TEC-5

ELECTRICAL RESISTIVITY SURVEY AT
SOUTH VALE PROSPECT
MALHEUR COUNTY, OREGON

Prepared for

AMAX EXPLORATION, INC.

Geothermal Group

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by

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Abstract

A reconnaissance electrical resistivity survey was conducted by Terraphysics in the south Vale area, Malheur county. Oregon.

A combination of telluric and magnetotelluric methods were used. Data were obtained at two frequencies, 8 Hz and 0.05 Hz. Some d.c. resistivity measurements were obtained.

A large zone of low apparent resistivity was defined. It appeared to become more conductive with depth (< 5 ohm meters at 0.05 Hz).

A dome type feature adjacent to the low resistivity zone and a number of possible contacts or faults are suggested by the data.

Additional electrical survey work is recommended in the area.

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Introduction

Terraphysics conducted electrical surveys in the vicinity of Vale, Malheur county, Oregon, on behalf of the Geothermal Group of Amax Exploration, Inc. The work was performed during the interval 15 September to 23 September and on 26 September and 14 October, 1975. Telluric and magnetotelluric (MT) and d.c. resistivity measurements were made.

Survey Objective

The objective of the survey was to aid in the evaluation of the geothermal energy potential in the area. Various hot springs exist in the region.

Many geophysical techniques are used to evaluate a geothermal area. Since a decrease in resistivity usually occurs where the temperature of the earth increases, an electrical resistivity survey can be a useful diagnostic technique. The resistivity change with temperature can be on the order of 2.5%/C^{o} (Keller and Frischnecht, 1970). Consequently, resistivity decreases on the order of a factor of 5 or more may be associated with geothermal brines (Keller, 1970). Intrinsic resistivities of less than 10 ohm meters may be expected.

If a geothermal area is at a sufficiently high temperature that a vapor phase is present, higher electrical resistivities are likely. Zohdy, et. al. (1973) report intrinsic resistivities of about 75-130 ohm meters for a vapor-dominated layer in Yellowstone National Park.

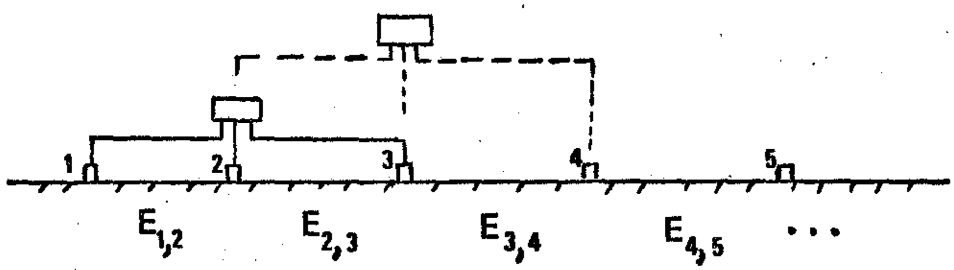
Procedure and Instrumentation

A combination of telluric and magnetotelluric methods were used as a reconnaissance technique. The collinear telluric method is illustrated in Figure 1, and has been described by Dahlberg (1945) and Boissonnas and Leonardon (1948). The technique involves measuring the ratio of the electric fields (E) between two adjacent collinear dipoles. After the readings are completed at one station the instruments are moved to the next site and the next dipole ratio is measured.

The electric field ratio is proportional to the square root of the apparent resistivity ratio beneath the particular dipoles, see Figure 1 (Slankis and Becker, 1969; Slankis, Telford and Becker, 1972). Successive ratios are referenced back to an initial dipole so that a relative resistivity profile across the region results.

The equipment used are itemized in Table 1 and are illustrated in the schematic of Figure 1. Porous pots are used as electrodes for the telluric dipoles. Each electrode consists of a porous ceramic cup and a copper rod in a saturated copper sulphate solution. Voltages from two adjacent telluric dipoles are narrow-band filtered, amplified (2 Ithaco filters) and then displayed on a X-Y chart recorder (Simpson). The voltage ratio is easily measured as the slope of the resulting X-Y plot. An example of such data is shown in Figure 2. Measurements are usually made at 0.05 Hz and may be supplemented by data at other frequencies, such as 8 Hz. Monitoring of the higher frequency provides additional depth information. A theoretical example is described in Appendix A.

Magnetotelluric measurements are made at intervals along the telluric lines. These provide control points to calibrate the relative telluric profiles. Continous profiles of apparent resistivity values across the area are obtained.



ELECTRIC FIELD RATIO

$$\frac{E_{i,j}}{E_{1,2}} = \frac{E_{2,3}}{E_{1,2}} \frac{E_{3,4}}{E_{2,3}} \cdots \frac{E_{i,j}}{E_{i-1,j-1}} = \left(\frac{\rho_{a_{i,j}}}{\rho_{a_{1,2}}} \right)^{\frac{1}{2}}$$

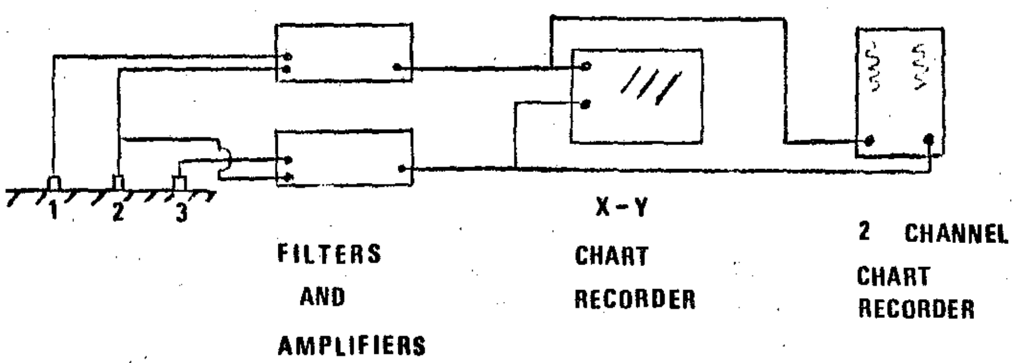
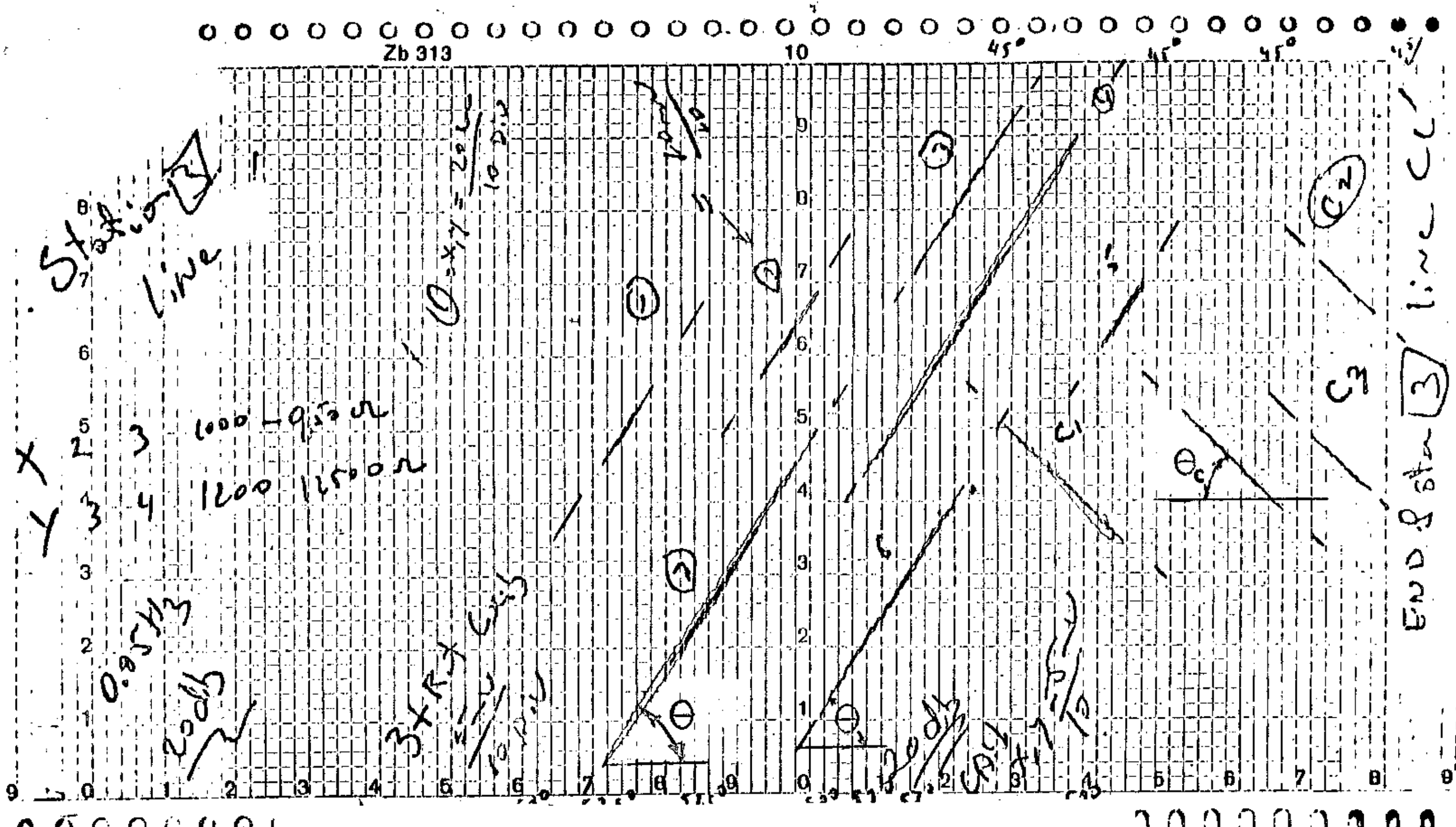


Figure 1. Collinear telluric method and instrumentation

Table 1

SURVEY EQUIPMENT

4	Ithaco model 4211 filters with amplifier options
2	Simpson X-Y model 2745 chart recorders
1	2 channel Brush 222 chart recorder
1	2 channel Gulton model TR 722J chart recorder
1	Develco 3 component superconducting Josephson Junction magnetometer
1	Tektronix 2 channel oscilloscope
2	2 channel amplifiers
1	2 channel 60 Hertz notch filter
1	Equipment trailer
5	reels wire (30,000 feet)
1	Toyota Landcruiser 4 wheel drive
1	Chevrolet 1/2 ton pickup with instrument camper shell
1	500 watt d.c. resistivity transmitter
1	Vacuum pump (for pumping vacuum on cryogenic devices)
1	Liquid He Transfer line
1	Liquid He Level indicator
1	Simpson digital voltmeter
1	100 liter Liquid He dewar (Rental)



Telluric data, 0.05 Hz

Figure 2. The X axis represents the voltage monitored from dipole 2-3 and the Y axis represents dipole 3-4. The ratio of the voltages of these adjacent dipoles is determined from the tangent of the angle Θ from the expression

$$\frac{V_{3,4}}{V_{2,3}} = \frac{\text{TAN}\ \Theta}{\text{TAN}\ \Theta_c}$$

Calibration of the instruments is taken into consideration by the measurement of the angle Θ_c.

The electric field ratio is obtained from the expression

$$\frac{E_{3,4}}{E_{2,3}} = \frac{V_{3,4}}{L_{3,4}} \cdot \frac{L_{2,3}}{V_{2,3}} = \frac{L_{2,3}}{L_{3,4}} \frac{\text{TAN}\ \Theta}{\text{TAN}\ \Theta_c}$$

Where $L_{2,3}$ and $L_{3,4}$ are the lengths of the dipoles 2-3 and 3-4 respectively.

The electric field (E_x) is measured at the same stations used for the collinear telluric data. The orthogonal magnetic field component H_y is measured using a Josephson Junction ("J.J.") magnetometer. Scalar apparent resistivities ρ_{a_x} are calculated from the expression

$$\rho_{a_x} = \frac{.2}{f} \left(\frac{E_x}{H_y}\right)^2$$

where E_x is in millivolts/km, H_y is in gammas and f is the frequency in Hertz (Hz).

Measurements normally are made at a narrow-band frequency of 0.05 Hz. Additional measurements at other frequencies such as .1, .8 and 8 Hz are sometimes obtained.

The orthogonal pair of field components E_y and H_x are measured at some stations. The resulting determination of apparent resistivity ρ_{a_y} gives an indication of the anisotropic nature of the earth.

D.C. resistivity measurements were taken in some areas. Wenner arrays with spacings up to 400 meters are sometimes used. These provide near-surface resistivity information.

Where warranted dipole-dipole arrays are used to obtain deeper resistivity properties. Measurements are obtained with 300 to 1000 meter dipoles having separations up to 3 km. These techniques provide a check on the 8 Hz telluric and MT data.

In summary, the field procedure is as follows:

1) Telluric lines are run in a direction normal to geologic strike where feasible.
2) MT measurements are made at appropriate sites to calibrate the telluric lines.

3) D.C. resistivity measurements are taken to determine shallow resistivities.
4) Results of the above may warrant supplementary deeper resistivity soundings and/or electromagnetic (EM) measurements over possible geothermal target zones.

Field Operation at Vale

In the Vale survey, telluric dipoles ranging from 0.5 to 1.5 km in length were employed, depending on topographic conditions. Telluric measurements were made at 8 and 0.05 Hz.

Geologic strike in the area runs between north and northwest. A telluric line was run northeast-southwest as determined by roads and access, and as specified by the client. Twenty-seven (27) telluric stations were measured and a total of six (6) MT stations were occupied at strategic locations on the telluric line. In addition, six (6) d.c. resistivity measurements were made.

Composition of Crew

A detailed summary of the work and personnel is documented in Appendix B. The personnel involved on the project are listed below.

A. Pessah	Party Chief	Instrumentation, survey and data analysis
P. Guzman	Field Hand	Wire crew, equipment maintenance

In addition, John Wood from Amax Exploration, Inc., assisted in the field on three days.

Terraphysics personnel worked a total of eighteen (18) field man days in the Vale, Oregon area over a period of nine (9) days.

Operating Conditions

The weather was generally favorable and work proceeded smoothly except for one day when low amplitude signal levels delayed the work. On two days, high winds impeded some of the MT readings.

The personnel stayed at the Tapadera Motel in Ontario, Oregon during the work. Maximum commuting time to the furthest station was about 60 minutes.

Specific vehicles used in the project were a Toyota Landcruiser (4-wheel drive), a Chevrolet 1/2 ton pickup with a camper shell and an equipment trailer.

DATA

The location of the telluric line and stations are shown in Plate 1.

The telluric profiles are plotted in Figure 3. The relative electric field strength is plotted on the left side ordinate. The station locations are projected on the abscissa at the top of the plot. The E-field ratio is plotted midway between the electrode stations.

Each station represents an average of 5 to 10 measurements. In some cases, in particular when the ground becomes anisotropic, wide variations in the telluric ratio were observed. The various values are plotted.

MT readings are shown in the rectangles at their corresponding locations. The average resistivity and standard deviation are indicated. Telluric values between MT readings on a given profile were adjusted linearly to correspond to the MT readings. An apparent resistivity scale in ohm meters is shown on the right side ordinate. A summary of all the magnetotelluric data is presented also in Table 2.

Contour maps of apparent resistivities for the 8 and 0.05 Hz frequencies are depicted in Plates 2 and 3 as described from the profile data. The apparent resistivities are plotted in logarithmic contour intervals. Since only one line was surveyed, the contour lines are arbitrarily drawn perpendicular to the survey direction.

Orthogonal telluric measurements were obtained at four sites. In many cases, at a given station, wide variations in both the phase and the amplitude ratio were observed over a period of time. The data were averaged over a number of cycles. The approximate direction of the telluric ellipses are summarized in Table 3.

They range from N 70° W in the southwest portion of the line to N 35° E in the northeast portion.

The results of d.c. resistivity measurements are summarized in Table 4 and are plotted in Figure 4. These measurements were taken in the area of stations 18 to 23.

PLACE South Vale, Oregon

Table 2

MAGNETOTELLURIC

APPARENT RESISTIVITY OHM METERS ∓ STANDARD DEVIATION (NUMBER OF SAMPLES)

LINE & STATION	LENGTH IN METERS	DATE	0.05 Hz	8.0 Hz			COMMENTS
AA' 7-8A	991	9/18	37 ∓ 12 (15)	6.3 ∓ 9.2 (9) ?			very windy 8 Hz data very poor
8A-8B	396	9/18	128 ∓ 38 (7)	≈ 2 ?			very windy, 8 Hz data poor, orthogonal MT
13-14	805	9/19	13.4 ∓ 3.8 (17)	11.0 ∓ 2.9 (19)			
20-21	777	9/21	5.2 ∓ 4.0 (12)	8.5 ∓ 7.7 (16)			windy
25-26	750	9/22	4.0 ∓ 3.6 (20)	5.9 + 5.5 (11)			
30-31	1448	9/23	7.3 ∓ 2.1/(15) 22.0 ∓ 7.0/(4) all 10.4∓ 7.1/(19)	59 ∓ 21 (10)			2 groups 0.05 Hz

Table 3

Orthogonal Telluric Measurements
at 0.05 Hz, South Vale

Location	Approximate Direction Telluric Field	Comments
ORTHO 1	N 35° E N 49° W	2 groups N 35° E dominant (only 2 cycles at S 49° E)
ORTHO 2	North N 80° E	2 groups, north group dominant (only 2 cycles at N 80° E)
ORTHO 3	N 42° W	
ORTHO 4 (Line AA' Station 8A)	N 70° W	

Table 4

D.C. Resistivity, South Vale Area

Location	Type Array	a Spacing meters	Apparent Resistivity ohm meters
Line AA' Station 20	Wenner	15	49.0
22	Wenner	15	102
19 - 20	Wenner	267	16.4
22 - 23	Wenner	332	41.6
Stations 19 - 20 to 22 - 23	Dipole-Dipole	dipole center to center 2700 meters	<5 ($\approx 3 \pm 1$)

Sources of Error

The principal sources of error in the telluric-magnetotelluric methods are:

1) Station locations and dipole lengths are determined from topographical maps, bench marks, and actual field measurements. In general, dipole lengths are determined to within 5%. The possibility of the accumulation of small errors yielding a large uncertainty after a number of stations was reduced by taking magnetotelluric measurements at intervals along the telluric profiles. Telluric values between MT readings were adjusted linearly to correspond to the MT values.

2) Errors due to instrumentation are kept to a minimum. At each frequency reading, the instruments were calibrated. In some cases, calibrations were taken before and after the data.

3) In cases where the earth becomes highly anisotropic, a phase shift can occur between measurements of adjacent telluric dipoles. In this case, the E-field ratio depends upon the polarization of the incident field and in general wide variations in both amplitude and phase are observed. Then attempts are made to obtain information over as much of the area as possible with MT readings and d.c. resistivity measurements.

4) In some areas, considerable noise is observed on the higher frequency data, 8 Hz; this is probably caused by local industrial electrical activity. Attempts are made to minimize any error from these near field sources by careful inspection of each cycle of data on high speed oscillographic records. Considerable scatter in the data usually results, however, in those areas.

Discussion of Data

Geological Province

The Vale area lies at the border between the Blue Mountains and Basin and Range Provinces in the eastern central part of the state of Oregon. This area is "characterized by north trending mountain ranges and intervening flat valleys, which are blanketed with alluvium or recent lava flows." (McKee, 1972) "The rocks consist primarily of extensive sheets of solidified lava. Much of the lava is basalt, but some widespread silicic ash flows and tuffs are present." (McKee, 1972). Nonmarine sandstone, shale and conglomerates are interbedded with the volcanic strata.

Vale Area

The area surveyed was about 12 kilometers southeast of the town of Vale. The elevation ranges from 600 to 1000 meters. The water at Vale hot springs, 0.8 kilometers east of Vale, has a temperature of 198^{o}F. (Waring, 1965). Younger Cenozoic (Miocene and Pliocene) nonmarine sedimentary rocks, ash flow tuffs, and some interbedded rhyolite flows and domes have been mapped in the general area (McKee, 1972). A detailed geology map along the survey line, however, was not available for a direct comparison with the present results.

(a) 8 Hz Data

The 8 Hz apparent resistivity data shown in Figure 3 and Plate 2 range from 59 to 6 ohm meters. A large general low ($<$10 ohm meters) occurs between stations 20 to 28, the lowest value, about 6 ohm meters, occurs between stations 24 to 28.

Further to the southwest, the values range between 10 and 20 ohm meters.

A resistive contact occurs about stations 28 to 29, the apparent resistivity increases to about 59 ohm meters.

(b) 0.05 Hz Data

The 0.05 Hz data reflect deeper resistivity properties of the area. The profile shown in Figure 3 exhibits much the same pattern as the 8 Hz data.

A large resistivity low ($<$ 5 ohm meters) occurs between stations 20 to 28. This could be associated with hot geothermal brines, highly conductive sedimentary rocks, or a combination of the two cases. The data in this segment suggest that the area becomes more conductive with depth, for example, at stations 21-22, 4 ohm meters is observed at 0.05 Hz vs 10 ohm meters at 8 Hz.

The apparent skin depth at 0.05 Hz for a resistivity of 4 ohm meters is about 5 kilometers. The actual sensing depth, however, is usually much less than this depending upon the actual situation. Multifrequency MT data, with a complete model solution, would be required to determine the actual properties and depths.

To the southwest of this resistivity low area, the 0.05 Hz resistivity increases. A dome type feature is suggested between stations 15 to 19. This structure is slightly suggested in the 8 Hz data, but it has now become more prominent with the greater depth of exploration of the 0.05 Hz data. To the southwest of station 19, the 0.05 Hz values are slightly greater than the 8 Hz data. This would suggest that this area becomes uniform or possibly slightly more resistive with depth.

A number of values are indicated for the telluric response at station 16-17. This would suggest a contact or possible fault in the area.

At station 28, the 0.05 Hz telluric data indicated a negative ratio. This result is not fully understood. This situation may arise when the direction of the total electric field is approximately perpendicular to the survey line. While this ratio is not usable for the profile calculations, it suggests an inhomogeneity or possible contact could occur in the area.

Since the telluric response to lateral resistivity changes is different for different frequencies, all the above depth interpretations are subjected to some uncertainty. Two dimensional modelling of the area would be required to evaluate this effect.

(c) D.C. Resistivity

D.C. resistivity measurements were taken between stations 18 to 23 to check the 8 Hz and 0.05 Hz data and to give some additional interpretation insight. The data are plotted in Figure 4. Fairly large lateral near-surface resistivity variations are indicated. The data also indicate fairly resistive near-surface values, apparent resistivity values of 40 to 100 ohm meters are observed at 15 meter Wenner "a" spacings. Apparent resistivity values of 16 to 40 ohm meters are observed at about 300 meter "a" spacings. This indicates that the area becomes more conductive with depth. The dipole-dipole measurement indicates a further decrease in the apparent resistivity value with depth. An apparent resistivity of less than 5 ohm meters is observed at a dipole-dipole separation of 2700 meters.

These values are in reasonable agreement with the telluric-magnetotelluric data. At stations 19-20, the resistivity value of 16.4 ohm meters, obtained at an "a" spacing of 267 meters, is on the same order of magnitude as the 8 Hz data there (9.3 ohm meters, skin depth 541 meters). The resistivity value of less than 5 ohm meters obtained with the dipole-dipole separation of 2700 meters also is in reasonable agreement with the 0.05 Hz data at stations 22 to 23 (3.8 ohm meters, skin depth 4390 meters).

These d.c. resistivity results support the telluric-magnetotelluric indication that this zone (stations 19 to 28) becomes more conductive with depth.

Summary and Recommendations

The present resistivity survey delineates a low apparent resistivity zone (<5 ohm meters) that appears to become more conductive with depth.

A dome type feature and a number of possible contacts or faults are indicated.

The present results by themselves are inconclusive to the possible existence of a geothermal reservoir.

A more detailed geological study of the area should be obtained for correlation with the present survey results.

Additional survey work closer to Vale hot springs may provide clues to the existence of a possible geothermal reservoir in the present surveyed area.

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APPENDIX A

Theoretical telluric results over hypothetical models are shown in Figures A1 and A2. The difference between the two models in the inclusion of a 1 ohm meter body in Figure A2. This could be representative of a geothermal target.

Two points are of particular note.

(1) The telluric response is characteristically dominated by resistivity variations occurring beneath the measuring stations. This is seen in both the figures.

(2) The use of multifrequencies provides some initial determination of depth information. For example, a significant difference is observed between the 0.03 Hz telluric response over the two models. The 8 Hz response is not effected. The 8 Hz E.M. wave in this case does not significantly penetrate to the depth of the 1 ohm meter body. (The skin depth of an 8 Hz E.M. wave is 562 meters in a 10 ohm meter material. The top of the 1 ohm meter body was 500 meters deep). These results place a bound on the depth of the anomoly observed on the 0.03 Hz data. It must be deeper than a few hundred meters and less than a few thousand meters. A more precise depth could, of course, be determined with intermediate frequency data.

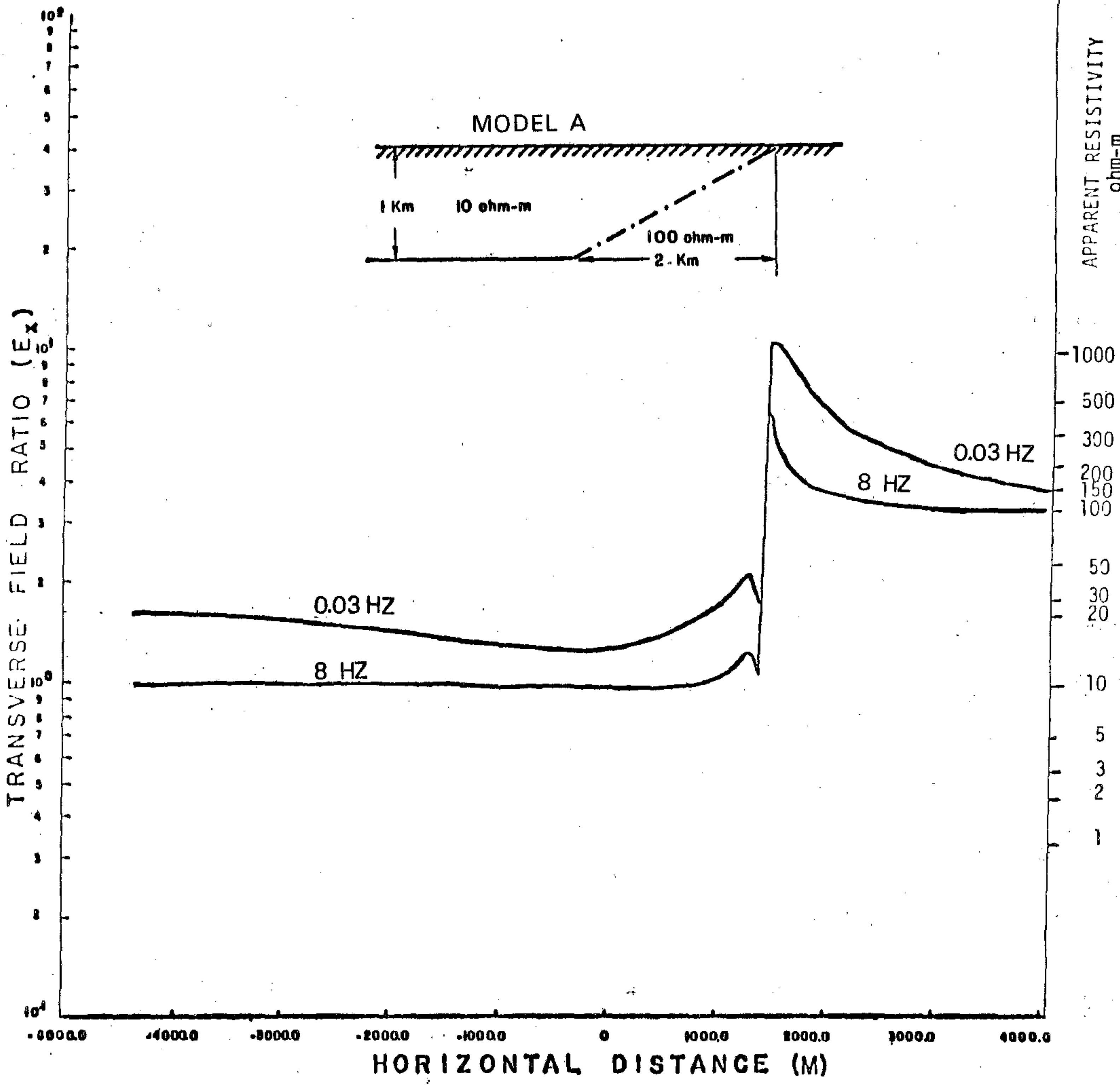

Figure A1. Telluric response at 8 Hz and at 0.03 Hz over Model A.

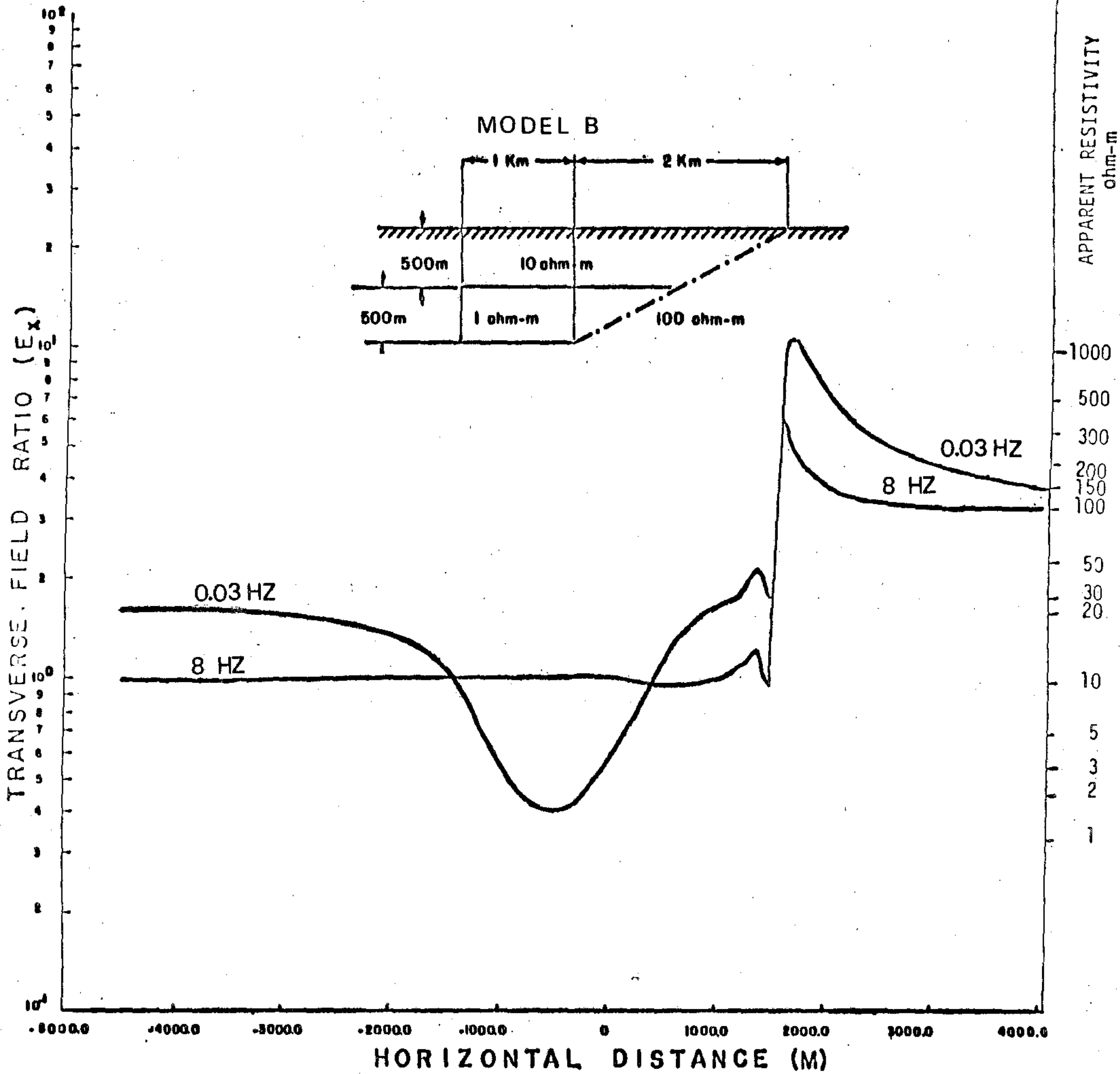

Figure A2. Telluric response at 8 Hz and at 0.03 Hz over Model B, inclusion of a 1 ohm-m body at 500 meters depth.

Appendix B

Personnel and Operations Summary

TERRAPHYSICS

MONTH September

PROJECT South Vale, Oregon

PERSONNEL

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	WOOD (AMAX)
Mon.	15th			Load vehicles and mobilize to Vale, Oregon							X	X		
Tue.	16th			Mobilization, arrived at Ontario (Vale, Oregon) Unload vehicles							X	X		
Wed.	17th	OT	3	Orthogonal 1, 2, 3	X			X			X	X		
Thu.	18th	T	1	Line AA' ST 8A	X			X			X	X		
		OT	1	Line AA' 8A	X			X			X	X		
		MT	2	Line AA' ST (7-8A)⊥(8A-8B) (Very windy)	X			X			X	X		
Fri.	19th	T	5	Line AA' ST 9, 10, 11, 12, 13	X			X			X	X		
		MT	1	Line AA' ST (13-14)	X			X			X	X		
Sat.	20th	T	5	Line AA' ST 14, 15, 16, 17, 18	X			X			X	X		

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS
R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

MONTH

September/Oct.

TERRAPHYSICS

PROJECT South Vale, Oregon

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S Hz 05	01	08	8		PERSONNEL MAZZELLA	PESSAH	GUZMAN	HARVEY	WOOD (AMAX)
SEPTEMBER Sun.	21st	T	4	Line AA' ST 19, 20, 21, 22	X			X			X	X		
		MT	1	Line AA' ST (20-21)	X			X			X	X		
Mon.	22nd	T	6	Line AA' ST 23, 24, 25, 26, 27, 28	X			X			X	X		X
		MT	1	Line AA' ST (25-26) (Low signal level)	X			X			X	X		X
Tue.	23rd	T	2	Line AA' ST 29, 30	X			X			X	X		X
		MT	1	Line AA' [(Low signal level ST (30-31)]	X			X			X	X		X
Fri.	26th	R	2	Line AA' ST 22 50' W, (22-23) 1090' W							X	X		X
OCTOBER Tue.	14th	R	4	Line AA' ST 22, 20 50' W, ST (19 to 20) 875' W Dipole-Dipole (DD) ST (19-20) to (22-23) 5900' W							X	X		

TECHNIQUE CODES T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC (ACTIVE)

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