MAGNETOTELLURIC SURVEY AT
LA GRANDE PROSPECT
UNION COUNTY, OREGON

Prepared for
AMAX EXPLORATION, INC.
Geothermal Group

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by
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Abstract

A reconnaissance electrical survey was conducted by Terraphysics in the La Grande area, Union County, Oregon.

A magnetotelluric method was used. Data were obtained at frequencies of 8, .8, .1 and 0.05 Hz.

The results appear to reflect some of the geological formations in the area.

A scalar multilayer interpretation of the data is presented. Various depths to a resistive basement ($>$100 ohm meters) are suggested, ranging from 100 to over 1000 meters.

The sediments in the basin appear to be fairly thick in some areas; 250 to 1200 meters, with resistivity values of 8 to 55 ohm meters.

Two shallow low-resistivity ($<$ 3 ohm meters) areas are indicated, and two deeper low-resistivity zones are suggested. In view of two-dimensional effects, the deeper zones should be viewed with caution.

Additional survey work is recommended in the area.

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Introduction

Terraphysics conducted an electrical survey in the La Grande area, Union County, Oregon, on behalf of the Geothermal Group of Amax Exploration, Inc., during the interval 6 to 11 October 1975. Magnetotelluric (MT) 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° (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

Magnetotelluric measurements were used as a reconnaissance technique. The method consists of measuring the electric field (E_x) and orthogonal magnetic field (H_y) at a site. Scalar apparent resistivities ρ_{a_x} are calculated from the expression (Keller and Frischnecht, 1970)

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

where E_x is in millivolts/km, H_y is in gammas, f is the frequency in Hertz (Hz) and the resulting apparent resistivity is in ohm meters.

The direction of the electric field measurement, also referred to as the telluric direction, is usually chosen perpendicular to the geologic strike.

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

The equipment used is itemized in Table 1 and illustrated in the schematic of Figure 1. Porous pots are used as electrodes for the electric field measurement, the telluric dipole. Each electrode consists of a porous ceramic cup and a copper rod in a saturated copper sulphate solution. Voltages from the telluric dipole and the output of the superconducting magnetometer are narrow-band filtered, amplified and displayed on a two-channel chart recorder. Measurements are usually made at a number of frequencies down to 0.05 Hz. An example of such data is shown in Figure 2.

The amplitude ratio (E_x/H_y) is easily obtained from the corresponding peak-to-peak amplitudes off the chart records.

The instruments are calibrated at each frequency reading.

Monitoring different frequencies provides various depth information. An indication of the depth penetration is sometimes given by the apparent skin depth, δ_a. This is defined as the depth where the amplitude of the electric field has fallen to 1/e of its value at the surface and is calculated from the expression

$$\delta_a = 503 \left(\frac{\rho_a}{f} \right)^{\frac{1}{2}}$$

where ρ_a is the apparent resistivity in ohm meters, f is the frequency in Hz, and the resulting skin depth is in meters. The lower the frequency, the deeper the penetration.

An example of the different frequency responses over theoretical models is described in Appendix A.

The actual sensing depths are usually much less than the skin depths. Complete model solutions are required to determine the intrinsic properties and depths. In cases where there is little lateral resistivity variation, an interpretation can be performed with multilayer models. Two-dimensional computer modelling would be required to interpret the results if significant lateral variations or anisotropy effects occur.

Table 1

SURVEY EQUIPMENT

4	Ithaco model 4211 filters with amplifier options
1	2 channel Brush 222 chart recorder
1	Develco 3 component superconducting Josephson Junction magnetometer
1	Tektronix 2 channel oscilloscope
1	2 channel amplifier
1	2 channel 60 Hertz notch filter
1	Equipment trailer
3	Reels wire (5,000 meters)
1	Toyota Landcruiser, 4 wheel drive
1	Chevrolet, 1/2 ton pickup with instrument camper shell
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)

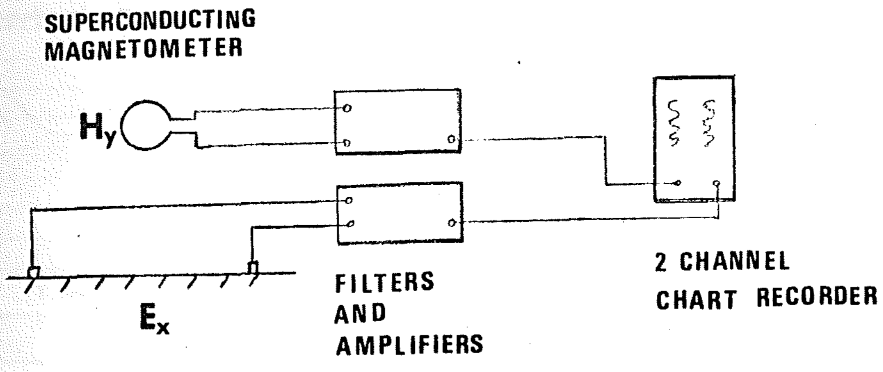

Figure 1. Magnetotelluric instrumentation.

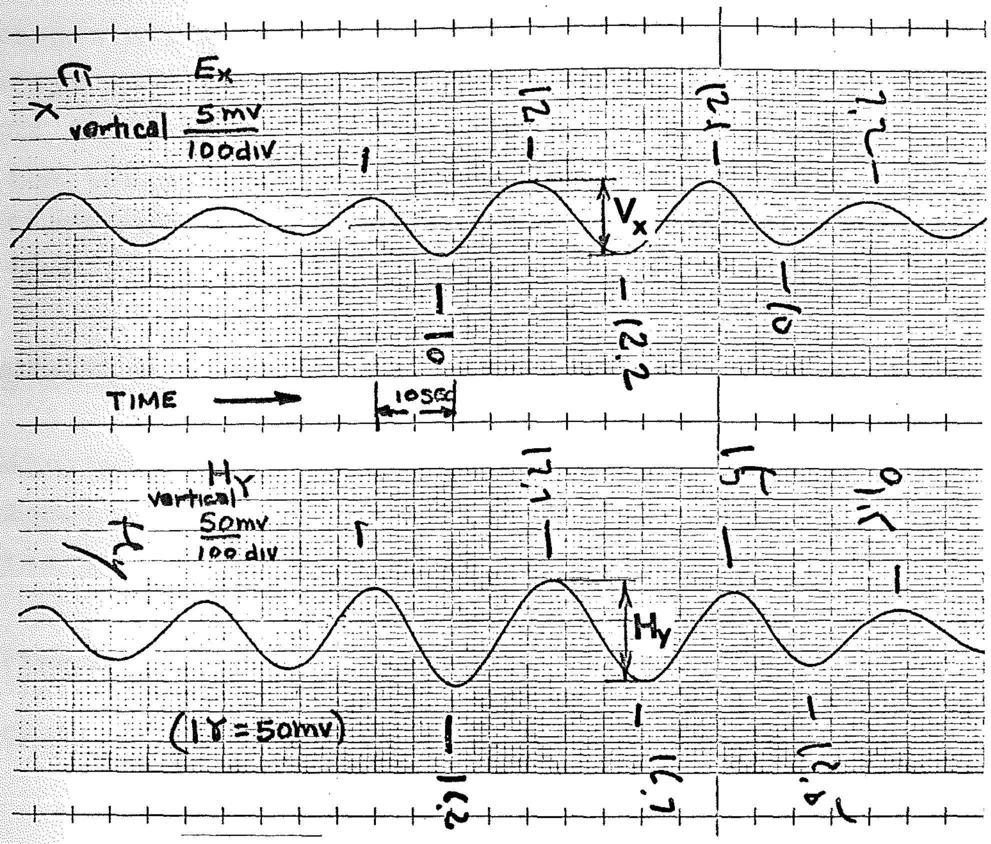

Figure 2. Magnetotelluric data, narrow-band filtered at 0.05 Hz. The scalar apparent resistivity ρ_{a_x} is calculated from the expression

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

where L_x is the length of the telluric dipole.

Field Operation at La Grande

In the La Grande survey, telluric dipoles ranging from .3 to .7 kilometers in length were employed, depending on topographic conditions. Magnetotelluric measurements were made at 8, 0.8, 0.1 and 0.05 Hz.

Geologic strike in the area runs predominately northwest. A profile line was run southwest-northeast as determined by roads and access, and as specified by the client. The directions of the telluric dipoles were N 55° E and N 35° W. Ten (10) MT stations were occupied with orthogonal MT measurements obtained at five (5) sites.

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

Terraphysics personnel worked a total of ten (10) field man days in the La Grande area over a period of five (5) days.

Operating Conditions

The weather was somewhat adverse for optimum field operation. High winds, with gusts over 30 miles per hour, occurred every day. Extra care, therefore, was required in shielding and stabilizing the "J.J." magnetometer.

The personnel stayed at the Pony Soldier Motel in La Grande, Oregon during the work period. Maximum commuting time to the farthest station was about 45 minutes.

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

DATA

The locations of the stations are shown in Plate 1. (The Figures and Plates for the data are in the second binder.)

A pseudo-section across line AA' is represented in Figure 3. The apparent skin depth is plotted as the ordinate, and station locations are projected on the abscissa at the top of the plot. The scalar apparent resistivity values are mapped for the N 55° E telluric measurements. Apparent resistivity contours are plotted in logarithmic intervals.

A different representation of the data is shown in Figure 4. Apparent resistivity values for the 0.05 Hz and 8 Hz data are plotted as the ordinate, and station locations are plotted as the abscissa. The orthogonal scalar resistivities are indicated for those stations where they were obtained. The standard deviations are represented as error bars.
A summary of all the magnetotelluric data is presented in Table 2.

The apparent resistivity values for stations 1 through 8 are plotted as a function of the period in Figures 5 through 12. The standard deviations are represented as error bars. The orthogonal scalar resistivities are plotted for those stations where they were obtained.

PLACE La Grande, Oregon

TABLE 2 MAGNETOTELLURIC DATA

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

LINE & STATION	LENGTH IN METERS	DATE	0.05 Hz	0.1 Hz	0.8 Hz	8.0 Hz	COMMENTS
AA' MT 1 A-B	579	10/10	291 ∓ 110 13	112 ∓ 92 8	47 ∓ 36 23	21 ∓ 14 24	very windy conditions for all data
MT 1 A-C	305	10/10	216 ∓ 83 15	143 ∓ 123 21	91 ∓ 85 21	14 ∓ 7 20	
MT 2 A-B	587	10/10	87 ∓ 52 14	115 ∓ 78 18	15 ∓ 15 20	4 ∓ 3 23	
MT 3 A-B	541	10/8	162 ∓ 34 13	213 ∓ 82 8	30 ∓ 24 22	13 ∓ 12 21	
MT 4 A-B	579	10/7	154 ∓ 86 20	279 ∓ 116 22	19 ∓ 14 10	29 ∓ 18 20	
MT 4 A-C	663	10/7	704 ∓ 234 16	416 ∓ 165 23	2 groups 228 ∓ 74/6 1223 ∓ 436/6 993 ∓ 820/12(all)	106 ∓ 82 17	poor correlation .8 Hz data
MT 5 A-B	701	10/8	101 ∓ 61 17	2 groups 30 ∓ 11/3 300 ∓ 237/4 184 ∓ 220/7(all)	5 ∓ 4 5	15 ∓ 6 4	
MT 6 A-B	640	10/9	47 ∓ 33 35	84 ∓ 48 28	21 ∓ 5 5	3 ∓ 2 5	

PLACE La Grande, Oregon

TABLE 2 MAGNETOTELLURIC DATA (CON'T)

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

LINE & STATION	LENGTH IN METERS	DATE	0.05 Hz	0.1 Hz	0.8 Hz	8.0 Hz	COMMENTS
AA' MT 7 A-B	564	10/8	232 ∓ 171 20	78 ∓ 49 20	6 ∓ 6 13	11 ∓ 6/11 68 ∓ 24/4 27 ∓ 28/15 (all)	poor correlation 8 and .8 Hz data
MT 7 A-C	549	10/8	570 ∓ 165 22	425 ∓ 225 17	5 ∓ 3 14	74 ∓ 29 7	
MT 8 A-B	541	10/9	158 ∓ 84 20	32 ∓ 17 8	15 ∓ 9 9	6 ∓ 5 9	
MT 9 A-B	564	10/11	38 ∓ 13 13	16 ∓ 14 11	5 ∓ 5 20	6 ∓ 4 20	
MT 9 B-C	305	10/11	446 ∓ 194 19	143 ∓ 101 16	30 ∓ 20 13	58 ∓ 42 20	
MT 11 A-B	366	10/11 10/10	97 ∓ 54 15	82 ∓ 55 7	108 ∓ 59 11	10 ∓ 7 18	
MT 11 A-C	305	10/11	852 ∓ 337 16	662 ∓ 358 13	52 ∓ 28 13	32 ∓ 21 20	

Discussion of Data

Geological Province

The La Grande area lies in the Blue Mountains Province in northeastern Oregon. Geologic formations in this province are similar to those observed in the Columbia Plateau Province to the north and the Basin and Range Province to the south; thick sections of Upper Cenozoic volcanic strata are present. These consist predominately of basaltic lava flows and thick layers of sedimentary rocks.

The overall structure of the Blue Mountains Province is a "large, asymmetric anticline with a steep north flank and a gentle south flank" (McKee, 1972). Folding, faulting and uplift of the Blue Mountains occurred in the Late Cenozoic Era. Numerous steeply dipping faults, generally trending north to northwest, occur in the region.

La Grande Area

The area survey was about 18 kilometers southeast of the town of La Grande, Oregon. The water at Hot Lake, 14 kilometers southeast of La Grande, has a temperature of 82°C (Waring, 1965).

Geologic formations in the area consist of basalt of the Columbia River Group and a large basin of Quaternary sedimentary deposits (Newcomb, 1970). The surveyed area, at the southern end of the basin, intersected both the sedimentary deposits and basalt units.

At least eleven northwest trending fault segments have been mapped across the survey line AA'.

The pseudo-section in Figure 3 is one method of representing the properties of the area as a function of depth. Even though only apparent values are indicated, this presentation delineates low resistivity areas and two-dimensional effects, and gives some indication of the resistivity behavior as a function of depth.

Two shallow areas of low apparent resistivity value (< 5 ohm meters) are indicated at stations 2 and 6. A spring coincides with the resistivity low at station 6. This area is mapped as Columbia basalt, and at least four faults occur within a three kilometer segment there. The resistivity low may be reflecting a highly fractured, water-saturated zone.

Most of the area appears to become more resistive with depth. A statistical analysis of the 0.1 and 0.05 Hz data between stations 2 to 6 indicates that only at station 4 are the apparent resistivity values significantly different, the value becoming more conductive at 0.05 Hz. The orthogonal MT measurement at station 4 (see Table 2) indicates an increase in resistivity with depth and suggests the presence of two-dimensional effects.

An attempt has been made to interpret some of the apparent resistivity responses in terms of the actual properties of the area. Figures 5 through 12 represent the apparent resistivity values vs period for stations 1 through 8. Where possible, a theoretical interpretation in terms of multilayer curves is in given.

Orthogonal MT measurements were made at stations 1, 4, 7, 9 and 11. The measurements were the same for the two orthogonal directions only at station 1. The layered interpretations, therefore, for the majority of the area should be taken with caution. Two-dimensional modelling could unfold a better representation.

Two theoretical curves are indicated in Figure 6 for station 2. Because of the large standard deviations, it is not possible to distinguish between the two cases. Consequently, a range of values is indicated. Similar situations occur for the other interpretations.

A summary of the multilayer interpretation is presented in Figure 13. The elevation is indicated on the ordinate, and the station locations are indicated on the abscissa. The surface topography varies in elevation across the profile from about 800 meters at station 4 to 1460 meters at station 2.

In spite of the many qualifications and uncertainties associated with Figure 13, a number of interesting observations can be made. The dotted line in the figure represents a possible basement profile (> 100 ohm meters), which appears to correlate fairly well with the topography. The sediments in the basin appear to be fairly thick, 250 to 1200 meters, with intrinsic resistivities from 8 to 55 ohm meters.

The resistivity lows (< 5 ohm meters) observed at stations 2 and 6 are still present and are indicated as fairly shallow conductive zones of less than 200 meters thick. Two additional low resistivity zones, about 200 meters thick, are suggested at depths of 300 to 600 meters at stations 5 and 7. They seem to occur on the flanks of an upthrust in the basement, possibly due to faulting. These zones should be viewed with caution because of the two-dimensional nature of the area. They should be investigated further if other geophysical evidence shows encouraging signs of geothermal potential. It is perhaps of interest to note that east-west trending fault segments have been mapped at Hot Lake (Newcomb, 1970) and that station 5 is 8 kilometers due east of this area.

Summary and Recommendations

The results of the present survey appear to reflect some of the geological formations in the area.

A multilayer interpretation of the data suggests a basement profile ($>$ 100 ohm meters) similar to the topography profile.

Sediments in the basin appear to be fairly thick, 250 to 1200 meters, with resistivity values of 8 to 55 ohm meters.

Two shallow low-resistivity areas are indicated ($<$ 200 meters thick and $<$ 5 ohm meters).

Two deeper low resistivity zones, $<$ 4 ohm meters and about 200 meters thick, are suggested at depths of 300 to 600 meters. They seem to occur on the flanks of an upthrust in the basement. In view of the two-dimensional nature of the area, they should be viewed with caution. They may warrant further investigation if other geophysical evidence shows encouraging signs of geothermal potential there.

The present preliminary interpretation suffered from considerable scatter in the data. This scatter could be reduced by obtaining solutions for MT impedance tensors (Grillot, 1975). Subsequent interpretations could be improved by two-dimensional modelling.

Additional survey work closer to Hot Lake would be of considerable help in understanding and evaluating the geothermal potential of the entire area.

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APPENDIX A

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

Two points are of particular note.

(1) The magnetotelluric 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 response over the two models. The 8 Hz response is not affected. The 8 Hz E.M. wave in this case does not significantly penetrate to the depth of the one 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 one ohm meter body is 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.

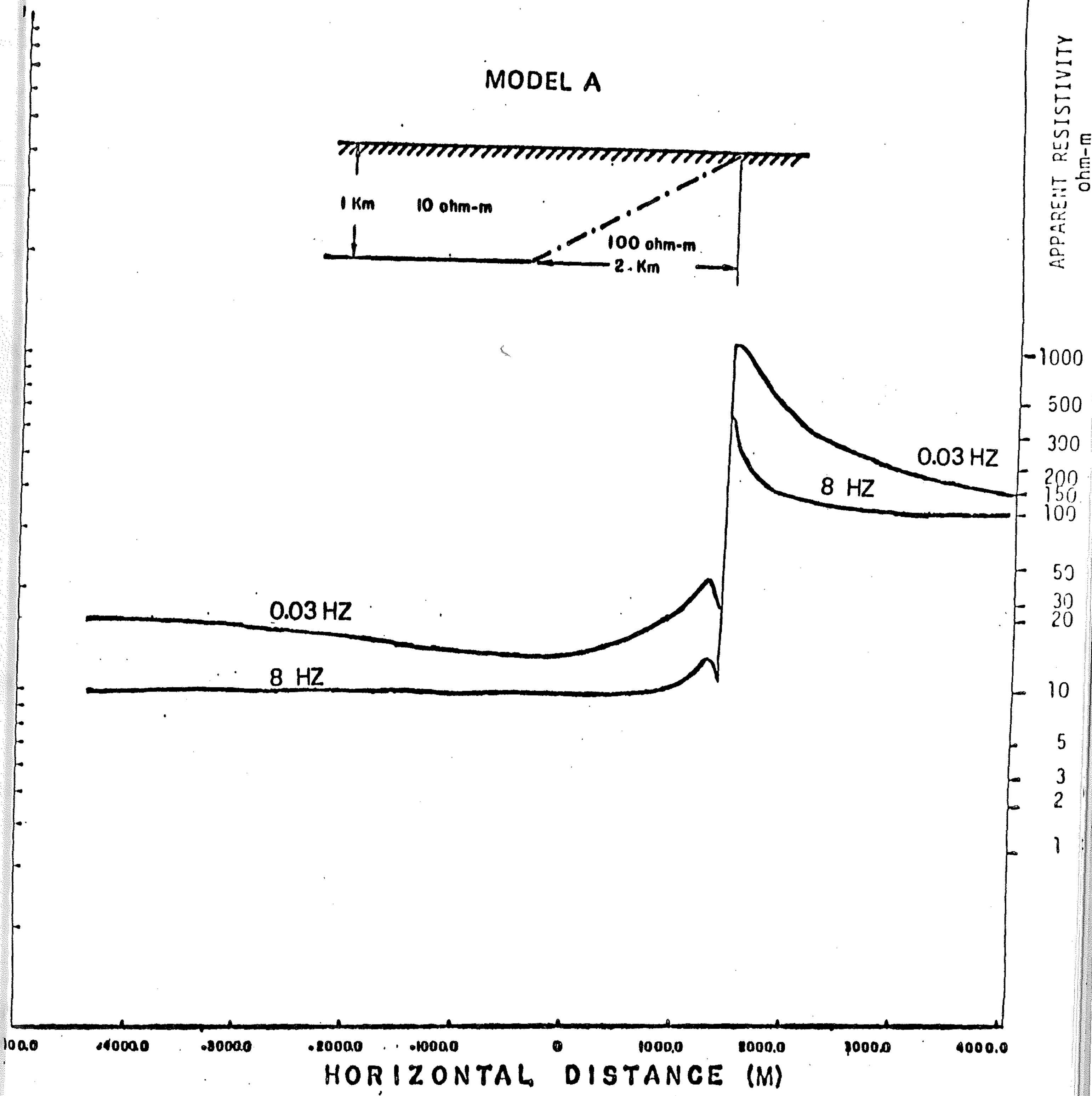

Figure A1. Magnetotelluric response at 8 Hz and at 0.05 Hz over Model A.

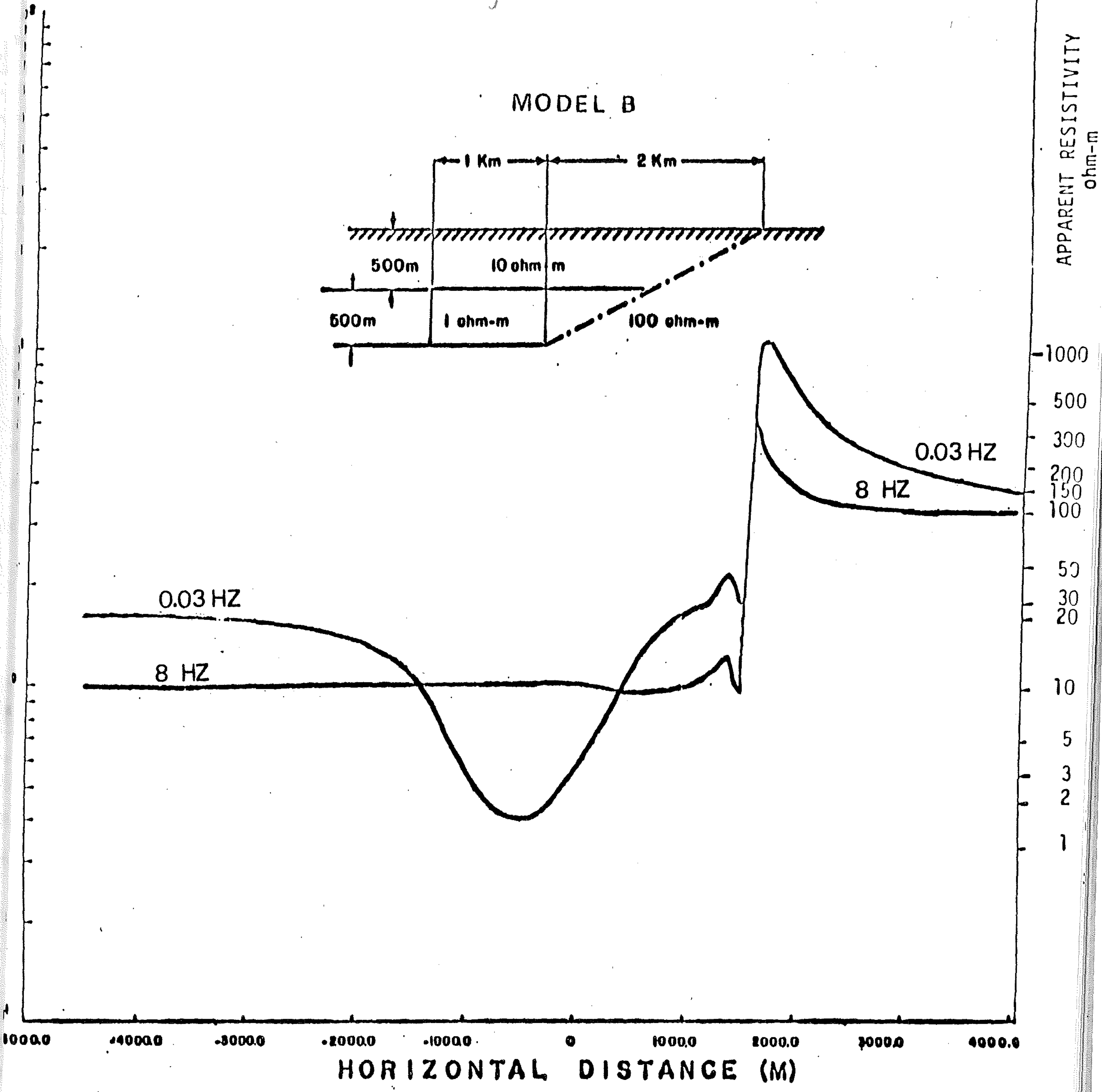

Figure A2. Magnetotelluric response at 8 Hz and 0.03 Hz over Model B, inclusion of a one ohm meter body at 500 meters depth.

Appendix B

Personnel and Operations Summary

MONTH

October

TERRAPHYSICS

PROJECT La Grande, Oregon

Crew 1
PERSONNEL

DAY	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ.S HZ 05	01	08	8		MAZZELLA	PESSAH	GUZMAN	HARVEY	MORONEY
Mon.	6th			Mobilization to La Grande							X	X	X	X
Tue.	7th	MT	2	MT 4, 4⊥ Very windy, 30 mph Magnetometer had to be buried for stability; condition prevailed for entire survey period.	X	X	X	X			X	X		
Wed.	8th	MT	4	MT 3, 5, 7, 7⊥ Very windy	X	X	X	X			X	X		
Thu.	9th	MT	2	MT 8, 6 Very windy	X	X	X	X			X	X		
Fri.	10th	MT	4	MT 2, 1, 1⊥, 11 Very windy	X	X	X	X			X	X		
Sat.	11th	MT	3	MT 9, 9⊥, 11⊥ Very windy	X	X	X	X			X	X		

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

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