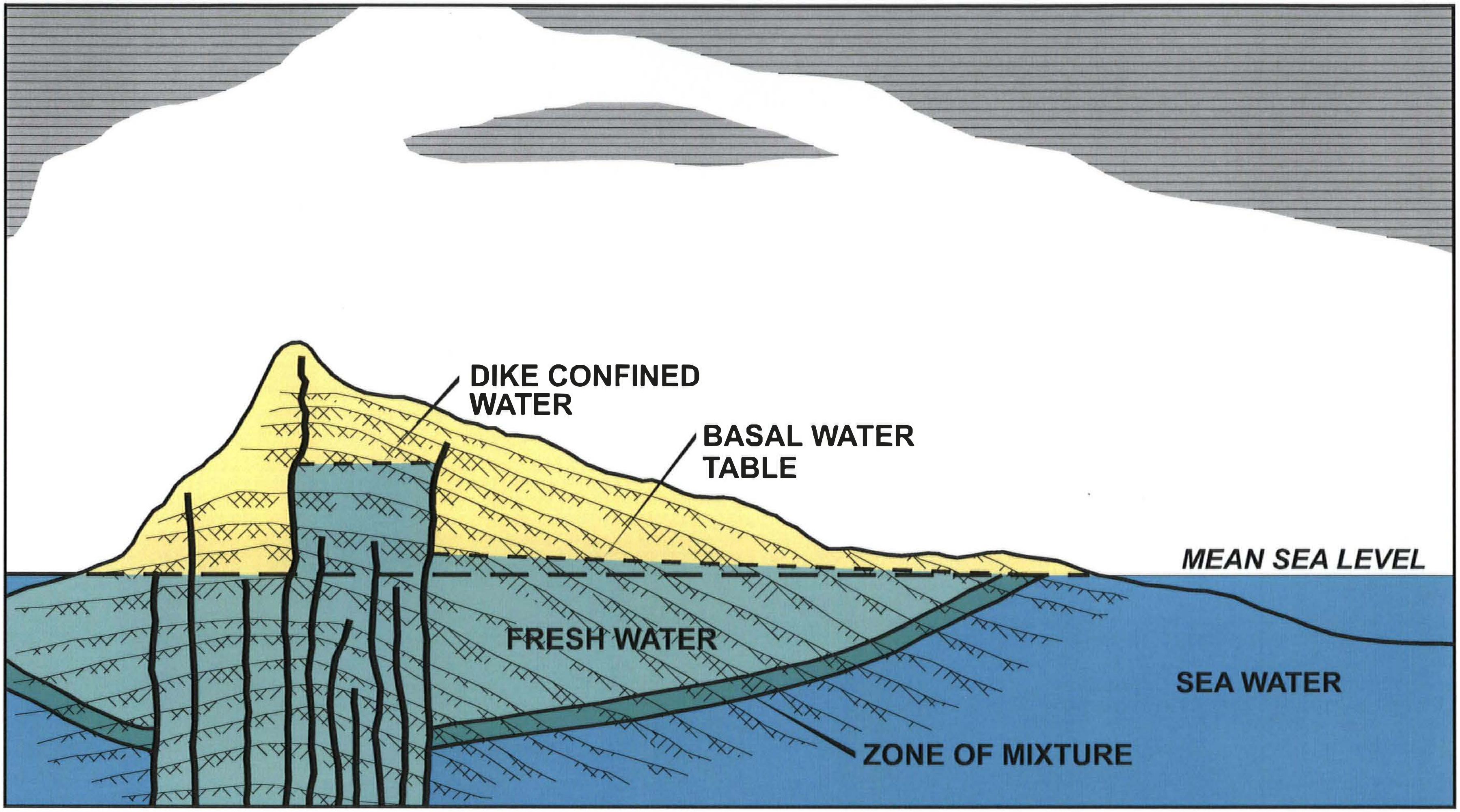
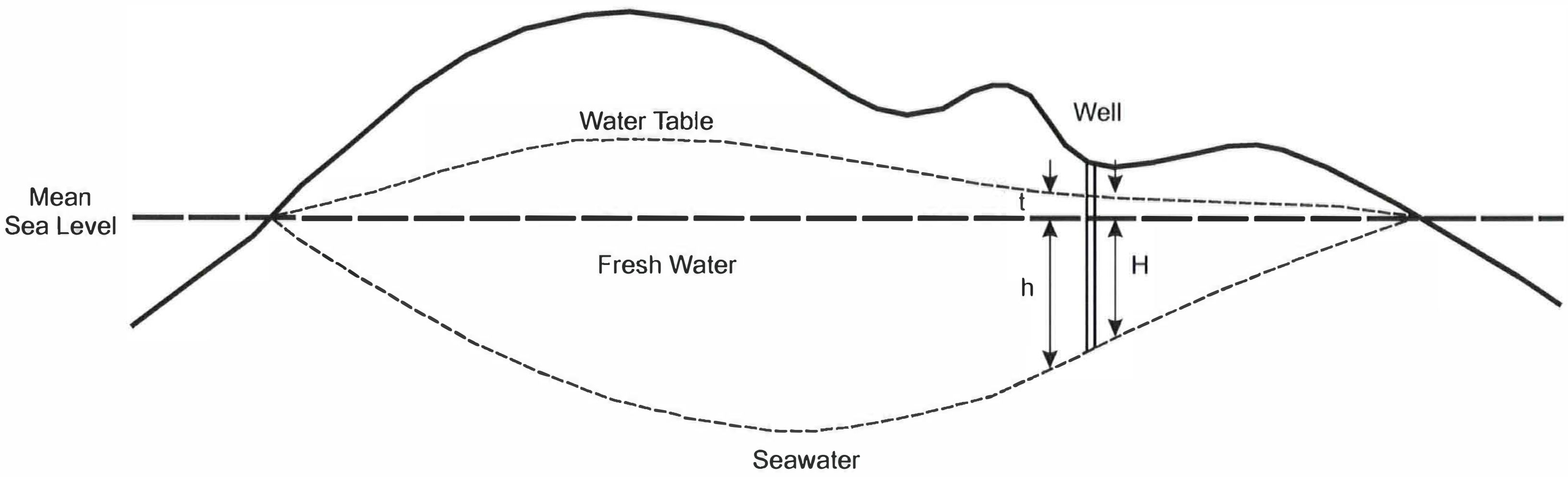
Kula 1800
Investment Partners, LLC

Geophysical TDEM Survey
Location Map
Maui County, Island of Maui

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5038	May, 2006	HJV	RJB	1"=2000'	1-1



BLACKHAWK A DIVISION OF ZAPATAENGINEERING		Kula 1800 Investment Partners, LLC			Schematic Hydrogeologic Cross Section *Island of Maui*		
301 Commercial Road, Suite B Golden, Colorado 80401	Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5038	Date: May, 2006	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 2-1



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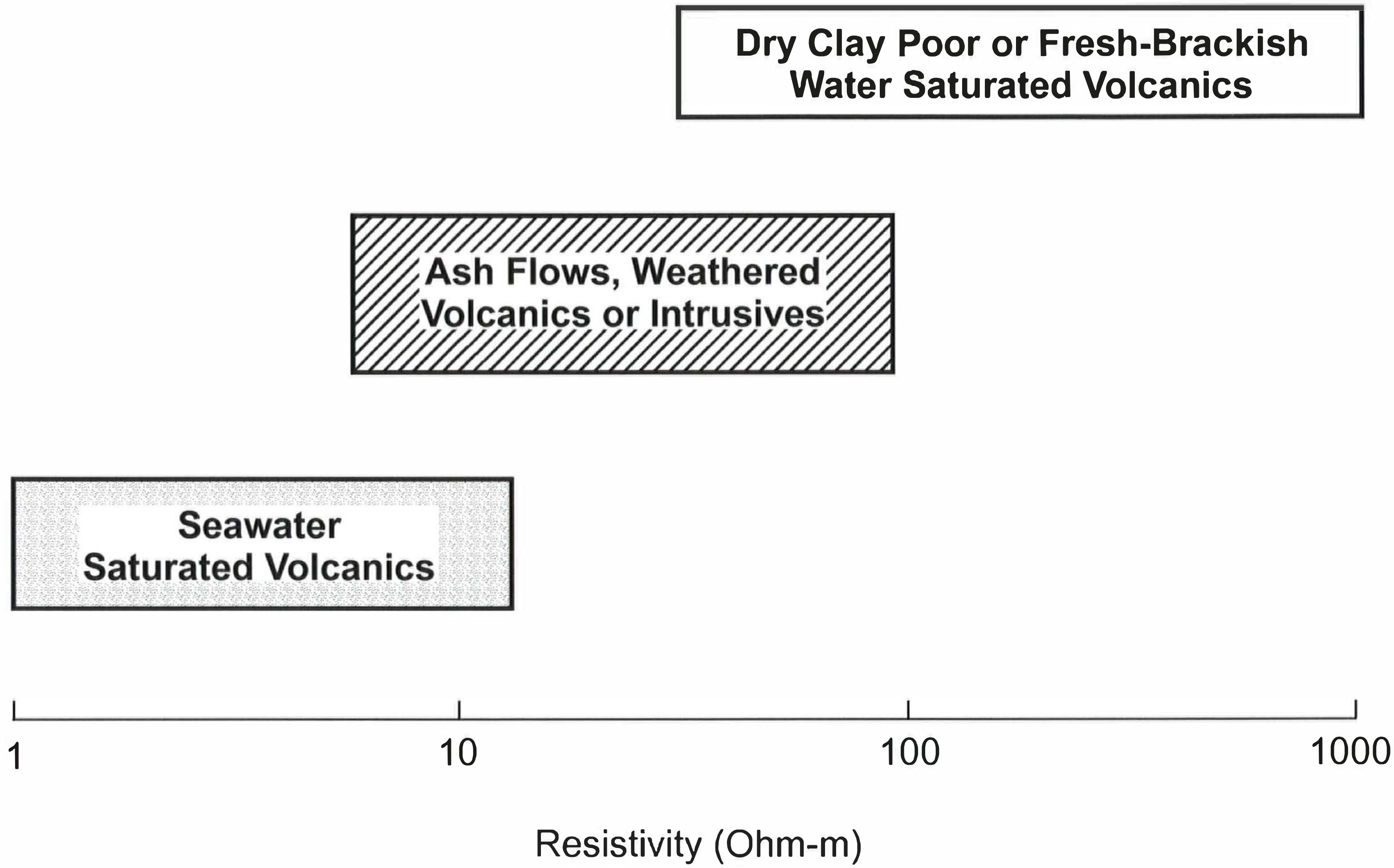
From: Herzberg

BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	**Kula 1800 Investment Partners, LLC**			**Illustration of the Ghyben-Herzberg Principle**		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5038	Date: May, 2006	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 2-2



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Kula 1800 Investment Partners, LLC	**Characteristic Resistivity Ranges** *Island of Maui*

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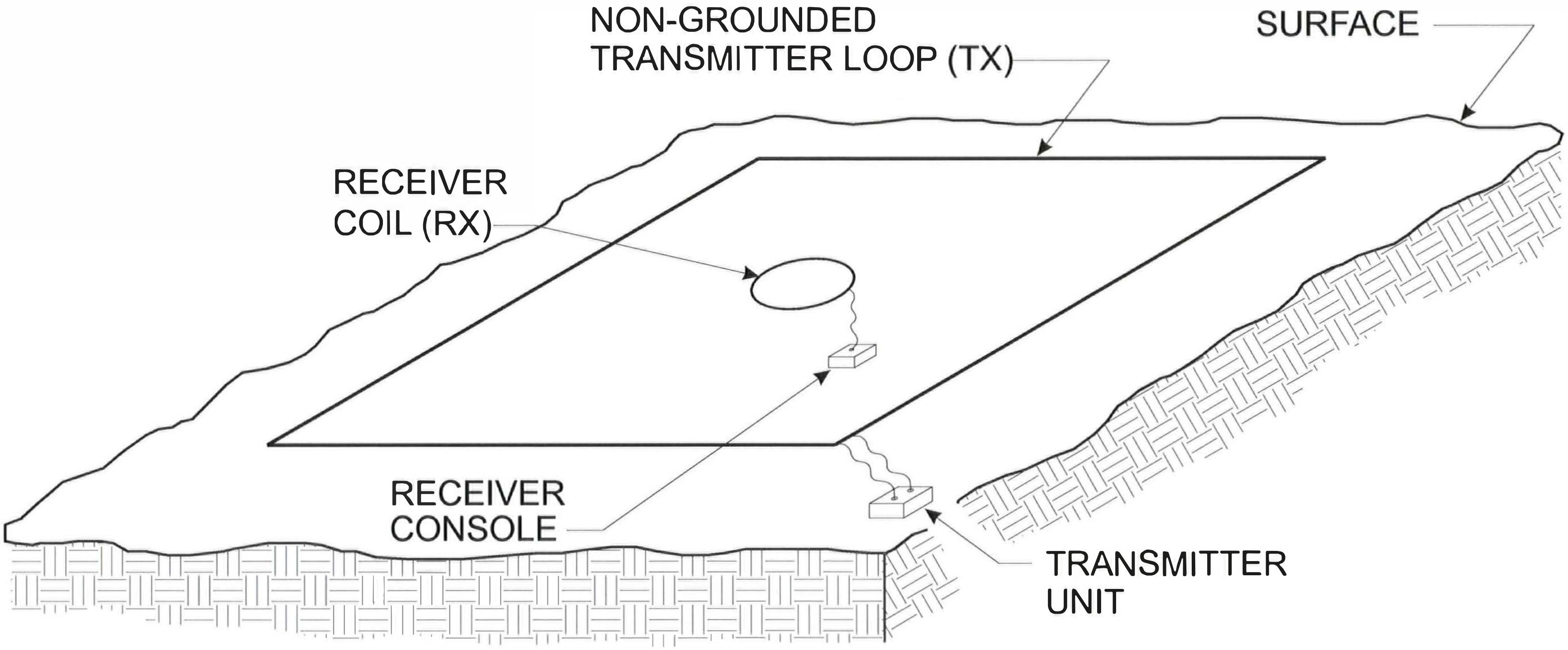
Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5038	May, 2006	HJV	RJB	No Scale	2-3



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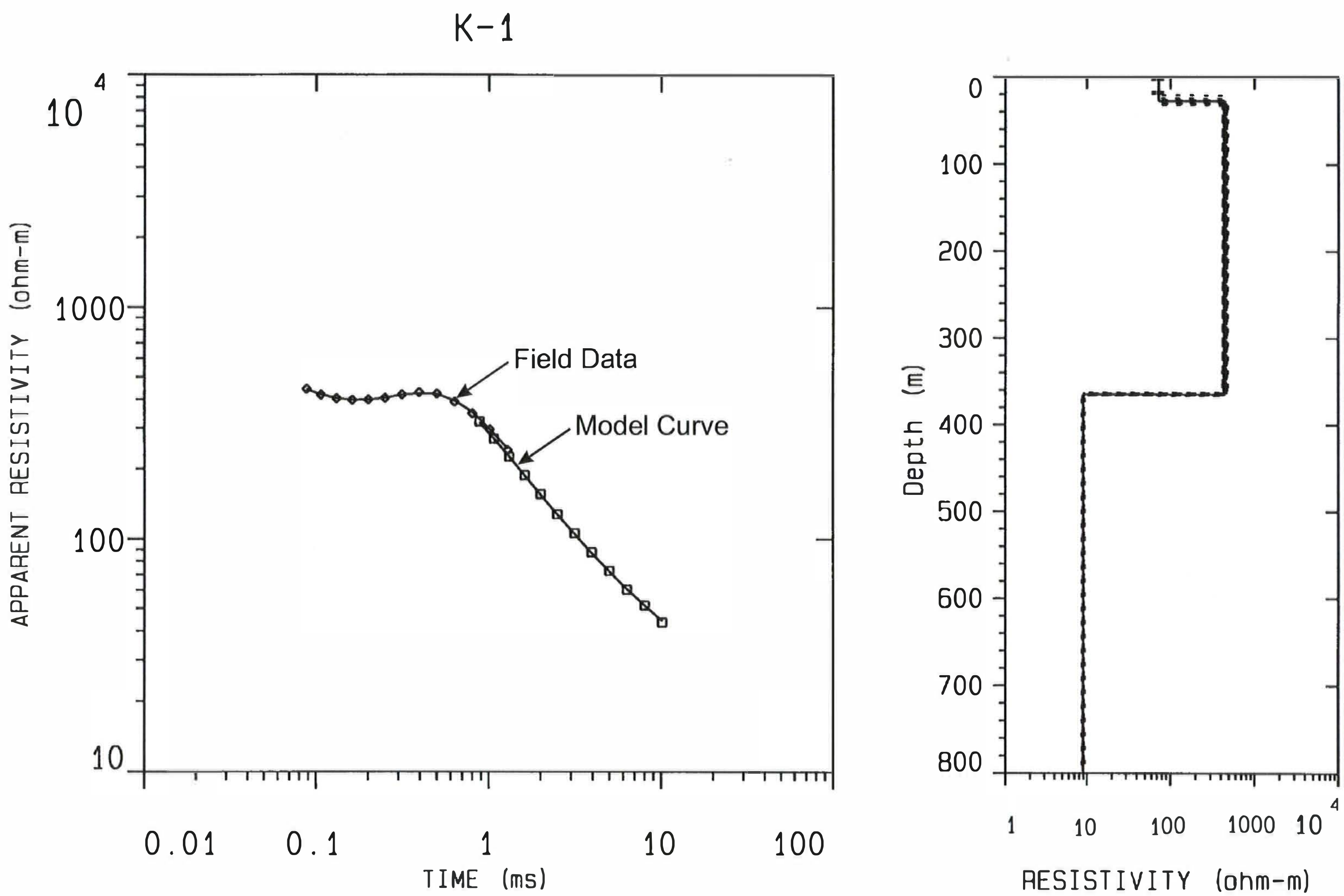
**Kula 1800
Investment Partners, LLC**

Schematic layout of TDEM system with locations of TX and RX for Central Loop Array measurements

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5038	May, 2006	HJV	RJB	No Scale	3-1



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	**Kula 1800 Investment Partners, LLC** *Island of Maui*			**Sounding K-1 Example Inversion Output Apparent Resistivity Curve** *Island of Maui*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5038	Date: May, 2006	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 4-1

DATA SET: K-1

CLIENT:	Pacific Rim Land, Inc.	DATE:	05-02-06
LOCATION:	Maui, Hawaii	SOUNDING:	1
COUNTY:	Maui	ELEVATION:	396.20 m
PROJECT:	Kula 1800 TDEM Survey	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)	TIME CONSTANT:	NONE
SOUNDING COORDINATES:	E: 1.0000 N: 1.0000	SLOPE:	NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 1.162 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			396.2	1300.0	
1	73.58	27.66	368.5	1208.9	0.376
2	449.3	337.0	31.51	103.4	0.749
3	8.99				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	61.584	73.582	81.883
	2	419.318	449.374	485.590
	3	8.610	8.992	9.433
THICK	1	21.154	27.669	32.078
	2	332.780	337.015	344.844
DEPTH	1	21.154	27.669	32.078
	2	362.739	364.684	366.068

Equivalence Analysis

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 6 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	155.7	158.5	-1.74
2	1.06	124.2	124.4	-0.0873
3	1.31	97.35	97.10	0.262
4	1.61	76.10	76.37	-0.346
5	2.00	59.09	59.77	-1.14
6	2.50	45.68	45.93	-0.550
7	3.14	34.39	34.85	-1.33
8	3.95	25.62	26.05	-1.68
9	4.99	18.90	19.08	-0.948
10	6.31	13.93	13.79	1.01
11	7.99	9.75	9.74	0.0545
12	10.14	6.91	6.77	2.09

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
13	0.0881	30380.5	30531.8	-0.497
14	0.106	20460.5	20356.7	0.507
15	0.131	12924.6	12870.6	0.417
16	0.161	7827.9	7828.0	-9.980E-04
17	0.200	4567.8	4559.0	0.191
18	0.250	2551.9	2546.6	0.210
19	0.314	1372.9	1378.4	-0.398
20	0.395	747.7	760.6	-1.72
21	0.499	425.8	428.1	-0.545
22	0.631	267.9	262.7	1.94
23	0.799	176.7	172.8	2.22
24	1.01	123.7	123.6	0.0570
25	1.28	92.80	90.94	2.11

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.80				
P 2	0.06	0.76			
P 3	0.03	-0.07	0.88		
T 1	-0.20	-0.08	0.00	0.69	
T 2	0.01	0.02	0.01	0.03	1.00
	P 1	P 2	P 3	T 1	T 2

BLACKHAWK
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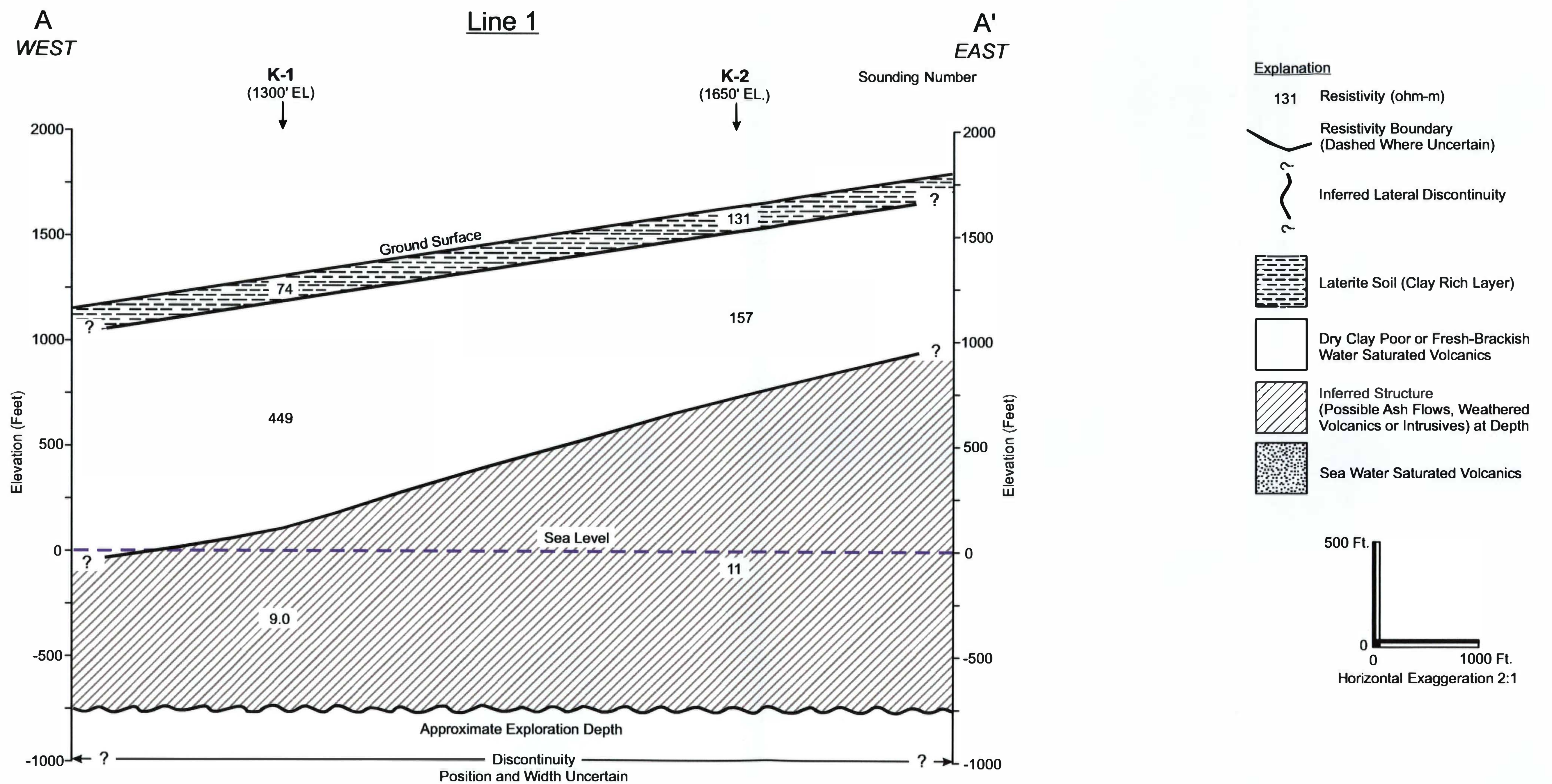
Kula 1800 Investment Partners, LLC

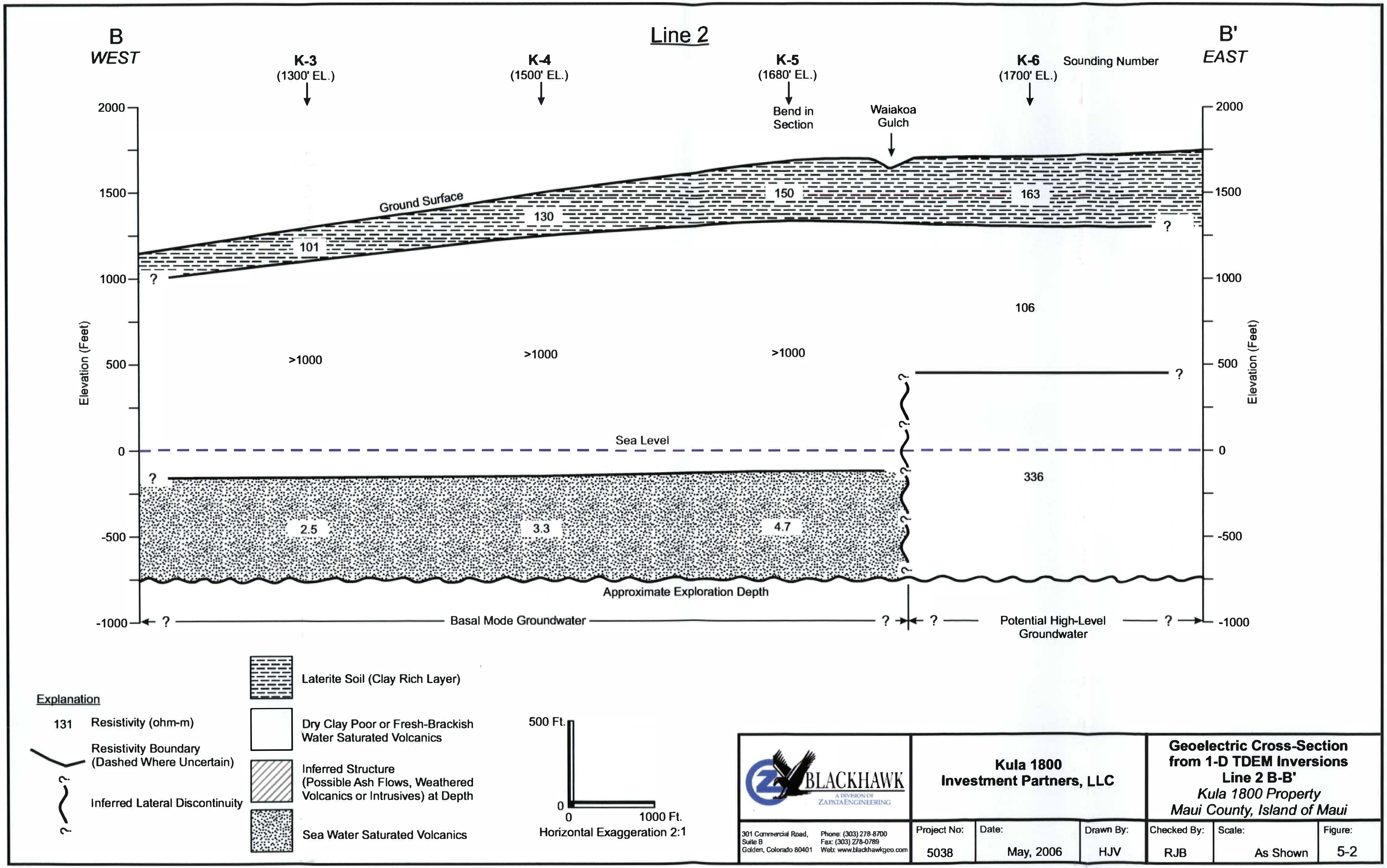
Sounding K-1
Example of Tabulated Data From Inversion
Island of Maui

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5038	May, 2006	HJV	RJB	No Scale	4-2



BLACKHAWK A DIVISION OF ZAINTAENGINEERING	Kula 1800 Investment Partners, LLC			**Geoelectric Cross-Section from 1-D TDEM Inversions Line 1 A-A'** *Kula 1800 Property* *Maui County, Island of Maui*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5038	Date: May, 2006	Drawn By: HJV	Checked By: RJB	Scale: As Shown	Figure: 5-1



Line 2
B
WEST
B'
EAST
K-3
(1300' EL.)
K-4
(1500' EL.)
K-5
(1680' EL.)
K-6
(1700' EL.)
Sounding Number
Bend in Section
Waiakoa Gulch
Ground Surface
101
130
150
163
106
>1000
>1000
>1000
Sea Level
336
2.5
3.3
4.7
Approximate Exploration Depth
Basal Mode Groundwater
Potential High-Level Groundwater
Elevation (Feet)
2000
1500
1000
500
0
-500
-1000
Explanation
131 Resistivity (ohm-m)
Resistivity Boundary (Dashed Where Uncertain)
Inferred Lateral Discontinuity
Laterite Soil (Clay Rich Layer)
Dry Clay Poor or Fresh-Brackish Water Saturated Volcanics
Inferred Structure (Possible Ash Flows, Weathered Volcanics or Intrusives) at Depth
Sea Water Saturated Volcanics
500 Ft.
0
0
1000 Ft.
Horizontal Exaggeration 2:1
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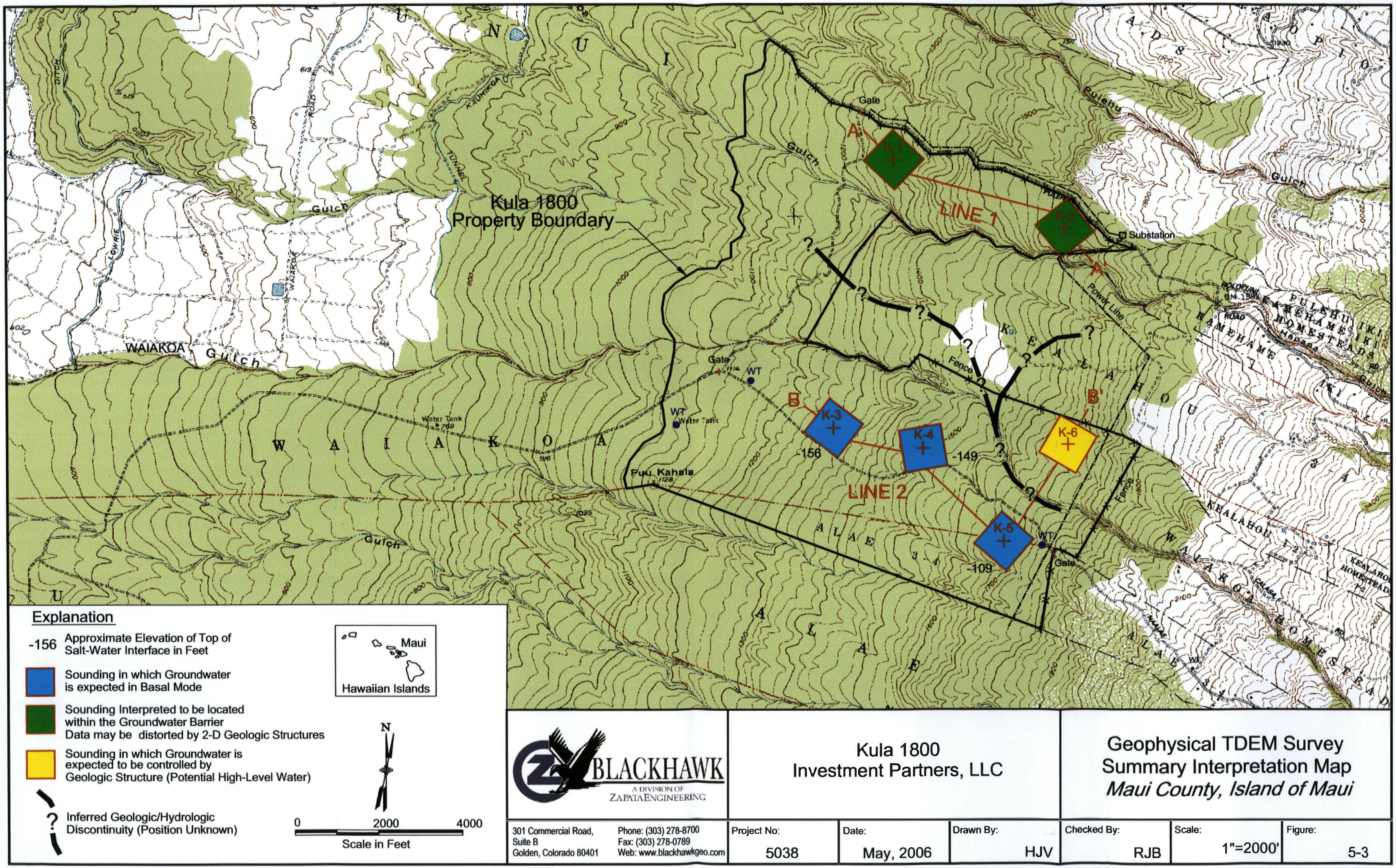
301 Commercial Road, Suite B Golden, Colorado 80401
Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com
Kula 1800 Investment Partners, LLC
Geoelectric Cross-Section from 1-D TDEM Inversions
Line 2 B-B'
Kula 1800 Property
Maui County, Island of Maui
Project No: 5038
Date: May, 2006
Drawn By: HJV
Checked By: RJB
Scale: As Shown
Figure: 5-2



Kula 1800
Property Boundary
LINE 1
LINE 2
A
A'
B
B'
K-1
K-2
K-3
K-4
K-5
K-6
-156
-149
-109
Gate
Substation
Power Line
Fence
WT
Water Tank
Puu Kahala
WAIAKOA Gulch
W A I A K O A
A L A E
Gulch
Explanation
-156 Approximate Elevation of Top of Salt-Water Interface in Feet
Sounding in which Groundwater is expected in Basal Mode
Sounding Interpreted to be located within the Groundwater Barrier
Data may be distorted by 2-D Geologic Structures
Sounding in which Groundwater is expected to be controlled by Geologic Structure (Potential High-Level Water)
Inferred Geologic/Hydrologic Discontinuity (Position Unknown)
Maui
Hawaiian Islands
N
0
2000
4000
Scale in Feet
BLACKHAWK
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Kula 1800
Investment Partners, LLC
Geophysical TDEM Survey
Summary Interpretation Map
Maui County, Island of Maui
Project No: 5038
Date: May, 2006
Drawn By: HJV
Checked By: RJB
Scale: 1"=2000'
Figure: 5-3

APPENDIX A

TECHNICAL NOTE

Blackhawk Project Number: 5038

Prepared For:
KULA 1800 INVESTMENT PARTNERS, LLC

Case Histories of Time-Domain Electromagnetic Soundings in Environmental Geophysics

Pieter Hoekstra and Mark W. Blohm**

Abstract

Time-domain electromagnetic (TDEM) soundings are a surface electromagnetic technique that finds increasing use in environmental geophysics. Commercial equipment is now available for TDEM soundings in the exploration depth range from about 5 m to about 5000 m. Application of TDEM is illustrated in three case histories.

The transmitter-receiver array used in all three investigations was the central-loop array, in which measurements of the electromotive force due to the vertical magnetic field are made with a receiver in the center of square, nongrounded transmitter loops. The dimensions of the transmitter loops were varied from 30 m by 30 m for effective exploration depths between 5 m to 75 m, to 500 m by 500 m for effective exploration depths to about 2500 m. These relatively small dimensions of receiver/transmitter arrays, compared to the exploration depth, allow TDEM surveys to be made in urban areas where open spaces are limited in size, and where environmental and ground-water problems are perhaps most urgent. Also, the procedures of signal processing used in TDEM facilitate operation in the presence of high ambient electrical noise prevalent in urban settings.

The three case histories map:

(1) the depth of first occurrence of brine for assisting site evaluation of a high-level nuclear-waste repository in bedded salts near Carlsbad, New Mexico,

(2) the encroachment of salt water in a multiple-zone coastal aquifer system in the Salinas Valley, California, (The availability of about 100 monitoring wells allowed correlation of formation resistivities to ground-water salinity.) and

(3) shallow basalt flows in the exploration depth range from 5 m to 30 m. (This case history shows the results of TDEM measurements over the time range from about 10^{-6} s to 10^{-4} s with central-loop soundings of small (30 m) dimensions.)

Introduction

Time-domain electromagnetic (TDEM) soundings increasingly are being employed for determining geoelectrical sections. Reported applications of this TDEM method are in mapping of volcanic cover (Frischknecht and Raab, 1984; Keller et al., 1984), onshore and offshore permafrost (Ehrenbard et al., 1983), geothermal reservoirs (Fitterman et al., 1988), hydrocarbons (Rabinovich et al., 1977; Wightman et al., 1983), and ground water (Fitterman and Stewart, 1986; Mills et al., 1988). Theoretical aspects of the method, such as behavior of magnetic and electric fields (e.g., Nabighian and Oristaglio, 1984), definition of apparent resistivity (Kaufman and Keller, 1983; Spies and Eggers, 1986), transmitter-receiver arrays (Kaufman and Keller, 1983), and influence of two-dimensional (2-D) and three-dimensional (3-D) structures on one-dimensional interpretations (Hohmann, 1988; Newman et al., 1987) are discussed throughout the geophysical literature [see also McNeill, Vol. I—Ed.].

Several reasons are apparent for the increasing use of TDEM in environmental geophysics. In urban areas ambient electrical noise is high, and open spaces limited. TDEM surveys can often work around these limitations. Small transmitter-receiver arrays can be laid out in athletic fields, parks, and other open spaces, and ambient

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electrical noise due to residential power service can often be removed by stacking. Also, recent availability of equipment with fast, current ramp turn-off and early-time measurements bring shallow mapping objectives for ground-water protection and contaminant investigations within the exploration depth range of TDEM.

A limitation of TDEM at this time is the lack of practical, cost-effective algorithms for interpreting 2-D and 3-D structures. At present, forward modeling of 2-D and 3-D structures (Newman et al., 1987), requires significant central processing unit (CPU) time on the mainframes negating their application to shallow TDEM exploration. It is in the development of practical algorithms for 2-D and 3-D interpretations for personal computers that the main advances in TDEM must come.

Illustrated applications of the method to three environmental objectives include (1) assisting in siting of high-level, nuclear-waste repositories, (2) mapping the intrusion of salt water in coastal aquifers, and (3) mapping the thickness of thin basalt flows. The basic principles of the equipment and the procedures of data acquisition and processing are similar for all three case histories. Some characteristics of central-loop array measurements, such as land survey requirements, location of plotting points, and vertical resolution are reviewed briefly. Equipment design parameters and data acquisition, processing, and interpretation procedures are discussed. These principles are illustrated subsequently on the three case histories. The Geonics EM-47, EM-37 or EM-42 were used in acquiring the data for all three case histories.

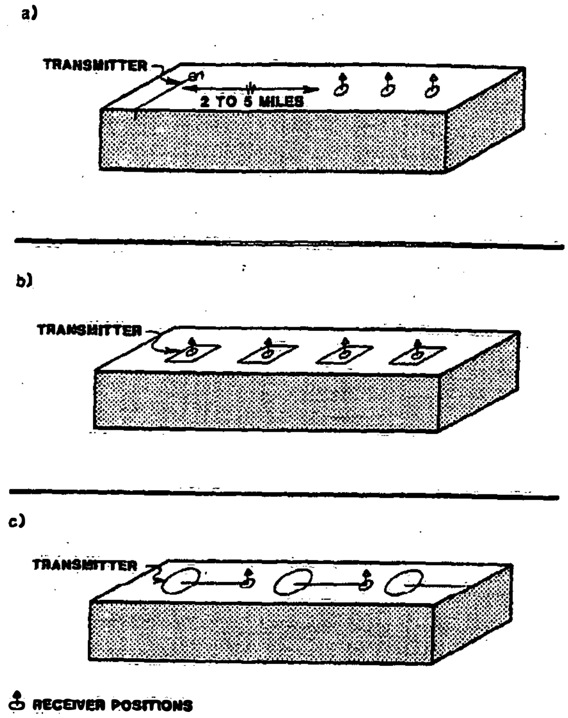

FIG. 1. Transmitter-receiver arrays, (a) grounded line, (b) central loop, and (c) loop-loop.

Practical Aspects of Data Acquisition

Transmitter-Receiver Arrays

The three types of transmitter-receiver arrays employed in TDEM soundings are illustrated in Figure 1. The array used in the three case histories is the central loop array (Figure 1b). For applications in environmental geophysics there are certain advantages to the central loop array, such as:

(a) Land survey and space requirements.—Figure 2 shows the measured behavior of the electromotive forces (emf's) due to horizontal (x) and vertical (z) magnetic field components on a profile through the center of a square transmitter loop at 2.2 ms after current turn-off. Data at other times would show a similar behavior but differ in amplitudes. The emf due to the z-component can be seen to be relatively flat about the center. Location errors of $\pm 10\% \, L$ (L is side of square) cause negligible errors, and deviations from a square transmitter loop have little effect on a data set. Because in central loop soundings the geoelectric section is derived from emf$_z$, requirements for accurate positioning are minimal which enhances the practical value of field survey productivity, and allows flexibility in choosing a station location. Because emf$_x$ has a zero crossing in the center of the loop, its measurement would require careful survey control. Also, ambient electrical noise is higher in horizontal components.

The dimensions of transmitter loops in central-loop arrays depend on required exploration depth, exploration objective, and geoelectric section. Optimum dimensions are generally selected from forward modeling and field tests. Typically, the length of a side of the transmitter loop is about two-thirds of the exploration depth for the EM-37. The EM-42 is generally employed for exploration depths from about 300 m to 2500 m with 500 m by 500 m transmitter loops, and with a grounded line array for deeper objectives.

The grounded line array (Figure 1a) with long offset receiver locations is dominantly used in deep electrical soundings in support of oil and gas exploration (Keller et al., 1984). The loop-loop array (Figure 1c) finds ap-

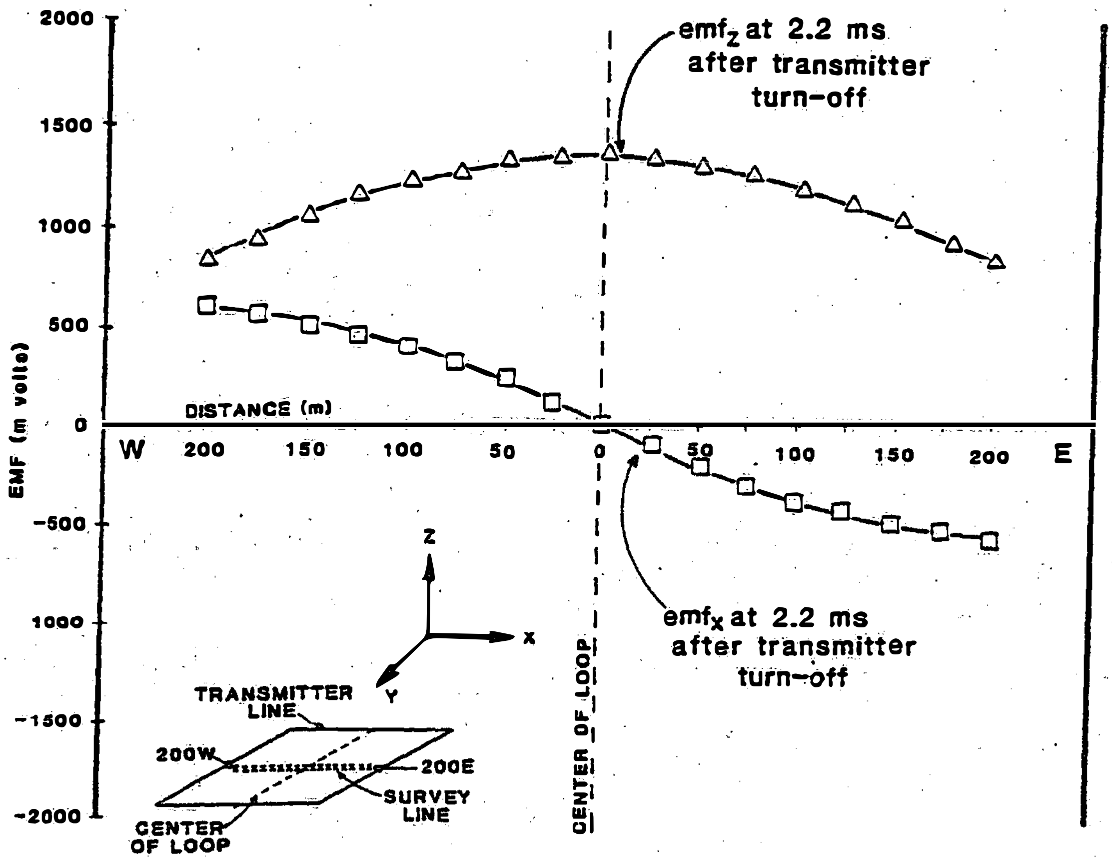

FIG. 2. Measured behavior of the electromotive forces due to vertical (emf_z) and horizontal (emf_x) magnetic fields on a profile through the center of a square transmitter loop.

plication in mineral exploration and in mapping of fractures and shear zones.

(b) **Well-defined sounding plotting points.**—The behavior of induced eddy currents and the resulting behavior of the secondary magnetic fields in horizontally-layered media are well documented (Kaufman and Keller, 1983; Ward and Hohmann, 1988). They show a current distribution diffusing downward and outward from the source. For nongrounded, square-loop transmitters currents are symmetrically distributed about the center. Therefore, the center is a well-defined plotting point.

In the grounded-line array or loop-loop array the entire section between transmitter and receiver is expected to influence the measurements, although subsurface conditions near the receiver may have a larger influence on emf_z measured. The correct plotting point of a station is not well defined. Some place the plotting point below the receiver (Keller et al., 1984) and others midway between the transmitter and receiver (Rabinovich and Surkov, 1978). This same situation prevails in loop-loop arrays. In frequency-domain loop-loop arrays the midpoint of the array has traditionally been used as the plotting point.

(c) **Vertical resolution.**—Kaufman and Keller (1983) show that (1) the asymptotic behavior of emf_z at late time, is given by

$$emf_z = \frac{\mu^{5/2}}{4\pi^{3/2}} \frac{\sigma^{3/2} M_t M_R}{t^{5/2}}, \tag{1}$$

where

t = time after current turn-off,
σ = conductivity of uniform half-space,
μ = magnetic susceptibility,
M_t = moment of transmitter,
M_R = moment of receiver;

and (2) that this asymptotic expression describes the emf over the time range given by;

$$\frac{\tau}{R} > 16, \qquad (2)$$

where

$$\tau \text{ is } \sqrt{\frac{8\,\pi^2 t}{\mu_0\,\sigma}}.$$

Figure 3 is a nomograph showing the onset of "late stage" behavior ($\tau/R > 16$), as a function of resistivity, and time at several values of R. Also shown on Figure 3 are the time ranges of measurement for the three systems used in the case histories. In central loop soundings typical values of R are between 15 m and 250 m, so that over a large time range of measurements emf, is proportional to $\sigma^{3/2}$. This high sensitivity of the quantity measured (emf,) to the geoelectric section often results in a reduced range of equivalence for certain sections compared to other electrical and electromagnetic techniques (Fitterman et al., 1988).

Equipment

The Geonics EM-47, EM-37 or EM-42 were used in acquiring the data for all three case histories. All three sets of equipment use the current waveform illustrated in Figure 4, consisting of equal periods of time-on and time-off. Figure 5 illustrates the difference in data acquisition between the EM-47 and EM-37, and the EM-42. In the EM-47 and EM-37 an analog stack is performed, and after completion of the stacking and A/D conversion, the data are stored in solid state memory. Normally, at the completion of a survey day, the data are transfered to a computer for data processing, plotting, and interpretation. During field operations no real-time processing is available. Minimum detectable signal in typical, urban, ambient-noise environments is 10^{-9} V/A-m^2 (normalized by current in transmitter loop, and effective area of receiver coil).

In the EM-42 the transient is sampled at 400 μs intervals, and these samples are digitally stored on 1/2-inch, 9-track tape. "Smart stacking" is applied to the data in real time. The minimum detectable signal with

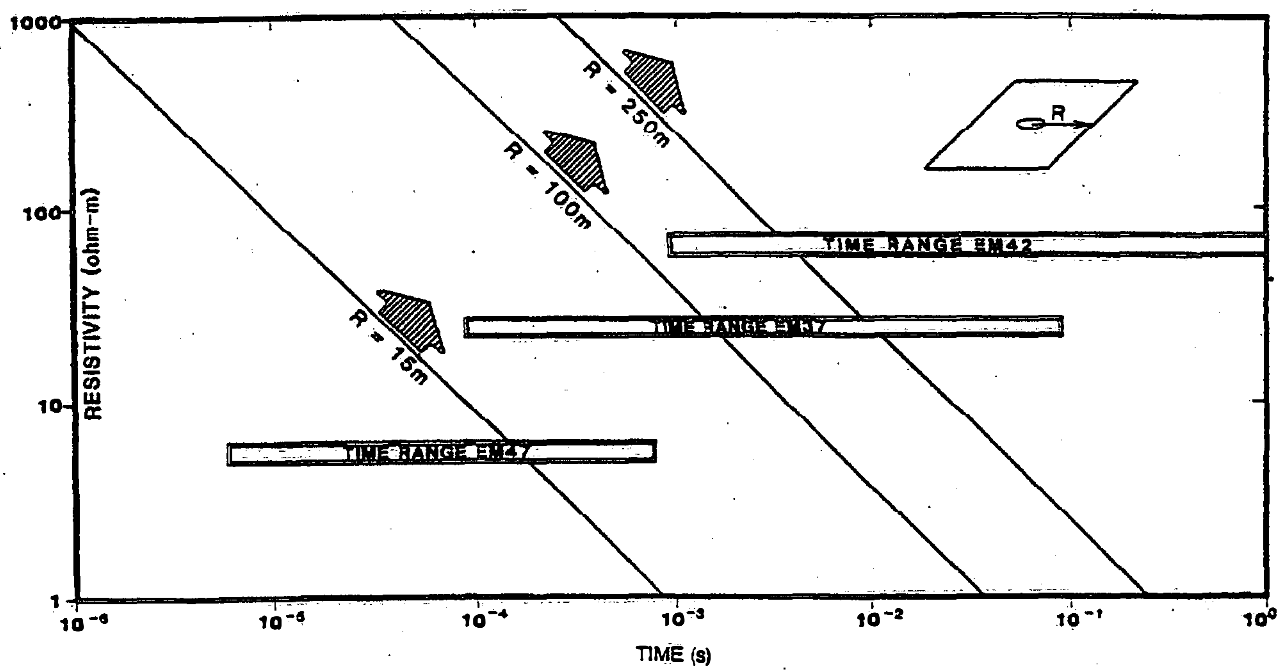

FIG. 3. Nomograph showing onset of late stage behavior for central-loop array as a function of time and resistivity of uniform half-space.

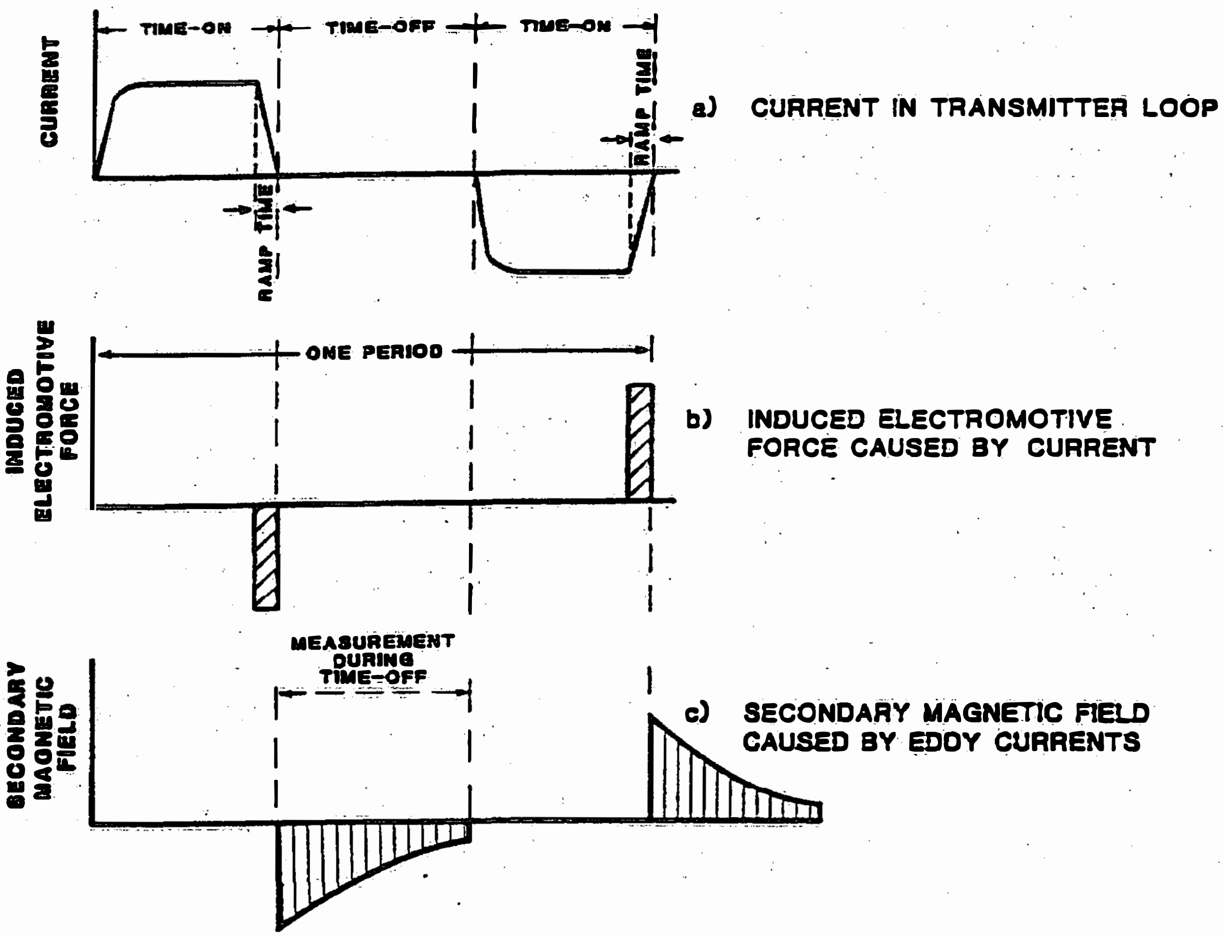

FIG. 4. System waveforms employed in Geonics EM-47, EM-37, and EM-42.

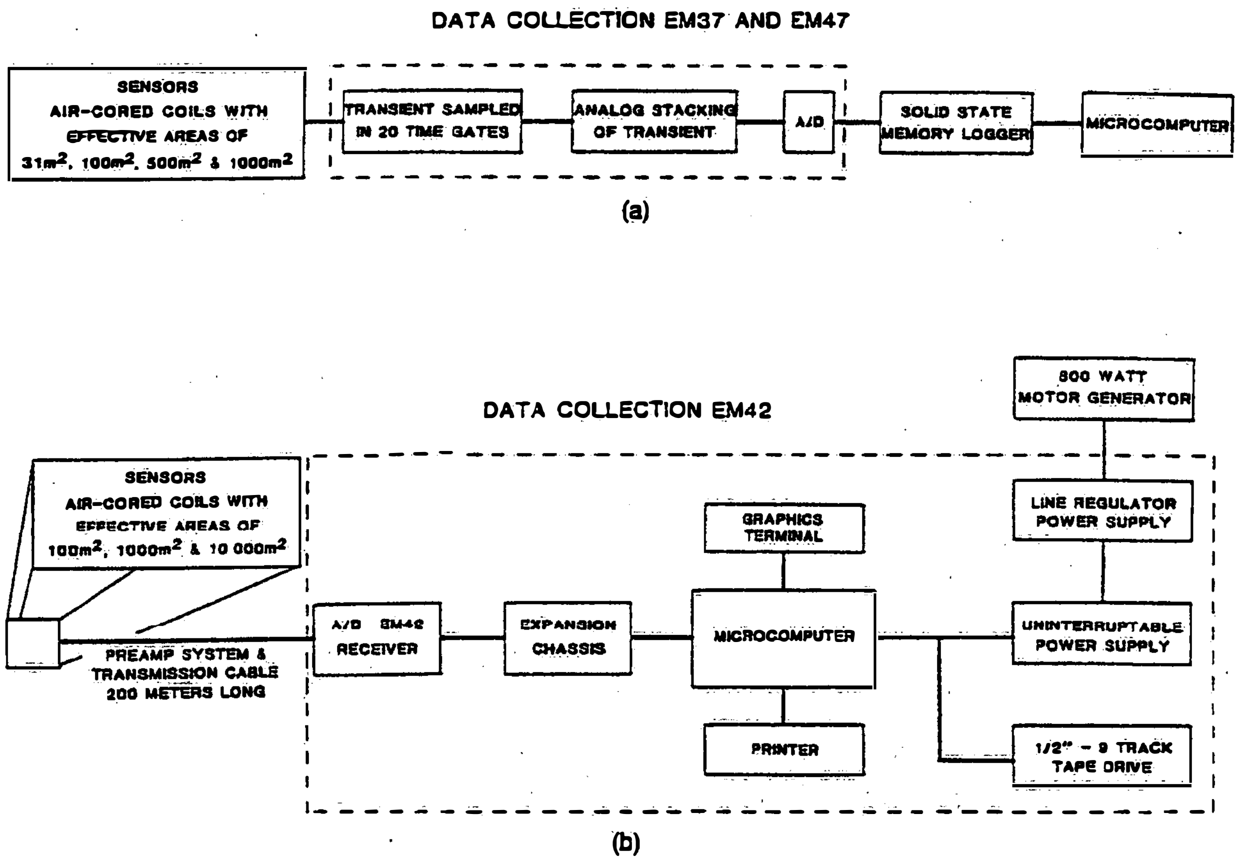

FIG. 5. Block diagrams of TDEM systems.

the EM-42 in typical ambient noise environments is 10^{-12} V/A-m^2

Data Acquisition

Recording transient decays with central loop soundings requires a large dynamic range, because emf, decays as $t^{-5/2}$, as shown in equation (1). This large dynamic range is often obtained by acquiring a data set in segments using different combinations of base frequencies, gains, and air coil receivers. An example of such a data set is given in Figure 6. The early time part of the curve was acquired at a base frequency of 3 Hz, 100 m^2 air coil and EM-37 receiver; the later time section was recorded with the EM-42 receiver, a 10 000 m^2 air coil and a base frequency of 0.075 Hz. When the 10 000 m^2 coil is used, the early time segment of this curve is purposely saturated. It is common to collect data sets at two receiver polarities, various gain settings, base frequencies, and with receiver coils of different effective areas. These various data sets are combined in one transient-decay curve that is subsequently entered into inversion routines.

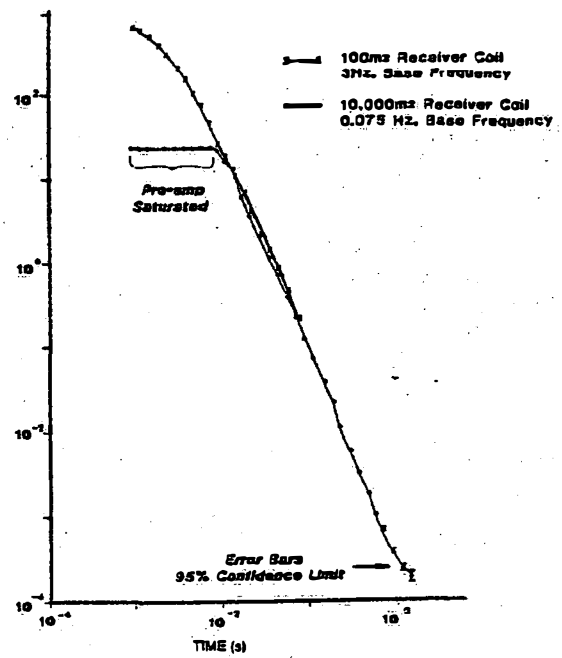

FIG. 6. Emf, measured in center of 500 m by 500 m transmitter loop.

Definition of Apparent Resistivity

All electrical and electromagnetic methods commonly transform the voltages or emf's measured into apparent resistivities. In TDEM several definitions of apparent resistivity are in use (Kaufman and Keller, 1983; Goldman, 1988) and the merits and pitfalls of the various definitions have been reviewed in Spies and Eggers (1986). These pitfalls are often avoided by (1) integrating inversions with available geologic data, and (2) using albums of forward-model curves for first-guess solutions. In all the case histories late-stage (Kaufman and Keller, 1983) apparent resistivity curves are used. Two reasons for that selection were (1) over a large range of time late-stage behavior is observed in central-loop soundings, and (2) extensive volumes of late-stage model curves (Goldman and Rabinovich, 1974) are available.

Data Interpretation

All the examples shown in the case histories were interpreted by one-dimensional (1-D) inversions of the data using a ridge-regression inversion program (ARRTI, Interpex Ltd, 1985). The input for the program are the emfs measured in various time gates, certain equipment and survey parameters (transmitter loop size, current, ramp time, receiver coil effective area), and number of layers to be used in the inversion. Also, an initial solution is entered. Goldman (1988) discussed the dependence of inversion routines on this first guess. To mitigate convergence to unrealistic solutions, first guesses are made to correspond with known geologic conditions, and depending on the quality of available geologic information, certain parameters in a geoelectric section may be fixed at specific values, e.g., as observed in borehole logs.

In TDEM soundings there is merit in carefully considering inversion errors at each time gate, because each section of the curve is often diagnostic of a certain depth section (Kaufman and Keller, 1983; Raiche and Gallagher, 1985). This can be illustrated by a central loop TDEM sounding with a 500 m by 500 m transmitter loop over a Tertiary valley fill in Nevada. Figure 7b shows the late-stage, apparent resistivity curve and Figure 7a two 1-D inversions for this sounding. The difference between the two inversions is the absence of a resistive layer (basalt flow) in section 1, and its presence in section 2. Figure 7c shows the error between the measured data and the two inversions. The increased error over the early time range suggested inserting an additional layer into the inversion. The existence of this resistive layer has been confirmed by drilling.

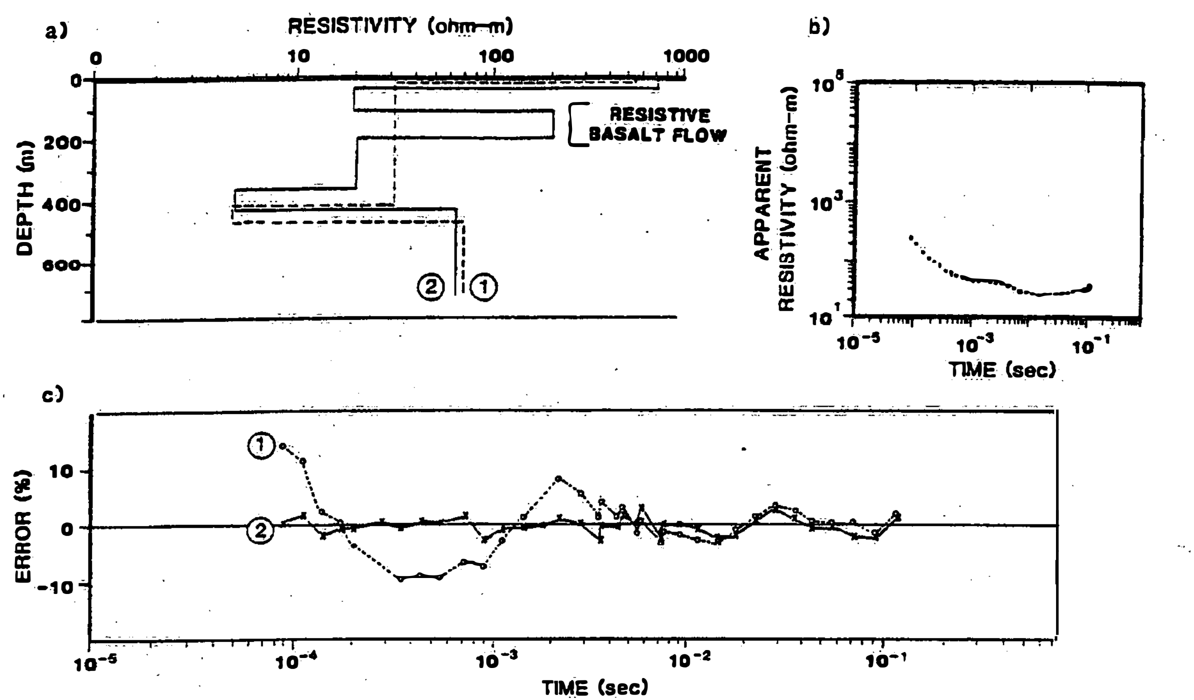

FIG. 7. Geoelectric sections (a) derived from 1-D inversions of measured apparent resistivity curve (b) over Tertiary Valley fill in Nevada. For each geoelectric section error of inversion is shown as function of time (c).

Validity of One-Dimensional Interpretation

The complexity of evaluating the influence of 2-D and 3-D structures of TDEM data is often cited as a disadvantage (Goldman, 1988). Indeed, currently, computations of 2-D and 3-D structures require computations that cannot be economically and practically applied in routine exploration programs. From the 2-D and 3-D computations (Newman et al., 1987) that have been published, important conclusions can be derived about the validity of 1-D interpretations in the presence of 2-D and 3-D structures. For example, Newman et al. (1987) computed the response over a resistive and conductive 3-D structure buried in a layered half-space at a depth of about 300 m. They reached the conclusion that 1-D inversions gave good estimates of the depth of burial of the 3-D structure, but unreliable depth extent and resistivities of the 3-D body. They used relatively large transmitter loops (1000 m by 1000 m) compared to exploration depth (1000 m) in their computations.

Drill-hole control is seldom sufficient to evaluate thoroughly the influence of 2-D and 3-D structures on a data set. Our experience, based on several thousand soundings with transmitter loop dimensions varying from 30 m by 30 m to 500 m by 500 m, is that 1-D interpretations yield good depth interpretations in the vast majority of work undertaken. Nevertheless, practical algorithms for data interpretation in the presence of 2-D and 3-D structures is an important need in TDEM soundings. Some efforts in that direction are promising (James, 1988).

Case Histories

Case History—High Level Nuclear Waste Repository Siting

The storage panels of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico are being mined in the bedded salts of the Salado formation at a depth of about 600 m below ground surface. Underlying the Salado formation is the Castile formation, which is composed primarily of anhydrite and halite. It is known from oil and gas drilling that the Bell Canyon formation, underlying the Castile formation, can contain brines (Barrows et al., 1982).

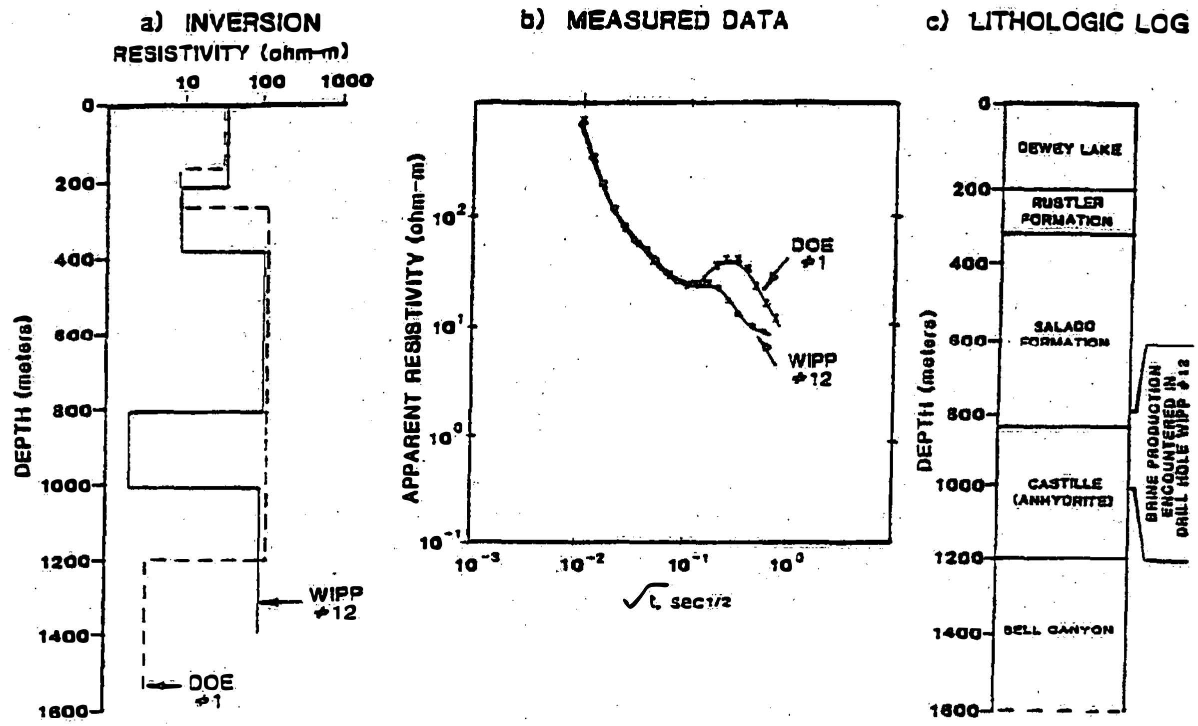

FIG. 8. Two measured late-stage apparent resistivity curves (b) and corresponding geoelectric sections derived from 1-D inversions (a). Also shown is a lithologic log common to both sounding locations (c).

The concept for placing a high level nuclear waste (HLW) repository in bedded salts at 600 m is to exploit the low hydraulic permeabilities of overlying bedded salts, and underlying anhydrites and halites. However, in the general vicinity of Carlsbad, New Mexico, drill holes encountered pressurized brine reservoirs at depths between 730 m and 915 m in the Castille formation (Register, 1981). The objective of TDEM surveys was to map the depth of first occurrence of brine over the waste storage panels and surrounding area.

A TDEM survey was conducted on a 500 m grid using central loop TDEM soundings over the waste storage panels and at selected drill hole locations. The transmitter loop dimensions employed were 500 m by 500 m and the TDEM equipment used was the Geonics EM-42.

Figure 8b shows two apparent resistivity curves located within 150 m of two drill hole locations, WIPP #12 and DOE #1. The resistivity layering derived from 1-D inversions for these two soundings is given in Figure 8a., and Figure 8c shows a lithologic log common to WIPP #12 and DOE #1. In the drilling of WIPP #12, brines were encountered at a depth of 850 m, and in drill hole DOE #1 no brines were encountered to total depth (TD = 900 m). The depth of first occurrence of brine observed in WIPP #12 is in excellent agreement with the depth of the low resistivity layer derived from the 1-D inversion of the adjacent TDEM sounding. Depth of occurrence of the low resistivity layer derived from the TDEM inversion near drill hole DOE #1 is at 1200 m, some 300 m below TD, and at a depth corresponding to the Bell Canyon formation.

The 1-D inversions of TDEM soundings over the waste storage panels showed first depth of occurrence of brine below 1050 m. This depth generally corresponds to the Bell Canyon formation. Thus, the 1-D interpretations of the depth of first occurrence of brine were consistent with available ground truth. A major concern remains the minimum dimensions of brine occurrences detectable with central loop soundings. This problem is being addressed by 2-D and 3-D forward modeling.

There are several other important objectives in environmental geophysics for mapping depth of first occurrences of brine, such as:

(1) Siting injection zones for oil field brines, and other liquid waste injection wells. Regulations require

injection zones to have a concentration of dissolved solids greater than 10 000 ppm and confining zones must separate US drinking water supplies (USDW) and injection zones (Federal Register, 1987).

(2) Monitoring migration of wastes upward from injection zones along fractures, abandoned wells, or faulty casings (Fitterman et al., 1986).

Mapping Encroachment of Salt Water Into Fresh-Water Aquifers

Intrusion of salt water in coastal aquifers often has as its main cause excessive withdrawal of ground water. It has long been recognized that surface electrical or electromagnetic methods can be effective in mapping fresh water—salt water interfaces (Flathe, 1964). Here, the application of TDEM surveys for this purpose is illustrated by a case history from the Salinas Valley, CA (Mills et al., 1988). A schematic hydrogeologic cross-section of the study area is given in Figure 9. There are four aquifer zones (1) a perched aquifer in which the ground water is heavily contaminated by fertilization, (2) a 180 ft aquifer approximately 60 m thick in which salt water has intruded under about 15 000 acres, (3) a 400 ft aquifer in which salt-water intrusion has been observed under about 6600 acres, and (4) a 900 ft aquifer in which no salt-water intrusion has yet been observed.

Thus, salt-water intrusion has progressed farthest inland into the 180 ft aquifer, so that to map water quality in the 400 ft aquifer requires exploration through a 180 ft aquifer containing high concentrations of dissolved solids. This information was used in designing the survey. To map salt-water encroachment in the 180 ft aquifer 100 m by 100 m transmitting loops were em-

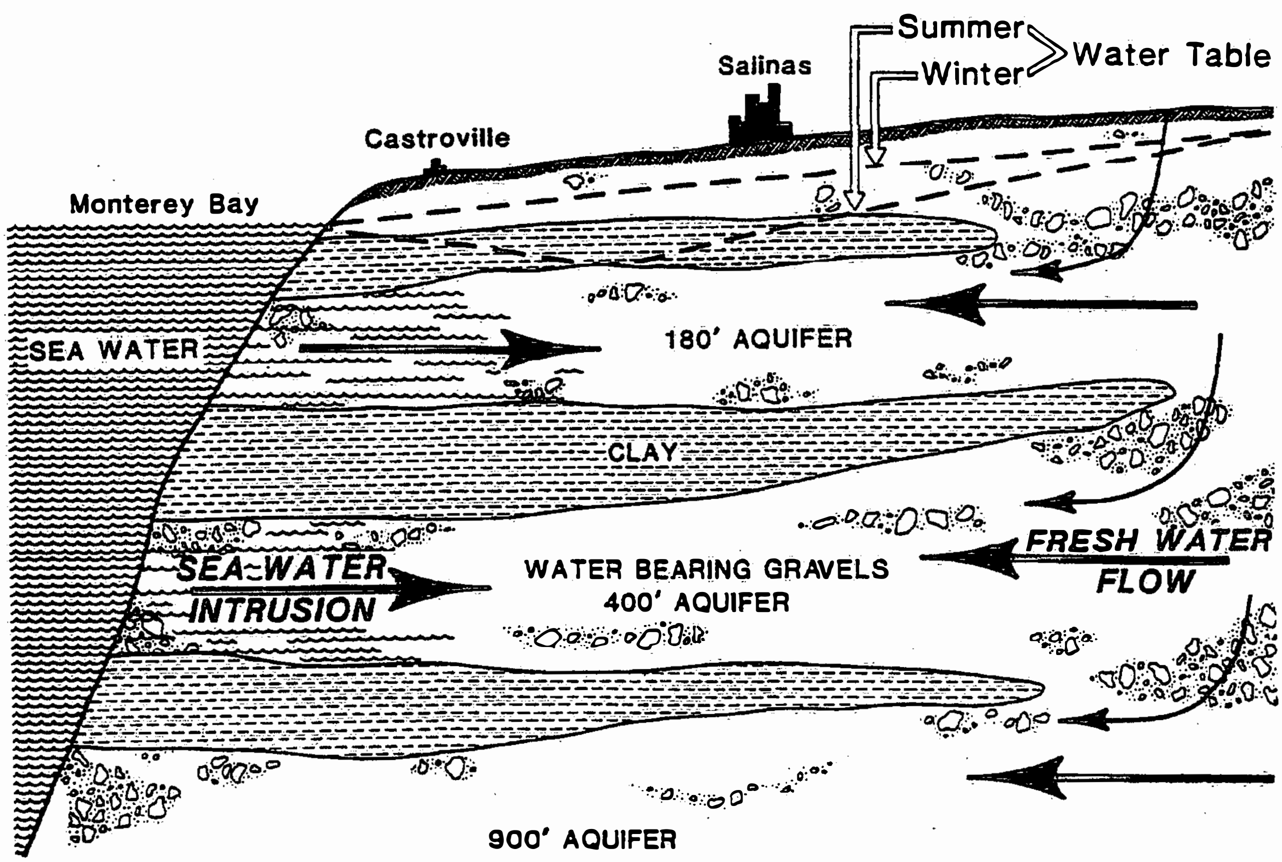

FIG. 9. Schematic hydrogeologic section of study area in the Salinas Valley, CA.

ployed. These transmitting loop dimensions provided sufficient field strength to derive the resistivity variation in the 180 ft aquifer. Larger transmitting loop dimensions (200 m by 200 m) were employed for exploration in the 400 ft aquifer. Approximately 100 stations were measured.

A series of four late-stage apparent-resistivity curves along cross-section B-B′ (Figure 12) are shown on Figure 10 along with geoelectric sections derived from 1-D inversions. Figure 11 shows the geoelectric section derived from TDEM soundings along profile B-B′. In the 180 ft aquifer the resistivity gradually increases inland from 1.5 Ω·m (station L24/3) to 18 Ω·m (station L10/1). In the 400-ft aquifer the resistivity increased from 6.0 Ω·m to in excess of 20 Ω·m.

Information from monitoring wells maintained by the Monterey County Flood Control and Water Conservation District was used to help constrain the number of layers used for the inversions of the TDEM data, and to correlate formation resistivities with equivalent chloride concentration. Correlation of formation resistivities with chloride concentration showed that a resistivity of approximately 8 Ω·m corresponds to a 500 ppm chloride concentration. Figure 12 shows the surface projection of the 500 ppm isochlor contours (8 Ω·m formation resistivity) in the 180 ft and 400 ft aquifers. The 500 ppm isochlor, based on monitoring wells, is also shown. There is more detail in the contours derived from the TDEM surveys mainly because of the higher station density.

These types of TDEM surveys have now been performed in several areas of Florida (Steward and Gay, 1981), Massachusetts (Fitterman and Hoekstra, 1982), California (Mills et al., 1988), and New York. Important advantages of TDEM soundings in these surveys are:

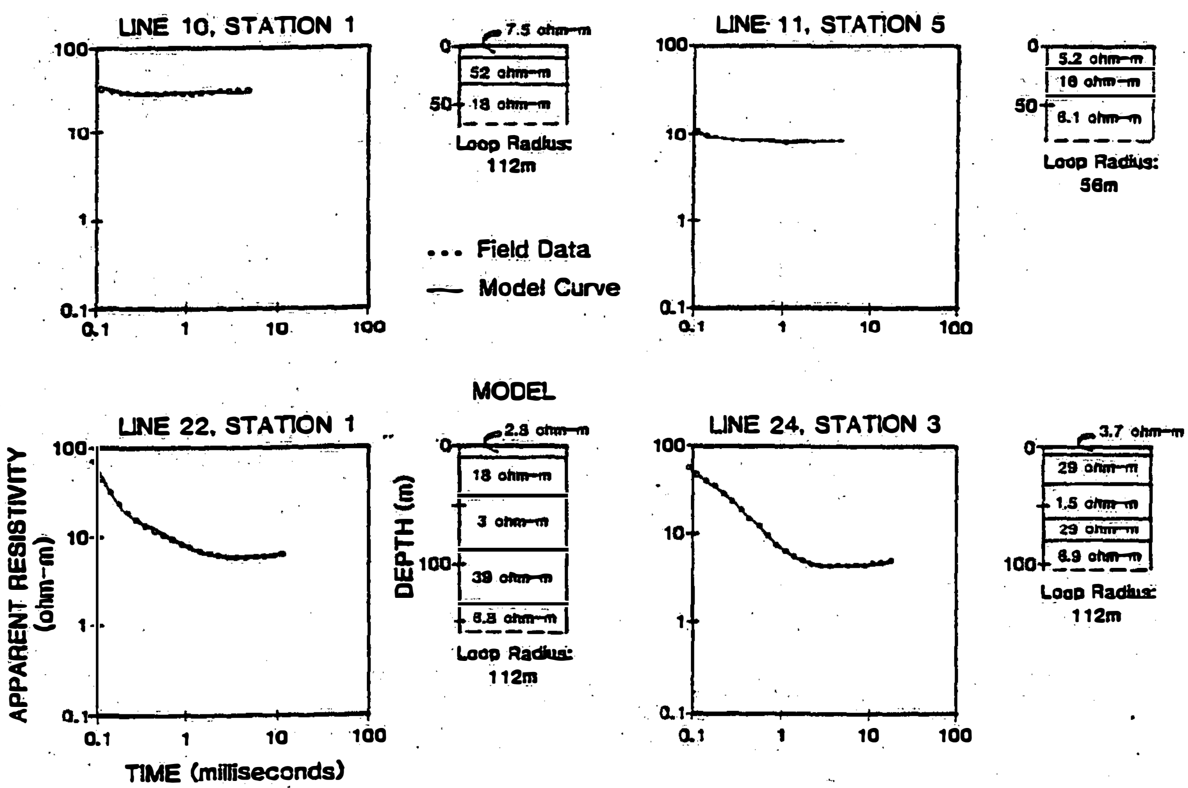

FIG. 10. Four apparent resistivity curves and inverted geoelectric sections along section B-B′ (Figure 12).

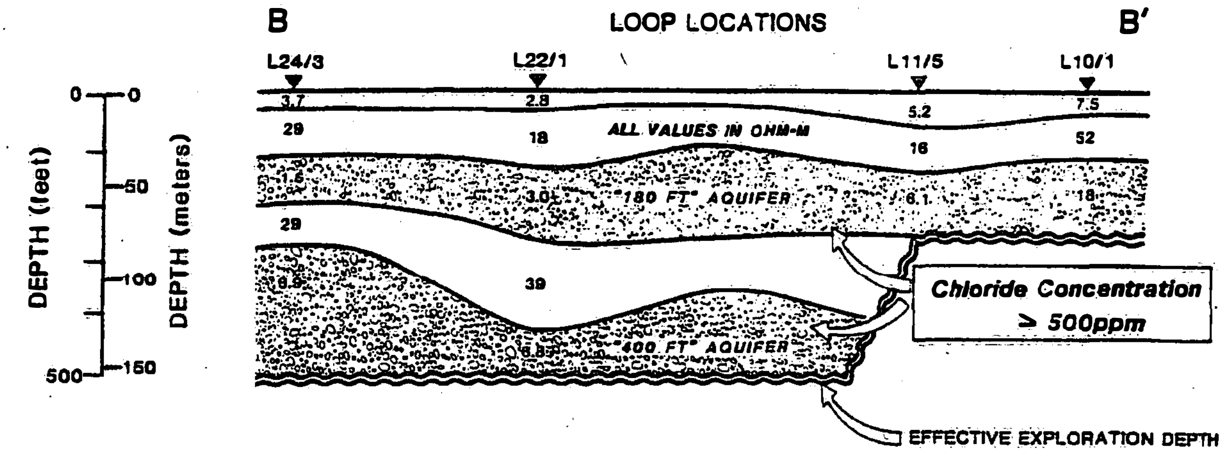

FIG. 11. Geoelectric section B-B' derived from TDEM soundings.

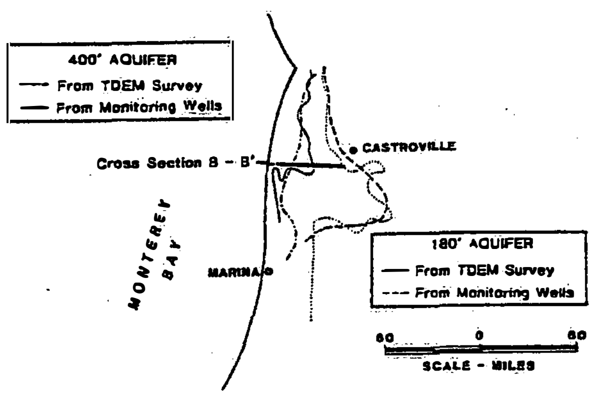

FIG. 12. Comparison of position of 500 ppm isochlor in 180 ft and 400 ft aquifers derived from monitoring wells and TDEM soundings.

(1) Coastal areas are often urbanized and limited space is available for measurements. TDEM measurements were often made in available open spaces such as high school athletic fields and parks.
(2) Ambient electrical noise (e.g., powerlines and radio stations) is high in developed areas. The signal stacking used in TDEM has proven an effective way for recovering signal from noise.

The utility of TDEM surveys for water management plans are in (1) providing optimum location for placement of monitoring and production wells, (2) determining depth of completion of such wells, (3) interpolating the position of the fresh water–saline water interface between wells, and (4) monitoring the movement of the interface over time. Geophysical stations can be moved from year to year, while monitoring wells lose some of their usefulness once the fresh water–saline water interface has migrated past their locations.

Shallow TDEM Surveys

Important exploration objectives for shallow (< 50 m) electrical exploration in environmental geophysics are

mapping continuity of confining layers, such as clay lenses;

mapping the presence of contaminants (e.g., originating from brine ponds) and pathways for migration of contaminants, such as fractures and shear zones;

correlating hydraulic transmissivities to electrical conductance (e.g., Huntley, 1986).

The geophysical methodologies applied to these exploration problems have mainly been dc resistivity soundings (e.g., Evans et al., 1982) and frequency-domain electromagnetic conductivity profiling (e.g., McNeill, 1982). With the recent availability of a TDEM system (Geonics EM-47) for shallow exploration, some of these objectives are now within the exploration depth range of TDEM. An example of shallow central-loop soundings with a prototype EM-47 is a survey over relatively thin basalt flows near Golden, Colorado.

On North and South Table Mountain in Golden, Colorado, lava flows overlie the Denver formation. Figure 13a shows the geologic section of the upper 100 m on North Table Mountain (Waldschmidt, 1939). Figure 13c shows an apparent resistivity curve measured in the center of a 30 m by 30 m transmitter loop with the EM-47 and its 1-D inversion. A peak current of 2 A was driven through the loop, and the ramp turn-off (Figure 4a) was 2.5 μs. The first time gate was centered at 6.4 μs and data were collected at base frequencies of 300 Hz and 30 Hz. The geoelectric section derived from the 1-D inversion (Figure 13b) shows good agreement between geologic boundaries and breaks in resistivity.

For this geoelectric section and for 30 m by 30 m transmitter loops (R = 15 m), late stage commences at about 10^{-5} s (Figure 3), so that almost the entire measured curve is in late-stage. Also shown on Figure 13c are forward modeled curves with different thicknesses of the upper basalt flow, while all other parameters were held constant. Large changes in the curves occur mainly

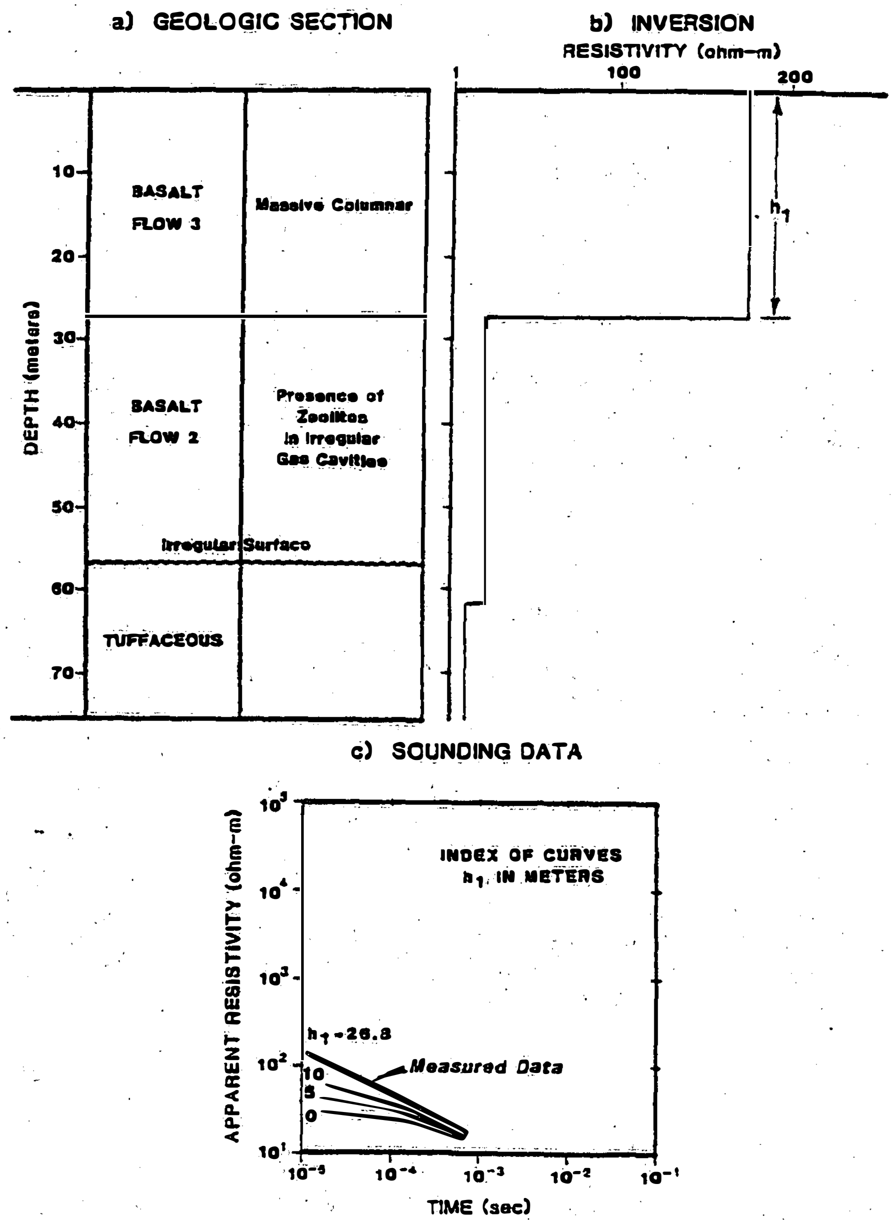

FIG. 13. (a) Geologic section of North Table Mountain, Golden, CO; (b); and geoelectric section derived from 1-D inversion of central loop sounding data with 30 m by 30 m transmitter loop; (c) the measured apparent resistivities are superimposed on a series of forward model curves in which the thickness of the upper basalt layer is varied.

over the time range from 10^{-5} s to 10^{-3} s; the time range covered by EM-47 measurements.

The conclusions from a number of conducted surveys is that the EM-47 can be employed in the depth range from 5 m to 75 m, depending somewhat on the geoelectric section. Since transmitter loop dimensions of 30 m by 30 m can be employed, survey productivity is high (30 to 50 stations per day). The TDEM EM-47 promises to be an effective methodology for electrical mapping in environmental geophysics, particularly in urban areas where space is limited and ambient noise is high.

Discussion

Focusing on the use of TDEM methods in environmental geophysics is such a narrow focus that there is a danger of overstating the utility of TDEM, compared to other electrical and electromagnetic measurement techniques. Raiche et al. (1985) and Fitterman et al. (1988) show that the range of equivalence in some geoelectric sections can in principle be reduced by combined use of dc resistivity and TDEM soundings. It is, therefore, important to note that the exploration objective in all three case histories consisted of determining depth to a conductive stratum, objectives optimally suited for electromagnetic techniques. TDEM surveys and other electromagnetic techniques have limitations for detecting thin resistive strata, and such limitations are readily evaluated by forward modeling.

One advantage of TDEM not evident from forward modeling computations is the absence of scatter in the data. The data scatter frequently observed in dc resistivity soundings, and distant source techniques (controlled source audiomagnetotelluric, audiomagnetotelluric, and magnetotelluric methods) are often due to lateral variation in resistivity and measurement of the electric field. The scatter is reduced in central loop TDEM soundings mainly because of the short source/receiver separation and measurement of the time derivative of magnetic fields. The apparent resistivity curves shown in these investigations are typical of a large number of stations. No smoothing of the data is performed before inversions.

The recent availability of a shallow TDEM system for the exploration depth range from 5 m to 75 m makes this technique suitable for such environmental studies as well-site protection programs, and mapping plumes of ground-water contamination. Contamination plumes are often confined to narrow zones, and the high lateral resolution possible with shallow central loop TDEM soundings allows definition of both the lateral and vertical extent of such plumes.

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APPENDIX B

SOUNDING CURVES, DATA PRINTOUTS AND GPS COORDINATES FOR TDEM SOUNDINGS

Blackhawk Project Number: 5038

Prepared For:
KULA 1800 INVESTMENT PARTNERS, LLC

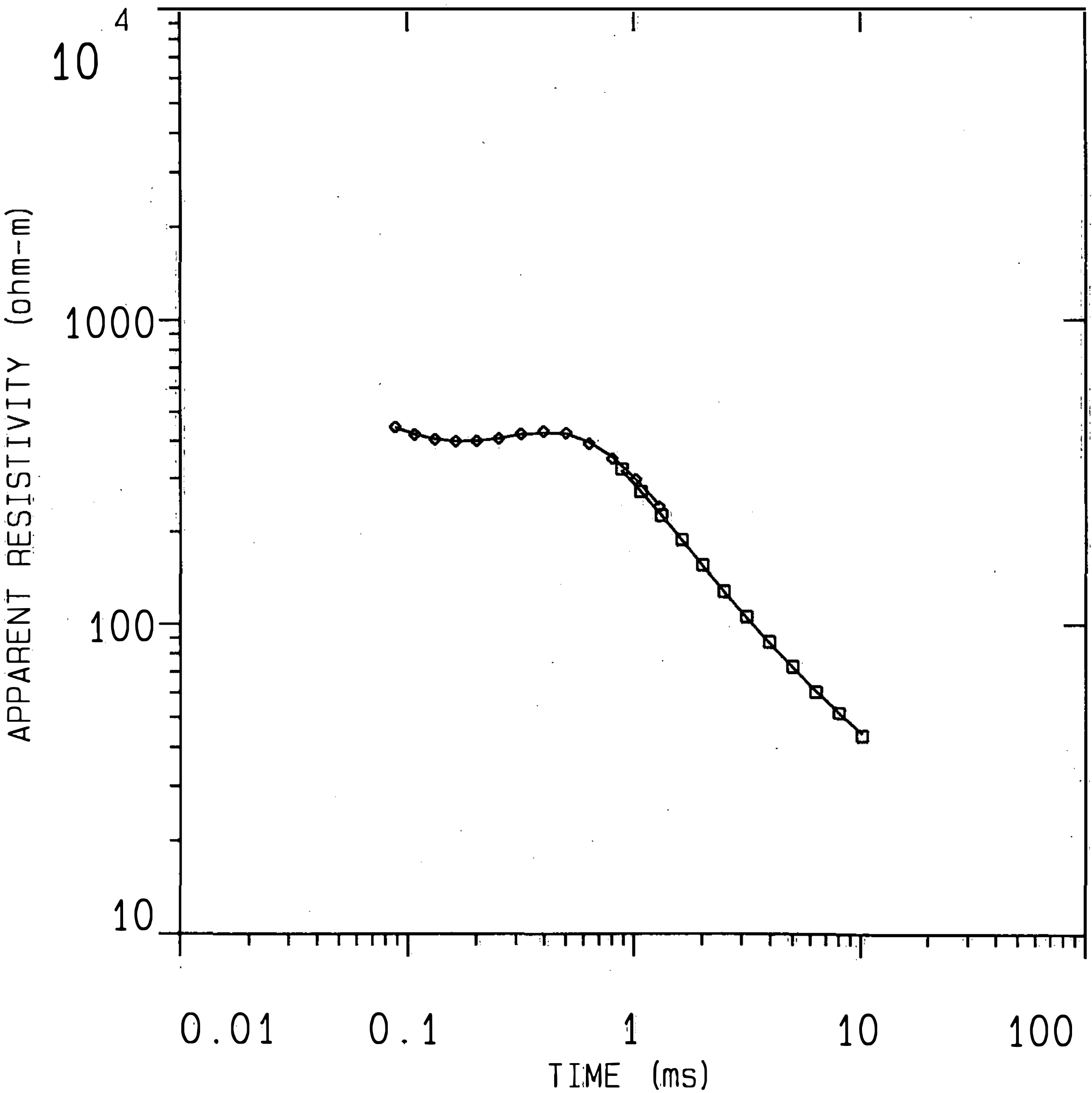
Table 3-2

GPS Coodinates for TDEM Soundings (Degrees, Minutes, Seconds)

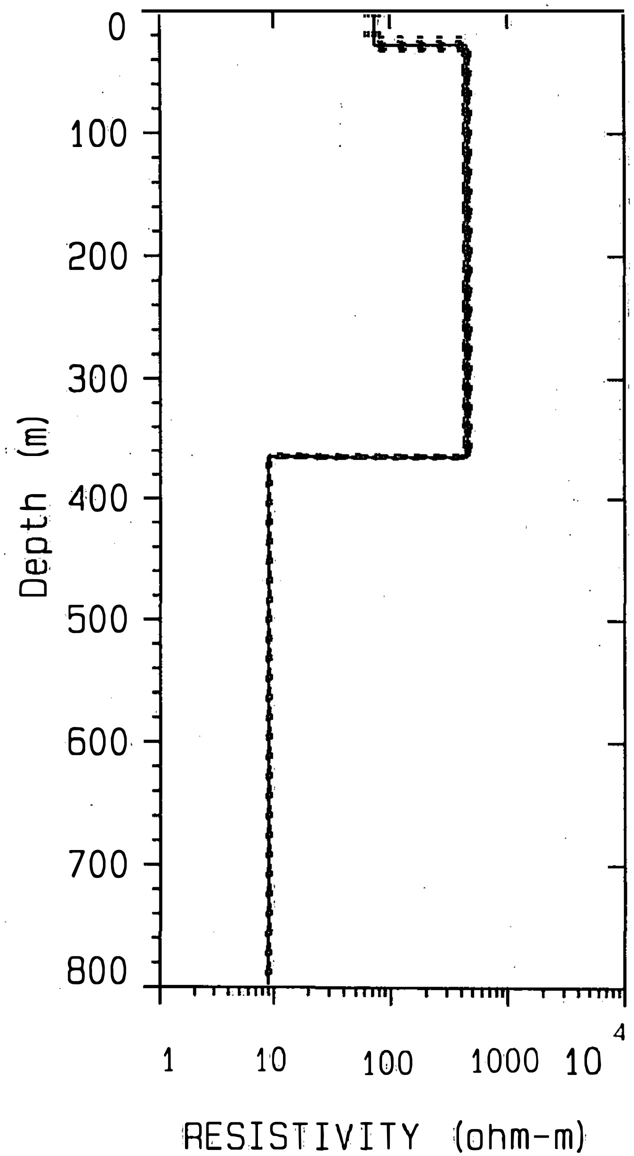
Kula 1800 Property, Maui County, Hawaii

Location	ID	Latitude (N)	Longitude (W)	Elev (ft)	Elev (M)	UTM (Meters) (N)	UTM (Meters) (E)	Comments
Line 1	K-1	20 47 29.5	156 21 51.1	1300	396.2	2301317.2	774387.6	Center of transmitter loop
Line 1	N. Corner K-1	20 47 37.0	156 21 51.2			2301547.9	774381	N. Corner of K-1 loop, 100 ft south of fence
Line 1	K-2	20 47 15.5	156 21 14.0	1650	502.9	2300904	775468.1	Center of transmitter loop
Line 1	N. Corner K-2	20 47 22.6	156 21 13.3			2301122.8	775484.7	N. Corner of K-2 loop, 100 ft south of fence
Line 2	K-3	20 46 28.7	156 22 09.7	1300	396.2	2299437.8	773879.9	Center of transmitter loop
Line 2	S.W. Corner K-3	20 46 27.9	156 22 18.2			2299409.2	773634.4	S.W. Corner of K-3 loop, along dirt road
Line 2	K-4	20 46 25.0	156 21 49.8	1500	457.2	2299333.4	774457.6	Center of transmitter loop
Line 2	S.E. Corner K-4	20 46 20.2	156 21 43.9			2299188.5	774630.7	S.E. Corner of K-4 loop, along dirt road
Line 2	K-5	20 46 03.9	156 21 30.5	1680	512.1	2298693.3	775026.7	Center of transmitter loop
Line 2	E. Corner K-5	20 46 03.4	156 21 22.8			2298681.6	775249.8	E. Corner of K-5 loop, 150 ft south of dirt road
Line 2	K-6	20 46 25.7	156 21 10.9	1700	518.2	2299373.3	775582.9	Center of transmitter loop
Line 2	S. Corner K-6	20 46 18.7	156 21 09.3			2299158.7	775632.7	S. Corner of K-6 loop, 200 ft west of powerline

K-1



10^4
1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
100
TIME (ms)



0
100
200
300
400
500
600
700
800
Depth (m)
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-1

CLIENT:	Pacific Rim Land, Inc.	DATE:	05-02-06
LOCATION:	Maui, Hawaii	SOUNDING:	1
COUNTY:	Maui	ELEVATION:	396.20 m
PROJECT:	Kula 1800 TDEM Survey	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)	TIME CONSTANT:	NONE

SOUNDING COORDINATES: E: 1.0000 N: 1.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 1.162 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			396.2	1300.0	
1	73.58	27.66	368.5	1208.9	0.376
2	449.3	337.0	31.51	103.4	0.749
3	8.99				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	61.584	73.582	81.883
	2	419.318	449.374	485.590
	3	8.610	8.992	9.433
THICK	1	21.154	27.669	32.078
	2	332.780	337.015	344.844
DEPTH	1	21.154	27.669	32.078
	2	362.739	364.684	366.068

CURRENT:	14.00 AMPS	EM-58	COIL AREA:	100.00 sq m.
FREQUENCY:	3.00 Hz	GAIN: 6	RAMP TIME:	150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	155.7	158.5	-1.74
2	1.06	124.2	124.4	-0.0873
3	1.31	97.35	97.10	0.262
4	1.61	76.10	76.37	-0.346
5	2.00	59.09	59.77	-1.14
6	2.50	45.68	45.93	-0.550
7	3.14	34.39	34.85	-1.33
8	3.95	25.62	26.05	-1.68
9	4.99	18.90	19.08	-0.948
10	6.31	13.93	13.79	1.01
11	7.99	9.75	9.74	0.0545
12	10.14	6.91	6.77	2.09

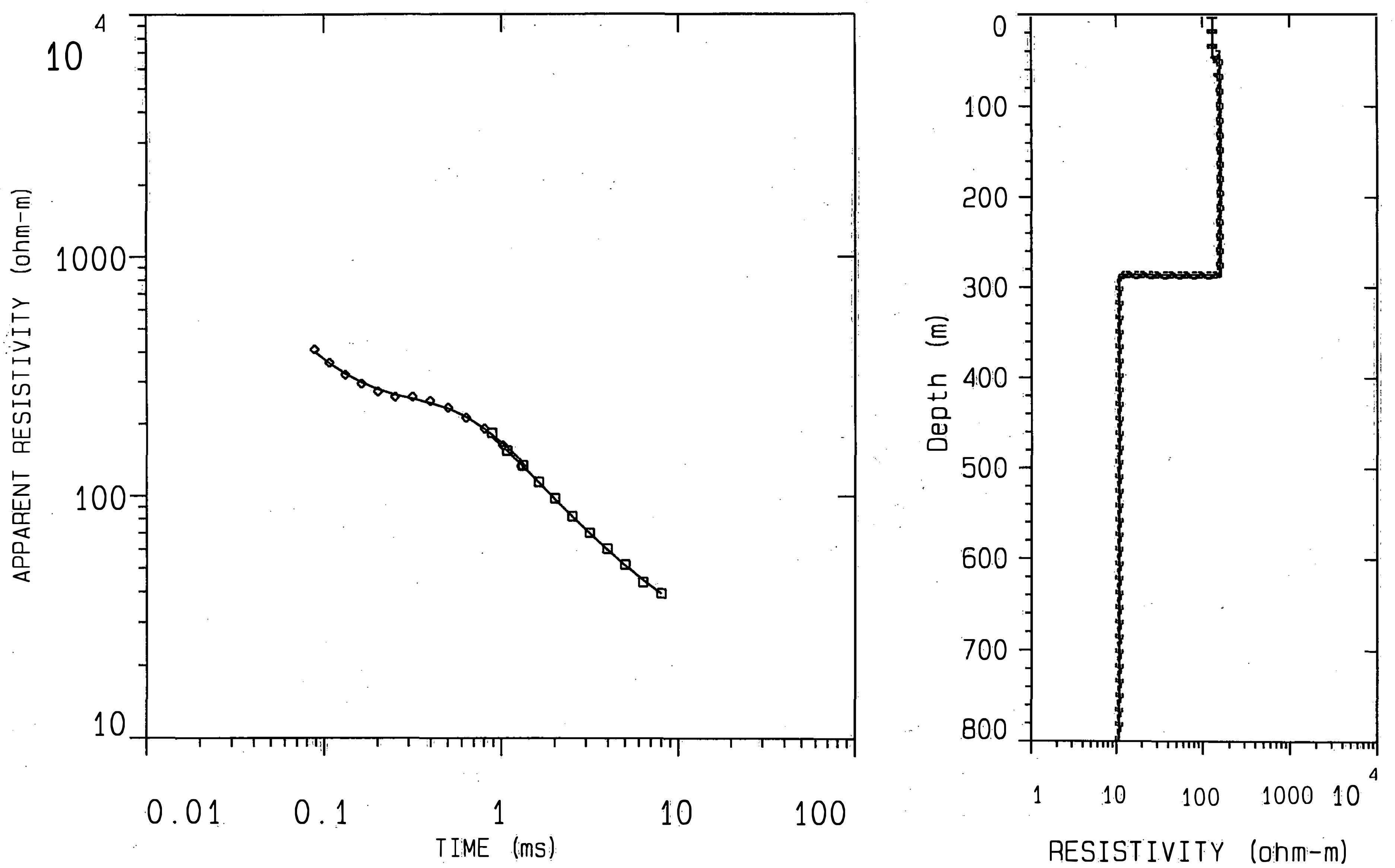
CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
13	0.0881	30380.5	30531.8	-0.497
14	0.106	20460.5	20356.7	0.507
15	0.131	12924.6	12870.6	0.417
16	0.161	7827.9	7828.0	-9.980E-04
17	0.200	4567.8	4559.0	0.191
18	0.250	2551.9	2546.6	0.210
19	0.314	1372.9	1378.4	-0.398
20	0.395	747.7	760.6	-1.72
21	0.499	425.8	428.1	-0.545
22	0.631	267.9	262.7	1.94
23	0.799	176.7	172.8	2.22
24	1.01	123.7	123.6	0.0570
25	1.28	92.80	90.84	2.11

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.80				
P 2	0.06	0.76			
P 3	0.03	-0.07	0.88		
T 1	-0.20	-0.08	0.00	0.69	
T 2	0.01	0.02	0.01	0.03	1.00

K-2



APPARENT RESISTIVITY (ohm-m)
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-2

CLIENT:	Pacific Rim Land, Inc	DATE:	05-02-06
LOCATION:	Maui, Hawaii	SOUNDING:	2
COUNTY:	Maui	ELEVATION:	502.90 m
PROJECT:	Kula 1800 TDEM Survey	EQUIPMENT:	Geonics PROTEM

LOOP SIZE: 305.000 m by 305.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 2.0000 N: 1.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 2.844 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			502.8	1650.0	
1	131.1	45.73	457.1	1499.6	0.348
2	156.9	240.2	216.9	711.6	1.53
3	10.79				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	116.261	131.152	144.519
	2	145.660	156.963	168.899
	3	9.897	10.792	11.725
THICK	1	33.754	45.732	66.580
	2	221.408	240.268	255.363
DEPTH	1	33.754	45.732	66.580
	2	283.338	286.000	289.698

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 5 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	361.5	385.6	-6.67
2	1.06	289.1	289.2	-0.0125
3	1.31	214.1	216.7	-1.24
4	1.61	161.2	162.6	-0.830
5	2.00	119.5	121.3	-1.48
6	2.50	88.68	88.94	-0.295
7	3.14	63.68	64.23	-0.871
8	3.95	45.04	45.65	-1.35
9	4.99	31.57	31.85	-0.874
10	6.31	22.51	21.86	2.90
11	7.99	14.62	14.72	-0.710

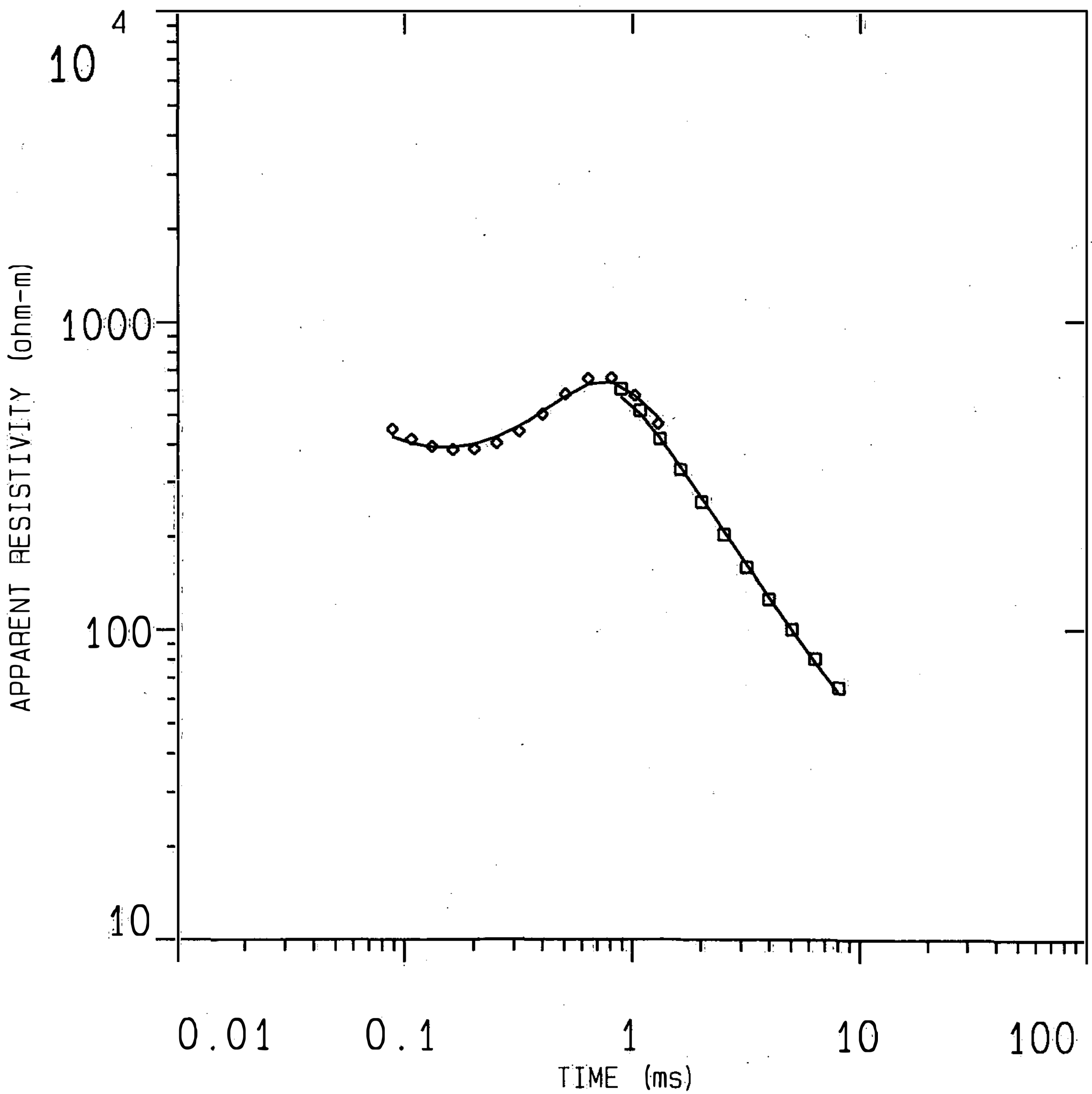
CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 2 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
12	0.0881	34210.8	35404.6	-3.48
13	0.106	25605.8	25824.8	-0.855
14	0.131	18271.7	17982.9	1.58
15	0.161	12346.3	12095.3	2.03
16	0.200	8083.3	7827.6	3.16
17	0.250	5003.8	4849.7	3.08
18	0.314	2840.0	2919.8	-2.80
19	0.395	1694.0	1743.9	-2.94
20	0.499	1042.4	1054.1	-1.12
21	0.631	672.9	662.5	1.54
22	0.799	435.2	436.7	-0.349
23	1.01	306.4	299.0	2.38
24	1.28	228.0	210.3	7.73

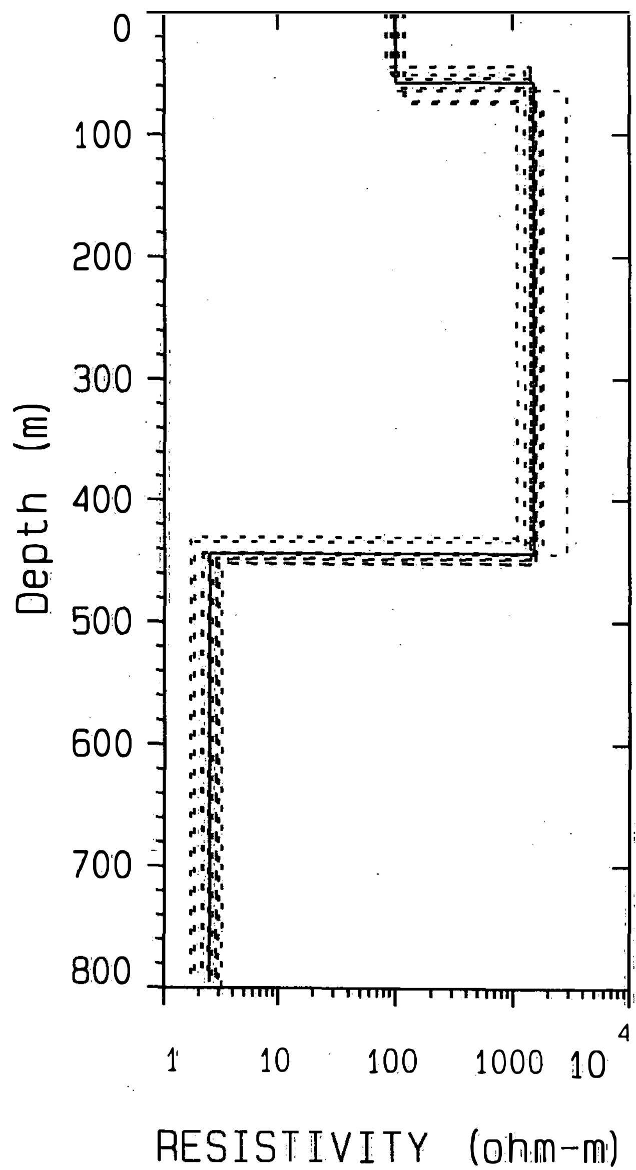
PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.89				
P 2	0.06	0.95			
P 3	0.02	-0.03	0.93		
T 1	-0.13	-0.01	-0.03	0.08	
T 2	0.02	0.01	0.01	0.18	0.96
	P 1	P 2	P 3	T 1	T 2

K-3



APPARENT RESISTIVITY (ohm-m)
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)



Depth (m)
0
100
200
300
400
500
600
700
800
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-3

CLIENT: Pacific Rim Land, Inc
LOCATION: Maui, Hawaii
COUNTY: Maui
PROJECT: Kula 1800 TDEM Survey
LOOP SIZE: 305.000 m by 305.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 3.0000 N: 2.0000 SLOPE: NONE

DATE: 05-03-06
SOUNDING: 3
ELEVATION: 396.20 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:
TIME CONSTANT: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.907 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			396.2	1300.0	
1	101.0	57.53	338.6	1110.9	0.569
2	1497.4	386.1	-47.48	-155.7	0.257
3	2.48				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	83.359	101.001	120.753
	2	1087.905	1497.484	2887.746
	3	1.697	2.484	3.195
THICK	1	44.618	57.534	74.377
	2	357.580	386.150	404.033
DEPTH	1	44.618	57.534	74.377
	2	430.647	443.684	452.089

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

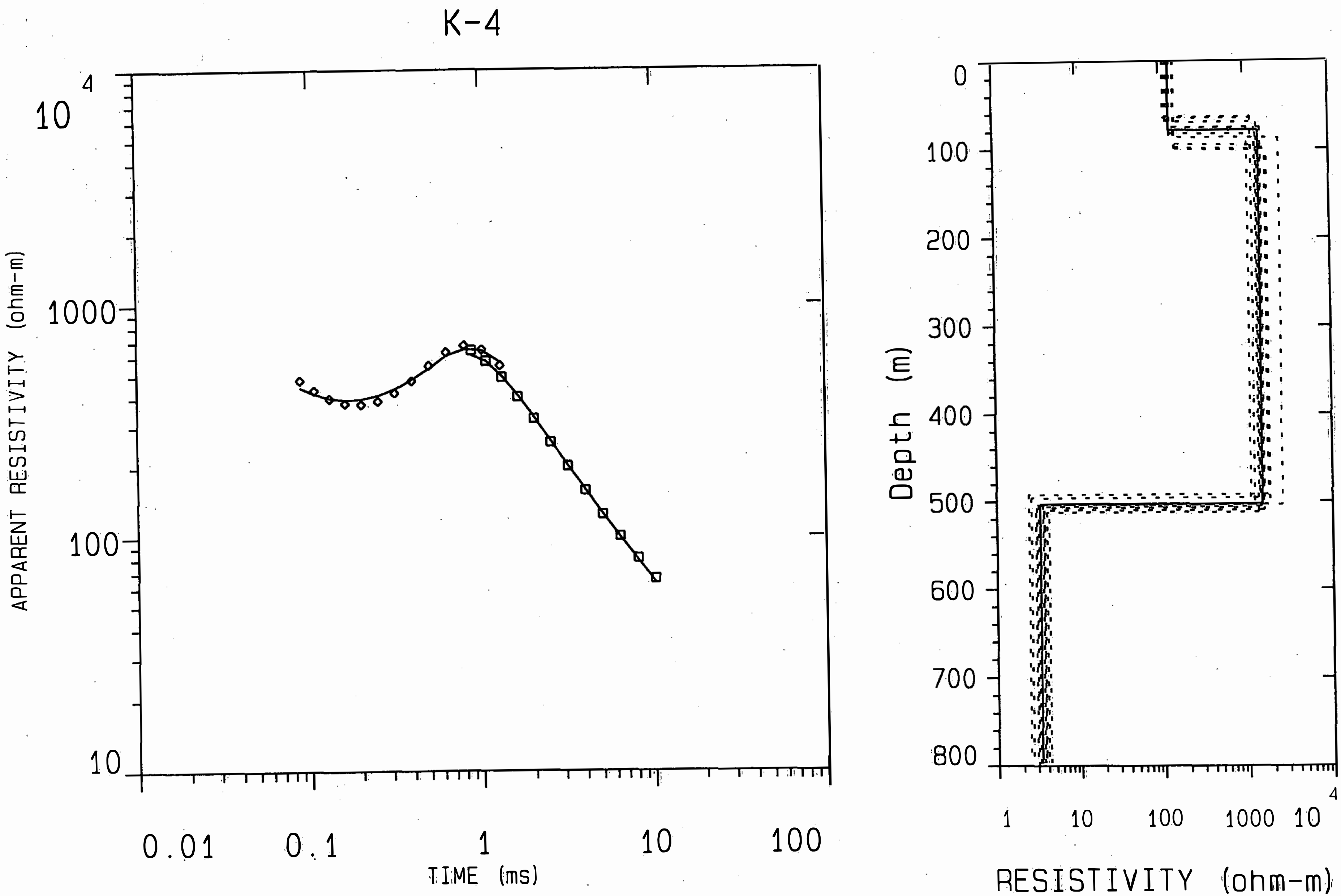
No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	60.24	65.92	-9.43
2	1.06	47.32	49.09	-3.74
3	1.31	38.95	38.59	0.912
4	1.61	32.79	32.02	2.36
5	2.00	27.58	26.41	4.23
6	2.50	22.75	21.90	3.71
7	3.14	18.54	17.99	2.99
8	3.95	14.94	14.65	1.94
9	4.99	11.73	11.79	-0.514
10	6.31	9.07	9.38	-3.47
11	7.99	6.88	7.36	-6.89

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
12	0.0881	29802.3	32516.2	-9.10
13	0.106	20664.0	21670.9	-4.87
14	0.131	13443.6	13518.9	-0.560
15	0.161	8282.1	8038.1	2.94
16	0.200	4804.5	4544.3	5.41
17	0.250	2571.6	2398.5	6.72
18	0.314	1276.5	1204.4	5.64
19	0.395	590.9	573.0	3.02
20	0.499	263.4	270.9	-2.85
21	0.631	123.3	131.4	-6.55
22	0.799	67.85	70.97	-4.59
23	1.01	45.57	45.77	-0.433
24	1.28	34.56	32.25	6.68

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.89				
P 2	-0.03	0.09			
P 3	0.08	-0.08	0.47		
T 1	-0.15	-0.15	0.12	0.79	
T 2	0.03	0.02	-0.06	0.04	0.99


K-4
APPARENT RESISTIVITY (ohm-m)
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-4

CLIENT:	Pacific Rim Land, Inc	DATE:	05-03-06
LOCATION:	Maui, Hawaii	SOUNDING:	4
COUNTY:	Maui	ELEVATION:	457.20 m
PROJECT:	Kula 1800 TDEM Survey	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)	TIME CONSTANT:	NONE

SOUNDING COORDINATES: E: 4.0000 N: 2.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.927 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			457.2	1500.0	
1	129.9	78.77	378.4	1241.4	0.606
2	1478.2	423.9	-45.51	-149.3	0.286
3	3.34				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	112.077	129.920	150.974
	2	1087.256	1478.277	2566.990
	3	2.447	3.344	4.260
THICK	1	62.671	78.778	100.383
	2	393.205	423.936	444.401
DEPTH	1	62.671	78.778	100.383
	2	491.925	502.714	512.150

CURRENT:	14.00 AMPS	EM-58	COIL AREA:	100.00 sq m.
FREQUENCY:	3.00 Hz	GAIN: 7	RAMP TIME:	150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	55.95	60.07	-7.35
2	1.06	40.14	40.30	-0.388
3	1.31	30.54	30.02	1.70
4	1.61	24.32	23.75	2.34
5	2.00	19.76	19.26	2.52
6	2.50	16.13	15.82	1.91
7	3.14	12.98	12.89	0.695
8	3.95	10.54	10.43	1.10
9	4.99	8.45	8.37	1.02
10	6.31	6.54	6.61	-1.11
11	7.99	5.02	5.17	-2.98
12	10.14	3.75	3.97	-5.95

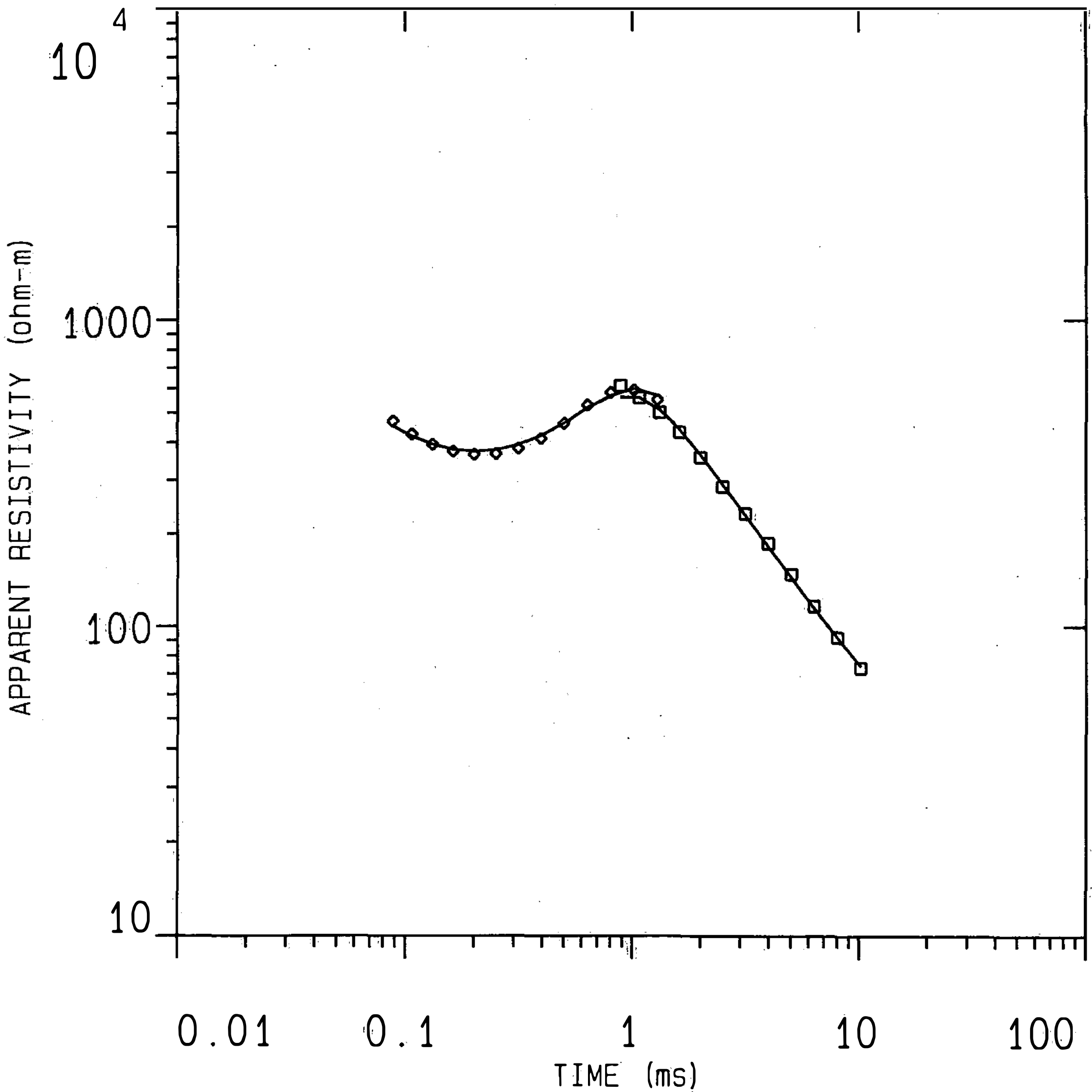
CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
13	0.0881	27161.1	30382.8	-11.86
14	0.106	19573.3	20591.0	-5.19
15	0.131	13221.6	13117.2	0.789
16	0.161	8432.6	7999.2	5.13
17	0.200	5020.4	4636.0	7.65
18	0.250	2746.5	2521.5	8.19
19	0.314	1380.5	1300.6	5.78
20	0.395	645.1	633.5	1.80
21	0.499	289.0	301.9	-4.46
22	0.631	132.3	139.5	-5.39
23	0.799	66.64	70.63	-5.98
24	1.01	38.96	39.35	-0.996
25	1.28	27.15	25.80	4.99

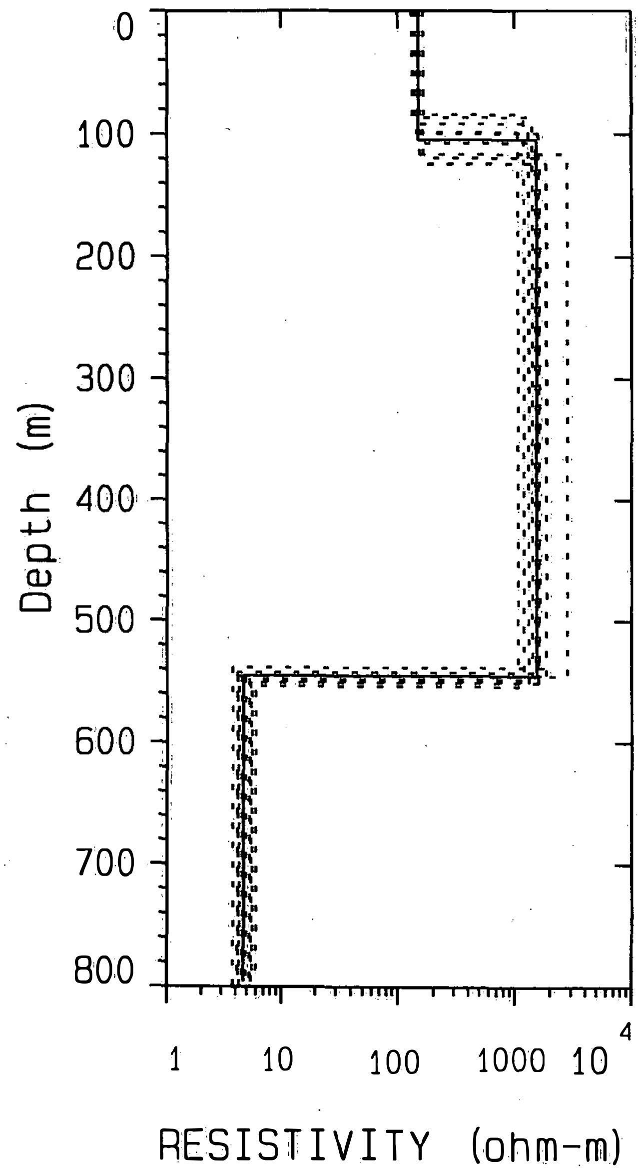
PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.93				
P 2	-0.02	0.16			
P 3	0.05	-0.11	0.55		
T 1	-0.10	-0.14	0.08	0.84	
T 2	0.02	0.02	-0.05	0.03	0.99

K-5



APPARENT RESISTIVITY (ohm-m)
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)



Depth (m)
0
100
200
300
400
500
600
700
800
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-5

CLIENT:	Pacific Rim Land, Inc	DATE:	05-04-06
LOCATION:	Maui, Hawaii	SOUNDING:	5
COUNTY:	Maui	ELEVATION:	512.10 m
PROJECT:	Kula 1800 TDEM Survey	EQUIPMENT:	Geonics PROTEM
LOOP SIZE:	305.000 m by 305.000 m	AZIMUTH:	
COIL LOC:	0.000 m (X), 0.000 m (Y)	TIME CONSTANT:	NONE
SOUNDING COORDINATES:	E: 5.0000 N: 2.0000	SLOPE:	NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.089 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			512.0	1680.0	
1	149.9	104.6	407.4	1336.6	0.697
2	1535.0	440.7	-33.27	-109.2	0.287
3	4.68				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	132.399	149.942	164.602
	2	1068.038	1535.024	2795.230
	3	3.762	4.680	5.971
THICK	1	84.051	104.644	124.374
	2	414.178	440.731	466.098
DEPTH	1	84.051	104.644	124.374
	2	538.552	545.375	554.224

CURRENT:	14.00 AMPS	EM-58		COIL AREA:	100.00 sq m.
FREQUENCY:	3.00 Hz	GAIN:	6	RAMP TIME:	155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	59.30	67.77	-14.29
2	1.06	41.88	41.89	-0.0367
3	1.31	29.53	28.67	2.91
4	1.61	21.92	21.24	3.13
5	2.00	17.14	16.64	2.93
6	2.50	13.68	13.36	2.34
7	3.14	10.52	10.73	-2.01
8	3.95	8.28	8.60	-3.79
9	4.99	6.56	6.80	-3.68
10	6.31	5.22	5.33	-2.09
11	7.99	4.11	4.12	-0.160
12	10.14	3.18	3.13	1.71

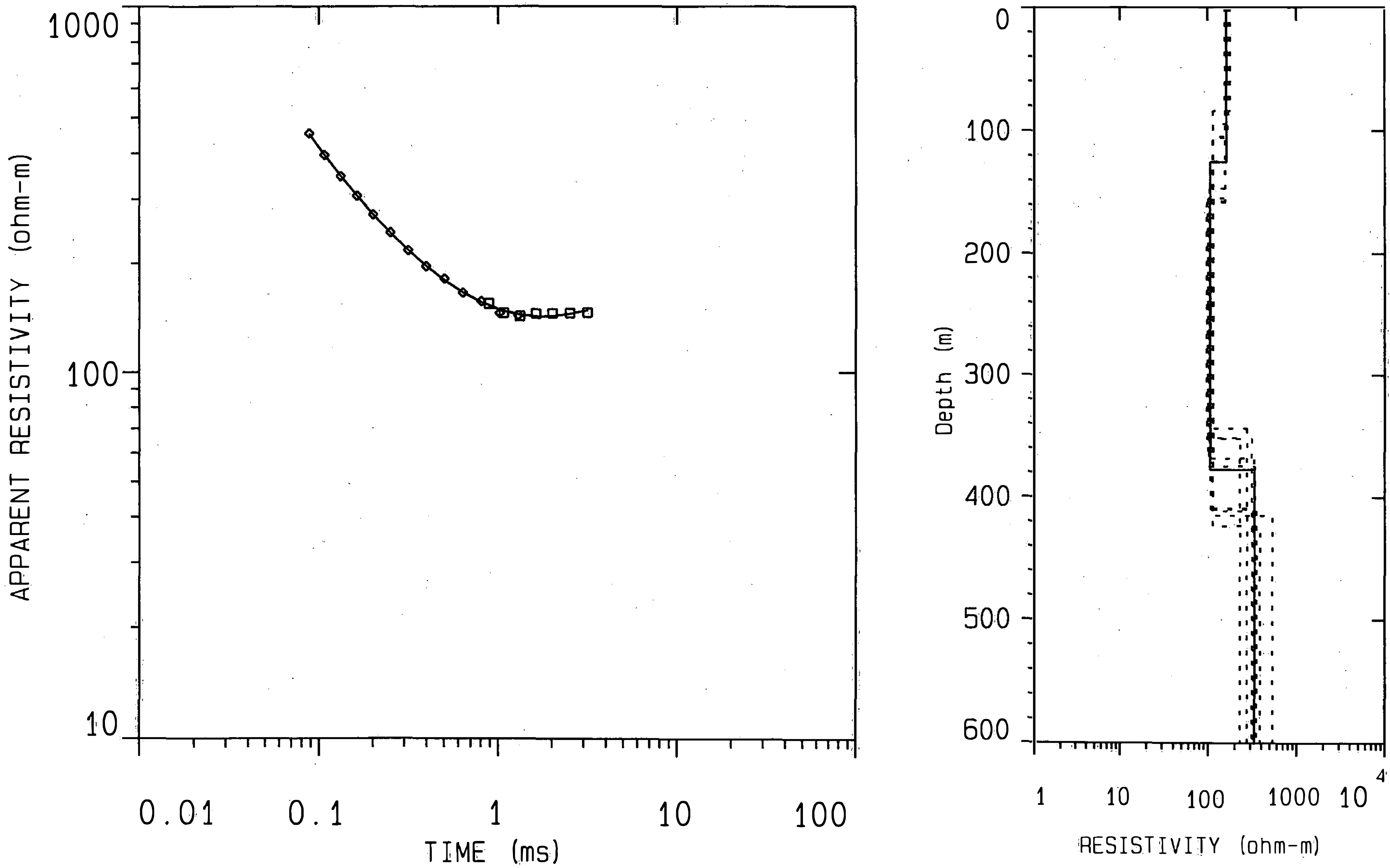
CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
13	0.0881	27925.7	29417.6	-5.34
14	0.106	19968.7	20442.1	-2.37
15	0.131	13436.2	13413.7	0.167
16	0.161	8608.4	8436.2	1.99
17	0.200	5237.5	5048.2	3.61
18	0.250	2974.0	2846.3	4.29
19	0.314	1589.1	1519.4	4.38
20	0.395	796.6	769.5	3.39
21	0.499	374.5	374.3	0.0538
22	0.631	169.8	174.7	-2.88
23	0.799	81.77	84.88	-3.80
24	1.01	43.99	43.17	1.86
25	1.28	27.00	25.69	4.83

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

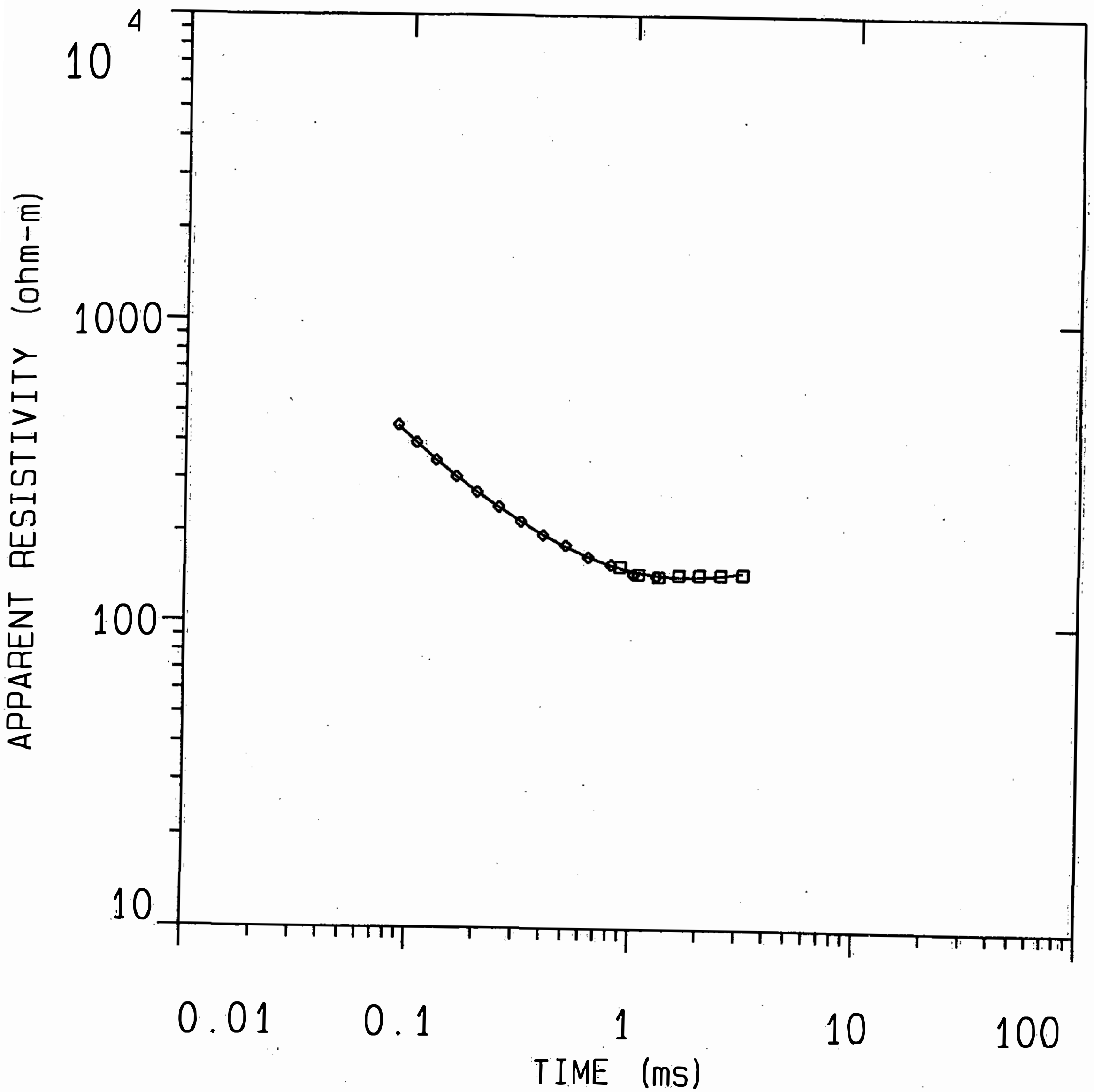
	P 1	P 2	P 3	T 1	T 2
P 1	0.95				
P 2	-0.03	0.09			
P 3	0.05	-0.08	0.54		
T 1	-0.08	-0.16	0.09	0.86	
T 2	0.02	0.04	-0.05	0.04	0.99

K-6

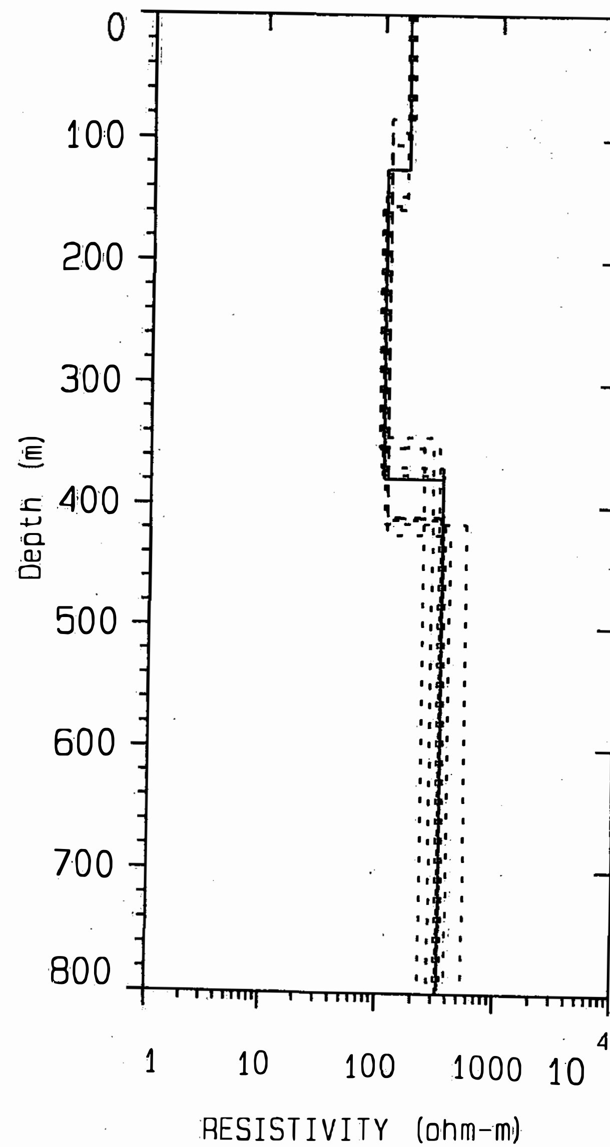


1000
100
10
APPARENT RESISTIVITY (ohm-m)
0.01
0.1
1
10
100
TIME (ms)
0
100
200
300
400
500
600
Depth (m)
1
10
100
1000
10⁴
RESISTIVITY (ohm-m)

K-6



APPARENT RESISTIVITY (ohm-m)
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)



Depth (m)
0
100
200
300
400
500
600
700
800
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K-6

CLIENT: Pacific Rim Land, Inc DATE: 05-05-06
LOCATION: Maui, Hawaii SOUNDING: 6
COUNTY: Maui ELEVATION: 518.20 m
PROJECT: Kula 1800 TDEM Survey EQUIPMENT: Geonics PROTEM
LOOP SIZE: 305.000 m by 305.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 6.0000 N: 2.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 1.540 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			518.2	1700.0	
1	162.6	125.3	392.8	1288.7	0.770
2	106.1	252.7	140.1	459.6	2.38
3	335.7				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	156.475	162.664	179.079
	2	96.990	106.139	114.421
	3	231.445	335.715	536.151
THICK	1	84.217	125.344	158.419
	2	186.418	252.730	326.124
DEPTH	1	84.217	125.344	158.419
	2	344.235	378.074	424.240

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	465.4	475.3	-2.14
2	1.06	313.4	308.3	1.61
3	1.31	193.6	190.8	1.42
4	1.61	111.8	114.8	-2.67
5	2.00	65.20	67.01	-2.77
6	2.50	37.28	37.62	-0.902
7	3.14	21.03	20.55	2.25

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 4 RAMP TIME: 155.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
8	0.0881	29463.4	29573.8	-0.375
9	0.106	22274.3	22223.3	0.229
10	0.131	16243.6	16178.7	0.399
11	0.161	11576.9	11561.7	0.131
12	0.200	8075.5	8088.5	-0.161
13	0.250	5484.8	5509.8	-0.455
14	0.314	3689.0	3674.8	0.384
15	0.395	2415.7	2404.0	0.483
16	0.499	1516.1	1538.8	-1.49
17	0.631	966.5	962.2	0.444
18	0.799	580.8	586.2	-0.932
19	1.01	358.4	346.6	3.30
20	1.28	201.5	199.0	1.22

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.99				
P 2	-0.01	0.96			
P 3	0.00	-0.03	0.22		
T 1	0.06	0.09	0.00	0.65	
T 2	-0.04	-0.10	-0.23	0.28	0.63
	P 1	P 2	P 3	T 1	T 2

APPENDIX C

CD WITH REPORT AND FIGURES

Blackhawk Project Number: 5038

Prepared For:
KULA 1800 INVESTMENT PARTNERS, LLC